Highlands Council
New Jersey

Water Resources Volume II
Water Use and Availability

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Technical Report

HIGHLANDS REGIONAL MASTER PLAN

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EXECUTIVE SUMMARY

The Water Resources Technical Report Volume II - Water Use and Availability addresses a variety of issues and findings regarding water resources of the Highlands Region, their management and protection. These include the requirements of the Highlands Act; a description of the Region's hydrologic units, ground water resources and aquifers, and the methods and results of the assessments performed to determine prime ground water recharge areas and both ground water and surface water availability.

REQUIREMENTS OF THE HIGHLANDS ACT

In accordance with Section 10(a) of the Highlands Act, the overarching goal of the Regional Master Plan "with respect to the entire Highlands Region shall be to protect and enhance the significant values of the resources thereof in a manner which is consistent with the purposes and provisions of this act."

The Highlands Act recognizes the importance of the Highlands Region as the *"essential source of drinking water, providing clean and plentiful drinking water for one-half of the State's population." An overarching goal of Act "with respect to the entire Highlands Region shall be to protect and enhance the significant values of the resources thereof in a manner which is consistent with the purposes and provisions of this act."*

The Highlands Act includes a goal to "protect, restore and enhance water quality and quantity of surface and ground waters." The Highlands Council's resource assessment must determine "the amount and type of human development and activity which the ecosystem of the Highlands Region can sustain while still maintaining the overall ecological values thereof, with special reference to surface and ground water quality and supply."

HYDROLOGIC UNITS OF THE HIGHLANDS

The Highlands Council uses the Hydrologic Unit Code (HUC) system developed by the U.S. Geological Survey to describe subwatersheds, watersheds and river basins of the Highlands Region. Watersheds are the land areas draining to a single hydrologic point, such as a stream. Each river basin (e.g., Passaic River Basin) is comprised of multiple watersheds (e.g., Whippany River watershed), which in turn are comprised of multiple subwatersheds (e.g., Malapardis Brook subwatershed). There are 183 subwatersheds entirely or partially within the Highlands Region. These are known as HUC14 subwatersheds because their Hydrologic Unit Code has fourteen digits. The HUC14 subwatersheds are used as the geographic area for purposes of assessing and establishing water resource protection needs in the Highlands Region.

GROUND WATERS OF THE HIGHLANDS

Ground water occurs where water beneath the land surface fills the pore and fracture space in a geologic formation. Ground water exists both in aquifers (ground water units that can provide economically useful quantities of water to wells) and non-aquifer units. Aquifers of the Highlands Region include glacial valley fill aquifers, Piedmont bedrock, crystalline Precambrian bedrock, and carbonate (limestone and dolomite) bedrock. Valley fill and carbonate aquifers can be highly prolific, while crystalline bedrock provides the poorest aquifer yield.

Glacial valley fill aquifers receive the most recharge from runoff or precipitation that falls on surrounding bedrock uplands. Recharge occurs both by direct infiltration of precipitation to valley fill aquifers and by inflow from adjacent bedrock aquifers. Recharge to Highlands bedrock aquifers is predominantly through precipitation that percolates downward through overlying soil to fractures, joints or solution openings in underlying bedrock.

PRIME GROUND WATER RECHARGE AREAS

Ground water recharge can be highly variable, as it is determined by local precipitation, runoff and evapotranspiration rates. The first two variables are influenced both by topographic relief and the capacity of the land surface to accept infiltrating water. The evapotranspiration rate is influenced by soil cover, types of vegetation, humidity, wind, and amount of sunlight.

Prime Ground Water Recharge Areas have been mapped for each subwatershed of the Highlands Region, identifying the land areas with the best recharge rates and that, in aggregate, yield 40 percent of the total recharge volume for that subwatershed during drought periods, when water recharge is most critical.

SELECTION OF A METHOD TO ASSESS WATER AVAILABILITY FROM GROUND WATER AND UNREGULATED STREAM FLOWS

A central goal of the Regional Master Plan is to determine the amount and type of human development and activity that the ecosystem of the Highlands Region can sustain while still maintaining the overall ecological values thereof, with special reference to surface and ground water quality and supply.

Based on an analysis of available methods and available data, the Low Flow Margin method was selected as the best scientific approach available at this time for estimating capacity of ground water supplies across the entire Highlands Region, to maintain both ecological flow needs and estimate sustainable levels of human consumption. The Low Flow Margin method uses two low flow statistics, and is derived using statistical analyses of data from reference drainage basins with minimal consumptive water uses. The HUC14 subwatershed was selected as the smallest drainage area available for application of the method.

The Highlands Council collaborated with the US Geological Survey, Water Resource Science Unit to develop Low Flow Margin results for each HUC14 subwatershed based on data from reference drainage basins with stream flow gaging stations to determine the Ground Water Capacity for each of the 183 HUC14 subwatersheds that occur within the Highlands Region.

WATER USE

Information on existing water uses by major use type was compiled from the NJDEP Bureau of Water Allocation for 2003. The year 2003 was selected because it is the most current year for which water use data has been compiled and checked. Statistics of water use included total use, monthly maximum use, and the anticipated use at full allocation based on prior issued water allocation permits. Within the Highlands Region, there are 144 water allocation permits covering withdrawals from 581 wells and surface water intakes.

The Highlands Region generates almost 870 million gallons per day (MGD) to meet the needs of potable drinking water, industry, and agriculture. The Region also includes the State's major reservoir systems providing in excess of 600 MGD of drinking water to the urban areas of northern and central New Jersey. Estimates of future water use projected to full allocation suggest that existing commitments of Highlands waters may be as high as 2.8 billion gallons of water daily, not including domestic use.

The majority of water use is either consumptive (not returned as recharge) or depletive (exported out of the watershed). Both consumptive and depletive water uses reduce the amount of water available to sustain human activity and the integrity of water resources. Estimates of maximum monthly consumptive and depletive use (excluding reservoirs and potable water supply intakes) were calculated for each HUC14 for use in estimating Ground Water Availability. There is a total of 103 MGD of consumptive and depletive water uses within the Highlands Region including from both ground water and surface water sources. Wastewater returns were identified and estimated for inclusion in the estimate of water availability as an import of water to a subwatershed.

ESTABLISHING ESTIMATES OF GROUND WATER AVAILABILITY

A key issue for water availability estimates is to what extent the estimated ground water capacity should be made available for both current and future human uses. Here, it is important to recognize that the Highlands Act emphasizes that human water uses should be constrained by ecological needs. Therefore, the definition of Ground Water Availability must be conservative and sensitive to how ecological needs vary within the Highlands Region, among other factors.

Ground Water Availability can be established by multiplying Ground Water Capacity by selected percentages that are related to the nature of the environmental resources and conservation objectives of the RMP for each regional zone identified in the Land Use Capability Map. Based on the nature of the critical environmental resources being protected and empirical evidence regarding aquifer stresses, there is significant justification for using water availability thresholds of 5, 15 and 20 percent of Ground Water Capacity for the Protection Zone, Conservation Zone (including a 10% availability threshold dedicated for agricultural uses, which may not be used for non-agricultural purposes) and Existing Community Zone, respectively. In addition, a further constraint should be applied to ensure continued flow from upstream subwatersheds to downstream subwatersheds that are identified as having existing water deficits. The policy is to allow current consumptive and depletive water uses plus 5% of the Low Flow Margin (but not to exceed the standard thresholds).

Net Water Availability was estimated for each subwatershed under current maximum monthly demands to determine current sustainability. Net Water Availability is determined by subtracting from Ground Water Availability an adjusted estimate of both the maximum monthly consumptive and depletive ground water use and the consumptive and depletive surface water uses that are not supported by reservoir storage or safe yields. Net Water Availability is also adjusted to account for a "lag time" between the withdrawal of ground water and the resulting impact on stream base flow, and to account for both the export and import of ground water and surface water from and to each subwatershed, other than exports supported by storage, to the extent that data are available.

The simplified equation used for deriving Net Water Availability would be:

$$\text{Net Water Availability} = (\text{LFM} * \%\ \text{Water Availability Threshold}) - (\text{Net Consumptive/Depletive Water Use})$$

Net Water Availability may be either a positive or negative value. Where positive, there is water available for human use beyond existing uses. Where negative utilizing current maximum monthly data, a Current Water Availability Deficit Area exists and no additional water is available for human use. Where a downstream HUC14 subwatershed is a Current Water Availability Deficit Area, then any upstream HUC14 subwatersheds would be Existing Water Availability Constrained Areas, managed to ensure that the downstream deficit is not exacerbated through additional upstream uses.

According to the results of the calculation of Net Water Availability, 114 of 183 subwatersheds have maximum monthly consumptive and depletive current water uses that exceed their Ground Water Availability; therefore, these areas are considered Current Deficit Areas.

SURFACE WATER AVAILABILITY

A major impetus behind passage of the Highlands Act was the need to protect potable water supply systems that are within or directly supported by Highlands water resources. These systems can provide a total safe yield of more than 500 million gallons per day, enough supply to provide water for over five million people during a repeat of the 1960's drought of record. A few small reservoirs have been built to provide supplies to Highlands municipalities, but the larger reservoirs and reservoir systems were constructed to supply potable water to urbanized areas of central and northeastern New Jersey.

There are a number of issues pertaining to the sustainability of surface water safe yields and supplies that will need to be addressed over time, including potentially outdated estimates of safe yields (which could be either higher or lower than prior estimates), the need for new and more ecologically sensitive estimates of stream flow requirements downstream of reservoirs and intakes, the potential for degradation of both reservoir quality and safe yields due to upstream land and water use, and whether the existing safe yields are sufficient to sustain the water supply to service existing demand and any additional demand.

An analysis of future water demands of the water supply systems that serve as source areas outside the Highlands Region was also conducted. This analysis evaluated the affect of future water demands on maintenance of safe yields of Highlands reservoirs and surface water supply intakes through the year 2030. Projections of water demands to the year 2030 indicate that several reservoirs in the Highlands Region may have insufficient amounts of water to provide anticipated future water needs including major cities like Newark, Jersey City, and Hackensack.

SOURCE WATER AND WELLHEAD PROTECTION

The resource assessment required by the Highlands Act includes an evaluation of Source Water Protection Areas (SWPA) and Wellhead Protection Areas (WHPA) for potable water sources when determining the land use capacity of the Highlands Region. Identification of these potable ground water and surface water supply zones in the Highlands Region is a critical step in identifying existing and potential distribution of surrounding land use and threats to public water supplies. The objective is to determine the areas supplying potable water through ground water well systems and surface water intakes, and the potential sources of pollution to these sources.

Residents of the Highlands Region rely on ground water supplies as a primary source of drinking water. A WHPA is a mapped area around a public water supply well that delineates the horizontal extent of ground water captured by a public water supply well pumping at a specific rate over a specific time. A WHPA has three tiers which serve to mark the boundaries for priority areas for the protection of ground water quality. Tier 1 is a two-year time of travel, (i.e. the ground water within this tier flows to the well within a two-year time period). Tier 2 is equivalent to a five-year time of travel, while Tier 3 is equivalent to a twelve-year time of travel.

The New Jersey Source Water Assessment Program Plan prepared by NJDEP describes the various sensitivity and intensity factors of concern used to develop the susceptibility ratings for ground water and surface water drinking water sources for the following categories of contaminants: pathogens, nutrients, pesticides, volatile organic compounds, synthetic organic compounds, inorganics, radionuclides, and disinfection byproduct precursors.

Protecting the source of water supplies is necessary to maintain a sustainable supply of water to support human use and development activities, as well as to maintain the health of the Highlands Region ecosystems. Most Highlands municipalities with public water supply systems are reliant on Highlands ground water aquifers through well field withdrawals. Protection of the quality of those potable water supply wells is critical to the sustainability of Highlands communities. The Regional Master Plan incorporates wellhead protection concepts from the Federal Safe Drinking Water Act and NJDEP's Source Water Assessment Reports, which limit the types of land uses within WHPAs to minimize the potential for pollutant discharges to a drinking water source.

HYDROLOGIC UNITS OF THE HIGHLANDS

This section provides a brief introduction of the physical characteristics of the watershed basins and major aquifers in the Highlands Region. The region includes the geological area known as the Highlands Physiographic Province, which is part of the Reading Prong formation that extends from Connecticut to Pennsylvania. The area designated as the Highlands Region in the Act also includes the remainder of any municipality that was included due to its intersection with the Reading Prong formation. Therefore, the Highlands Region includes small portions of the Piedmont and Valley and Ridge Physiographic Provinces to the east and south, and to the west and north, respectively.

New Jersey uses a system developed by the U.S. Geological Survey (USGS) consisting of Hydrologic Unit Codes (HUC), with a naming convention to identify these areas. Each HUC is delineated based on topography, so that a larger hydrologic unit (e.g., a river basin) is entirely comprised of a set of smaller hydrologic units (e.g., watersheds), each of which is comprised of a set of still smaller hydrologic units (e.g., subwatersheds). A watershed is an area of land that drains into a body of water such as a river, lake, stream or bay. It is separated from other systems by high points such as hills or slopes. It includes not only the waterway itself, but the entire land area that drains to it.

The largest HUC type in New Jersey is the eight digit HUC (HUC8), which includes entire river basins such as the Passaic and Raritan River Basins. The Rockaway and Whippany River watersheds are both HUCs with eleven digit identifiers (or HUC11). They are both Passaic River tributaries; therefore, the first eight digits of their codes are the same as for the Passaic River Basin HUC8. HUC14 subwatersheds carry the first eleven digits of their "parent" HUC11 watershed and are nested within it, such as the Malapardis Brook subwatershed within the Whippany River watershed. The Highlands Region includes all or part of 183 HUC14 subwatersheds.

Watersheds come in many sizes, from the drainage area of a local creek to the Mississippi River drainage area. Each larger watershed is comprised of two or more smaller watersheds. As stated above, HUC designations are used to identify these areas. All lands of the Highlands Region are contained within a HUC14 subwatershed, which is contained within a HUC11 watershed, which is contained within a HUC8 river basin. NJDEP has grouped HUC11 watersheds in New Jersey to identify 20 Watershed Management Areas, each of which is entirely contained within a HUC8 river basin. The Highlands Region includes part or all of eight Watershed Management Areas within the Upper Delaware River, Raritan River, Passaic River and Hudson River basins. The last, draining to the Hudson basin, is the Wallkill River Watershed Management Area. Each of these Watershed Management Areas is described in the Watersheds and Water Quality Technical Report.

The HUC14 unit is used because it is the smallest drainage area delineation that is uniformly available for the Highlands Region. The figure entitled *HUC14 Basins in and Partly in the Highlands Preservation and Planning Areas* shows the location of the Highlands Preservation and Planning Areas as well as the HUC14 subwatersheds evaluated in this assessment. As shown in blue, the study area was extended beyond the Highlands Region boundary to consider the entirety of all HUC14 subwatersheds located partly in the Region. The table *HUC14s and Associated Surface Water Bodies in the Highlands Region* provides the following information for each HUC14 subwatershed:

- HUC14 identification number
- Drainage area in square miles (mi2)
- Water Management Area number and name
- Water Region number and name
- Subwatershed name

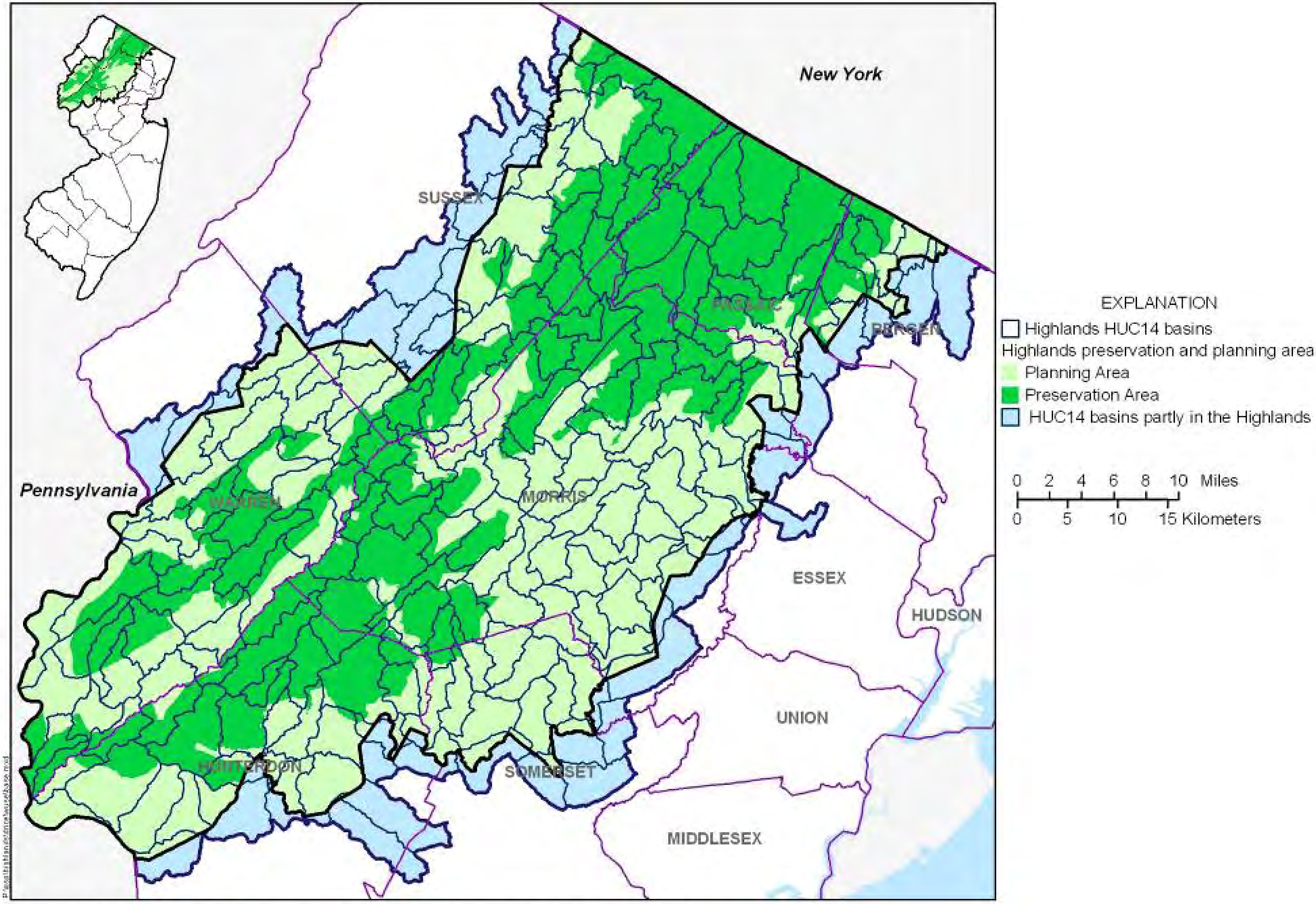


Figure 1. HUC14 basins in and partly in the Highlands preservation and planning areas

HUC14s and Associated Surface Water Bodies in the Highlands Region

HUC14	Drainage area mi^2	WMA	WMA Name	Water Region	Water Region name	Subwatershed Name
02040105040040	5.51	01	Upper Delaware	4	Northwest	Lafayette Swamp tribs
02040105040050	13.46	01	Upper Delaware	4	Northwest	Sparta Junction tribs
02040105040060	13.82	01	Upper Delaware	4	Northwest	Paulins Kill (above Rt 15)
02040105050010	18.95	01	Upper Delaware	4	Northwest	Paulins Kill (Blairstown to Stillwater)
02040105060020	12.28	01	Upper Delaware	4	Northwest	Delawanna Creek (incl UDRV)
02040105070010	5.37	01	Upper Delaware	4	Northwest	Lake Lenape trib
02040105070020	11.47	01	Upper Delaware	4	Northwest	New Wawayanda Lake/Andover Pond trib
02040105070030	13.45	01	Upper Delaware	4	Northwest	Pequest River (above Brighton)
02040105070040	8.63	01	Upper Delaware	4	Northwest	Pequest River (Trout Brook to Brighton)
02040105070050	9.42	01	Upper Delaware	4	Northwest	Trout Brook/Lake Tranquility
02040105070060	6.30	01	Upper Delaware	4	Northwest	Pequest R (below Bear Swamp to Trout Bk)
02040105080010	7.52	01	Upper Delaware	4	Northwest	Bear Brook (Sussex/Warren Co)
02040105080020	10.79	01	Upper Delaware	4	Northwest	Bear Creek
02040105090010	9.49	01	Upper Delaware	4	Northwest	Pequest R (Drag Strip--below Bear Swamp)
02040105090020	7.64	01	Upper Delaware	4	Northwest	Pequest R (Cemetary Road to Drag Strip)
02040105090030	8.23	01	Upper Delaware	4	Northwest	Pequest R (Furnace Bk to Cemetary Road)
02040105090040	6.05	01	Upper Delaware	4	Northwest	Mountain Lake Brook
02040105090050	7.71	01	Upper Delaware	4	Northwest	Furnace Brook
02040105090060	8.27	01	Upper Delaware	4	Northwest	Pequest R (below Furnace Brook)
02040105100010	8.32	01	Upper Delaware	4	Northwest	Union Church trib
02040105100020	10.31	01	Upper Delaware	4	Northwest	Honey Run
02040105100030	8.98	01	Upper Delaware	4	Northwest	Beaver Brook (above Hope Village)
02040105100040	9.06	01	Upper Delaware	4	Northwest	Beaver Brook (below Hope Village)
02040105110010	5.62	01	Upper Delaware	4	Northwest	Pophandusing Brook
02040105110020	14.72	01	Upper Delaware	4	Northwest	Buckhorn Creek (incl UDRV)
02040105110030	7.87	01	Upper Delaware	4	Northwest	UDRV tribs (Rt 22 to Buckhorn Ck)
02040105120010	7.75	01	Upper Delaware	4	Northwest	Lopatcong Creek (above Rt 57)
02040105120020	11.99	01	Upper Delaware	4	Northwest	Lopatcong Creek (below Rt 57) incl UDRV
02040105140010	10.08	01	Upper Delaware	4	Northwest	Pohatcong Creek (above Rt 31)
02040105140020	12.49	01	Upper Delaware	4	Northwest	Pohatcong Ck (Brass Castle Ck to Rt 31)
02040105140030	10.76	01	Upper Delaware	4	Northwest	Pohatcong Ck (Edison Rd-Brass Castle Ck)
02040105140040	5.63	01	Upper Delaware	4	Northwest	Merrill Creek
02040105140050	6.95	01	Upper Delaware	4	Northwest	Pohatcong Ck (Merrill Ck to Edison Rd)
02040105140060	6.33	01	Upper Delaware	4	Northwest	Pohatcong Ck (Springtown to Merrill Ck)
02040105140070	5.86	01	Upper Delaware	4	Northwest	Pohatcong Ck(below Springtown) incl UDRV
02040105150010	6.44	01	Upper Delaware	4	Northwest	Weldon Brook/Beaver Brook
02040105150020	18.88	01	Upper Delaware	4	Northwest	Lake Hopatcong
02040105150030	5.60	01	Upper Delaware	4	Northwest	Musconetcong R (Wills Bk to LkHopatcong)
02040105150040	8.00	01	Upper Delaware	4	Northwest	Lubbers Run (above/incl Dallis Pond)
02040105150050	10.07	01	Upper Delaware	4	Northwest	Lubbers Run (below Dallis Pond)
02040105150060	5.24	01	Upper Delaware	4	Northwest	Cranberry Lake / Jefferson Lake & tribs
02040105150070	6.95	01	Upper Delaware	4	Northwest	Musconetcong R(Waterloo to/incl WillsBk)
02040105150080	7.74	01	Upper Delaware	4	Northwest	Musconetcong R (SaxtonFalls to Waterloo)
02040105150090	4.95	01	Upper Delaware	4	Northwest	Mine Brook (Morris Co)
02040105150100	7.72	01	Upper Delaware	4	Northwest	Musconetcong R (Trout Bk to SaxtonFalls)
02040105160010	14.50	01	Upper Delaware	4	Northwest	Musconetcong R (Hances Bk thru Trout Bk)
02040105160020	17.77	01	Upper Delaware	4	Northwest	Musconetcong R (Changewater to HancesBk)
02040105160030	7.77	01	Upper Delaware	4	Northwest	Musconetcong R (Rt 31 to Changewater)
02040105160040	5.10	01	Upper Delaware	4	Northwest	Musconetcong R (75d 00m to Rt 31)
02040105160050	14.49	01	Upper Delaware	4	Northwest	Musconetcong R (I-78 to 75d 00m)
02040105160060	6.76	01	Upper Delaware	4	Northwest	Musconetcong R (Warren Glen to I-78)
02040105160070	7.48	01	Upper Delaware	4	Northwest	Musconetcong R (below Warren Glen)
02020007010010	11.46	02	Wallkill	4	Northwest	Wallkill R/Lake Mohawk(above Sparta Sta)
02020007010020	7.18	02	Wallkill	4	Northwest	Wallkill R (Ogdensburg to SpartaStation)
02020007010030	7.17	02	Wallkill	4	Northwest	Franklin Pond Creek
02020007010040	14.11	02	Wallkill	4	Northwest	Wallkill R(Hamburg SW Bdy to Ogdensburg)
02020007010050	5.47	02	Wallkill	4	Northwest	Hardistonville tribs
02020007010060	6.47	02	Wallkill	4	Northwest	Beaver Run
02020007010070	9.13	02	Wallkill	4	Northwest	Wallkill R(Martins Rd to Hamburg SW Bdy)
02020007020070	13.27	02	Wallkill	4	Northwest	Papakating Creek (below Pellettown)
02020007030010	9.15	02	Wallkill	4	Northwest	Wallkill R(41d13m30s to Martins Road)
02020007030030	5.19	02	Wallkill	4	Northwest	Wallkill River(Owens gage to 41d13m30s)
02020007030040	6.41	02	Wallkill	4	Northwest	Wallkill River(stateline to Owens gage)
02020007040010	5.41	02	Wallkill	4	Northwest	Black Ck(above/incl G.Gorge Resort trib)
02020007040020	14.95	02	Wallkill	4	Northwest	Black Creek (below G. Gorge Resort trib)
02020007040030	5.58	02	Wallkill	4	Northwest	Pochuck Ck/Glenwood Lk & northern trib
02020007040040	6.17	02	Wallkill	4	Northwest	Highland Lake/Wawayanda Lake
02020007040050	14.34	02	Wallkill	4	Northwest	Wawayanda Creek & tribs
02020007040060	7.85	02	Wallkill	4	Northwest	Long House Creek/Upper Greenwood Lake
02030103050010	5.41	03	Pompton, Wanaque, Ramapo	1	Northeast	Pequannock R (above Stockholm/Vernon Rd)
02030103050020	7.17	03	Pompton, Wanaque, Ramapo	1	Northeast	Pacock Brook
02030103050030	10.48	03	Pompton, Wanaque, Ramapo	1	Northeast	Pequannock R (above OakRidge Res outlet)

HUC14	Drainage area mi^2	WMA	WMA Name	Water Region	Water Region name	Subwatershed Name
02030103050040	13.25	03	Pompton, Wanaque, Ramapo	1	Northeast	Clinton Reservior/Mossmans Brook
02030103050050	18.37	03	Pompton, Wanaque, Ramapo	1	Northeast	Pequannock R (Charlotteburg to OakRidge)
02030103050060	7.88	03	Pompton, Wanaque, Ramapo	1	Northeast	Pequannock R(Macopin gage to Charl'brg)
02030103050070	7.30	03	Pompton, Wanaque, Ramapo	1	Northeast	Stone House Brook
02030103050080	16.92	03	Pompton, Wanaque, Ramapo	1	Northeast	Pequannock R (below Macopin gage)
02030103070010	5.43	03	Pompton, Wanaque, Ramapo	1	Northeast	Belcher Creek (above Pinecliff Lake)
02030103070020	9.03	03	Pompton, Wanaque, Ramapo	1	Northeast	Belcher Creek (Pinecliff Lake & below)
02030103070030	14.62	03	Pompton, Wanaque, Ramapo	1	Northeast	Wanaque R/Greenwood Lk(aboveMonks gage)
02030103070040	11.82	03	Pompton, Wanaque, Ramapo	1	Northeast	West Brook/Burnt Meadow Brook
02030103070050	21.47	03	Pompton, Wanaque, Ramapo	1	Northeast	Wanaque Reservior (below Monks gage)
02030103070060	5.99	03	Pompton, Wanaque, Ramapo	1	Northeast	Meadow Brook/High Mountain Brook
02030103070070	10.80	03	Pompton, Wanaque, Ramapo	1	Northeast	Wanaque R/Posts Bk (below reservior)
02030103100010	5.81	03	Pompton, Wanaque, Ramapo	1	Northeast	Ramapo R (above 74d 11m 00s)
02030103100020	4.35	03	Pompton, Wanaque, Ramapo	1	Northeast	Masonicus Brook
02030103100030	6.72	03	Pompton, Wanaque, Ramapo	1	Northeast	Ramapo R (above Fyke Bk to 74d 11m 00s)
02030103100040	4.71	03	Pompton, Wanaque, Ramapo	1	Northeast	Ramapo R (Bear Swamp Bk thru Fyke Bk)
02030103100050	6.31	03	Pompton, Wanaque, Ramapo	1	Northeast	Ramapo R (Crystal Lk br to BearSwamp Bk)
02030103100060	8.60	03	Pompton, Wanaque, Ramapo	1	Northeast	Crystal Lake/Pond Brook
02030103100070	11.28	03	Pompton, Wanaque, Ramapo	1	Northeast	Ramapo R (below Crystal Lake bridge)
02030103110010	13.11	03	Pompton, Wanaque, Ramapo	1	Northeast	Lincoln Park tribs (Pompton River)
02030103110020	10.87	03	Pompton, Wanaque, Ramapo	1	Northeast	Pompton River
02030103140010	5.30	04	Lower Passaic and Saddle	1	Northeast	Hohokus Bk (above Godwin Ave)
02030103140020	9.37	04	Lower Passaic and Saddle	1	Northeast	Hohokus Bk(Pennington Ave to Godwin Ave)
02030103140040	13.63	04	Lower Passaic and Saddle	1	Northeast	Saddle River (above Rt 17)
02030103010010	10.13	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Passaic R Upr (above Osborn Mills)
02030103010020	5.24	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Primrose Brook
02030103010030	7.92	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Great Brook (above Green Village Rd)
02030103010040	5.06	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Loantaka Brook
02030103010050	5.15	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Great Brook (below Green Village Rd)
02030103010060	14.19	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Black Brook (Great Swamp NWR)
02030103010070	8.89	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Passaic R Upr (Dead R to Osborn Mills)
02030103010080	7.60	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Dead River (above Harrisons Brook)
02030103010090	5.44	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Harrisons Brook
02030103010100	7.73	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Dead River (below Harrisons Brook)
02030103010110	6.68	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Passaic R Upr (Plainfield Rd to Dead R)
02030103010180	5.34	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Passaic R Upr (Pine Bk br to Rockaway)
02030103020010	6.05	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Whippany R (above road at 74d 33m)
02030103020020	6.27	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Whippany R (Wash. Valley Rd to 74d 33m)
02030103020030	7.77	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Greystone / Watnong Mtn tribs
02030103020040	5.61	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Whippany R(Lk Pocahontas to Wash Val Rd)
02030103020050	6.72	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Whippany R (Malapardis to Lk Pocahontas)
02030103020060	5.09	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Malapardis Brook
02030103020070	10.38	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Black Brook (Hanover)
02030103020080	10.06	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Troy Brook (above Reynolds Ave)
02030103020090	6.04	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Troy Brook (below Reynolds Ave)
02030103020100	5.61	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Whippany R (Rockaway R to Malapardis Bk)
02030103030010	8.56	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Russia Brook (above Milton)
02030103030020	4.84	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Russia Brook (below Milton)
02030103030030	6.70	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Rockaway R (above Longwood Lake outlet)
02030103030040	7.97	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Rockaway R (Stephens Bk to Longwood Lk)
02030103030050	7.37	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Green Pond Brook (above Burnt Meadow Bk)
02030103030060	7.90	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Green Pond Brook (below Burnt Meadow Bk)
02030103030070	9.10	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Rockaway R (74d 33m 30s to Stephens Bk)
02030103030080	4.89	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Mill Brook (Morris Co)
02030103030090	7.33	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Rockaway R (BM 534 brdg to 74d 33m 30s)
02030103030100	7.92	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Hibernia Brook
02030103030110	14.76	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Beaver Brook (Morris County)
02030103030120	9.01	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Den Brook
02030103030130	12.28	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Stony Brook (Boonton)
02030103030140	5.28	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Rockaway R (Stony Brook to BM 534 brdg)
02030103030150	6.90	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Rockaway R (Boonton dam to Stony Brook)
02030103030160	7.91	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Montville tribs.
02030103030170	8.02	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Rockaway R (Passaic R to Boonton dam)
02030103040010	11.87	06	Upper Passaic, Whippany, and Rockav	1	Northeast	Passaic R Upr (Pompton R to Pine Bk)
02030105010010	9.27	08	North and South Branch Raritan	2	Raritan	Drakes Brook (above Eyland Ave)
02030105010020	7.31	08	North and South Branch Raritan	2	Raritan	Drakes Brook (below Eyland Ave)
02030105010030	5.03	08	North and South Branch Raritan	2	Raritan	Raritan River SB(above Rt 46)
02030105010040	6.66	08	North and South Branch Raritan	2	Raritan	Raritan River SB(74d 44m 15s to Rt 46)
02030105010050	15.25	08	North and South Branch Raritan	2	Raritan	Raritan R SB(LongValley br to 74d44m15s)
02030105010060	14.88	08	North and South Branch Raritan	2	Raritan	Raritan R SB(Califon br to Long Valley)
02030105010070	7.89	08	North and South Branch Raritan	2	Raritan	Raritan R SB(StoneMill gage to Califon)
02030105010080	4.62	08	North and South Branch Raritan	2	Raritan	Raritan R SB(Spruce Run-StoneMill gage)
02030105020010	12.29	08	North and South Branch Raritan	2	Raritan	Spruce Run (above Glen Gardner)

HUC14	Drainage area mi^2	WMA	WMA Name	Water Region	Water Region name	Subwatershed Name
02030105020020	3.21	08	North and South Branch Raritan	2	Raritan	Spruce Run (Reservior to Glen Gardner)
02030105020030	14.70	08	North and South Branch Raritan	2	Raritan	Mulhockaway Creek
02030105020040	12.19	08	North and South Branch Raritan	2	Raritan	Spruce Run Reservior / Willoughby Brook
02030105020050	6.93	08	North and South Branch Raritan	2	Raritan	Beaver Brook (Clinton)
02030105020060	14.22	08	North and South Branch Raritan	2	Raritan	Cakepoulin Creek
02030105020070	8.22	08	North and South Branch Raritan	2	Raritan	Raritan R SB(River Rd to Spruce Run)
02030105020080	7.37	08	North and South Branch Raritan	2	Raritan	Raritan R SB(Prescott Bk to River Rd)
02030105020090	11.27	08	North and South Branch Raritan	2	Raritan	Prescott Brook / Round Valley Reservior
02030105040020	10.80	08	North and South Branch Raritan	2	Raritan	Pleasant Run
02030105040030	12.44	08	North and South Branch Raritan	2	Raritan	Holland Brook
02030105050010	6.27	08	North and South Branch Raritan	2	Raritan	Lamington R (above Rt 10)
02030105050020	11.03	08	North and South Branch Raritan	2	Raritan	Lamington R (Hillside Rd to Rt 10)
02030105050030	6.00	08	North and South Branch Raritan	2	Raritan	Lamington R (Furnace Rd to Hillside Rd)
02030105050040	8.90	08	North and South Branch Raritan	2	Raritan	Lamington R(Pottersville gage-FurnaceRd)
02030105050050	4.92	08	North and South Branch Raritan	2	Raritan	Pottersville trib (Lamington River)
02030105050060	6.23	08	North and South Branch Raritan	2	Raritan	Cold Brook
02030105050070	13.97	08	North and South Branch Raritan	2	Raritan	Lamington R(HallsBrRd-Pottersville gage)
02030105050080	16.93	08	North and South Branch Raritan	2	Raritan	Rockaway Ck (above McCrea Mills)
02030105050090	5.09	08	North and South Branch Raritan	2	Raritan	Rockaway Ck (RockawaySB to McCrea Mills)
02030105050100	12.35	08	North and South Branch Raritan	2	Raritan	Rockaway Ck SB
02030105050110	7.55	08	North and South Branch Raritan	2	Raritan	Lamington R (below Halls Bridge Rd)
02030105060010	6.69	08	North and South Branch Raritan	2	Raritan	Raritan R NB (above/incl India Bk)
02030105060020	6.64	08	North and South Branch Raritan	2	Raritan	Burnett Brook (above Old Mill Rd)
02030105060030	7.65	08	North and South Branch Raritan	2	Raritan	Raritan R NB(incl McVickers to India Bk)
02030105060040	7.50	08	North and South Branch Raritan	2	Raritan	Raritan R NB(Peapack Bk to McVickers Bk)
02030105060050	6.60	08	North and South Branch Raritan	2	Raritan	Peapack Brook (above/incl Gladstone Bk)
02030105060060	5.07	08	North and South Branch Raritan	2	Raritan	Peapack Brook (below Gladstone Brook)
02030105060070	8.40	08	North and South Branch Raritan	2	Raritan	Raritan R NB(incl Mine Bk to Peapack Bk)
02030105060080	6.68	08	North and South Branch Raritan	2	Raritan	Middle Brook (NB Raritan River)
02030105060090	8.69	08	North and South Branch Raritan	2	Raritan	Raritan R NB (Lamington R to Mine Bk)
02030105070010	9.32	08	North and South Branch Raritan	2	Raritan	Raritan R NB (Rt 28 to Lamington R)
02030105120050	9.57	09	Lower Raritan, South River, and Lawr	2	Raritan	Middle Brook EB
02030105120060	6.54	09	Lower Raritan, South River, and Lawr	2	Raritan	Middle Brook WB
02040105170010	6.03	11	Central Delaware	4	Northwest	Holland Twp (Hakihokake to Musconetcong)
02040105170020	17.54	11	Central Delaware	4	Northwest	Hakihokake Creek
02040105170030	11.83	11	Central Delaware	4	Northwest	Harihokake Creek (and to Hakihokake Ck)
02040105170040	6.73	11	Central Delaware	4	Northwest	Nishisakawick Creek (above 40d 33m)
02040105170050	8.49	11	Central Delaware	4	Northwest	Nishisakawick Creek (below 40d 33m)

GROUND WATERS OF THE HIGHLANDS

Ground water is defined as water below the land surface that saturates the pores and fractures of the soil and geological formation. Aquifers are defined as those geologic formations that can transmit usable amounts of ground water to wells for water supply uses. Not all ground water is contained within aquifers, but all aquifers are filled with ground water. Each aquifer receives its water from ground water recharge from the land surface, or flow from neighboring aquifers. This section addresses the major aquifer types, designated Sole Source Aquifers and prime ground water recharge areas of the Highlands Region.

Ground water is the primary source of drinking water for residents and businesses in the Highlands Region. Aquifer characteristics and the function of the ground water flow system are both directly related to the underlying geology, which controls the ability to transmit significant quantities of water for various uses. In addition, the Highlands Region supports several potable water supply reservoir systems that can provide more than 500 million gallons of water per day during a repeat of the drought of record, mostly to urban areas in northern and central New Jersey outside the Highlands Region. These reservoir systems are addressed in detail in a later section of this Technical Report.

Five major aquifer types within the Highlands Region are classified by the bedrock or surficial materials that are exposed at or near the land surface. These include crystalline, carbonate and clastic rocks, typical geologic formations of the Highlands physiographic province. The Highlands Region also includes sedimentary and igneous rocks of the Newark Basin, along the eastern boundary, that are typical of the Piedmont physiographic province to the east. Locally, these bedrock units are overlain by surficial deposits of glacial origin.

MAJOR AQUIFER TYPES OF THE HIGHLANDS

Aquifers of the Highlands Region include the glacial valley fill aquifers, Piedmont bedrock, crystalline Precambrian bedrock, and carbonate (limestone and dolomite) bedrock (see figure entitled *Generalized Aquifer Type: New Jersey Highlands*). Of these, the crystalline bedrock has the poorest aquifer capabilities.

Recharge to Highlands bedrock aquifers (see figure *Ground Water Recharge and Flow within Highlands Bedrock Aquifers*) is predominantly through precipitation that percolates downward through overlying soil to fractures, joints or solution openings in underlying bedrock. Ground water moves from upland recharge areas to discharge areas, such as springs and streams at lower altitude.

Recharge occurs both by direct infiltration of precipitation to valley fill aquifers and by inflow from adjacent bedrock aquifers. Glacial valley fill aquifers receive the most recharge from runoff or precipitation that falls on surrounding bedrock uplands. These sources are generally sufficient to maintain aquifer water levels above those of streams, so that water moves from the aquifer to the stream, though the reverse happens naturally in some situations. During droughts, discharge by seepage to adjacent bedrock, evapotranspiration and withdrawals from wells, coupled with a decrease in precipitation can lower aquifer water levels until flow is reversed and water moves from streams to the aquifer.

Ground water recharge can be highly variable, as it is determined by local precipitation, runoff and evapotranspiration rates. The first two variables are influenced both by topographic relief and the capacity of the land surface to accept infiltrating water. The degree to which the ground water system within the Highlands has the ability to store and transmit recharge water is based on the amount and connectivity of openings in the underlying rock or sediment. This characteristic is known as aquifer permeability and has a direct bearing on an aquifer's ability to yield sufficient quantities of water to wells.

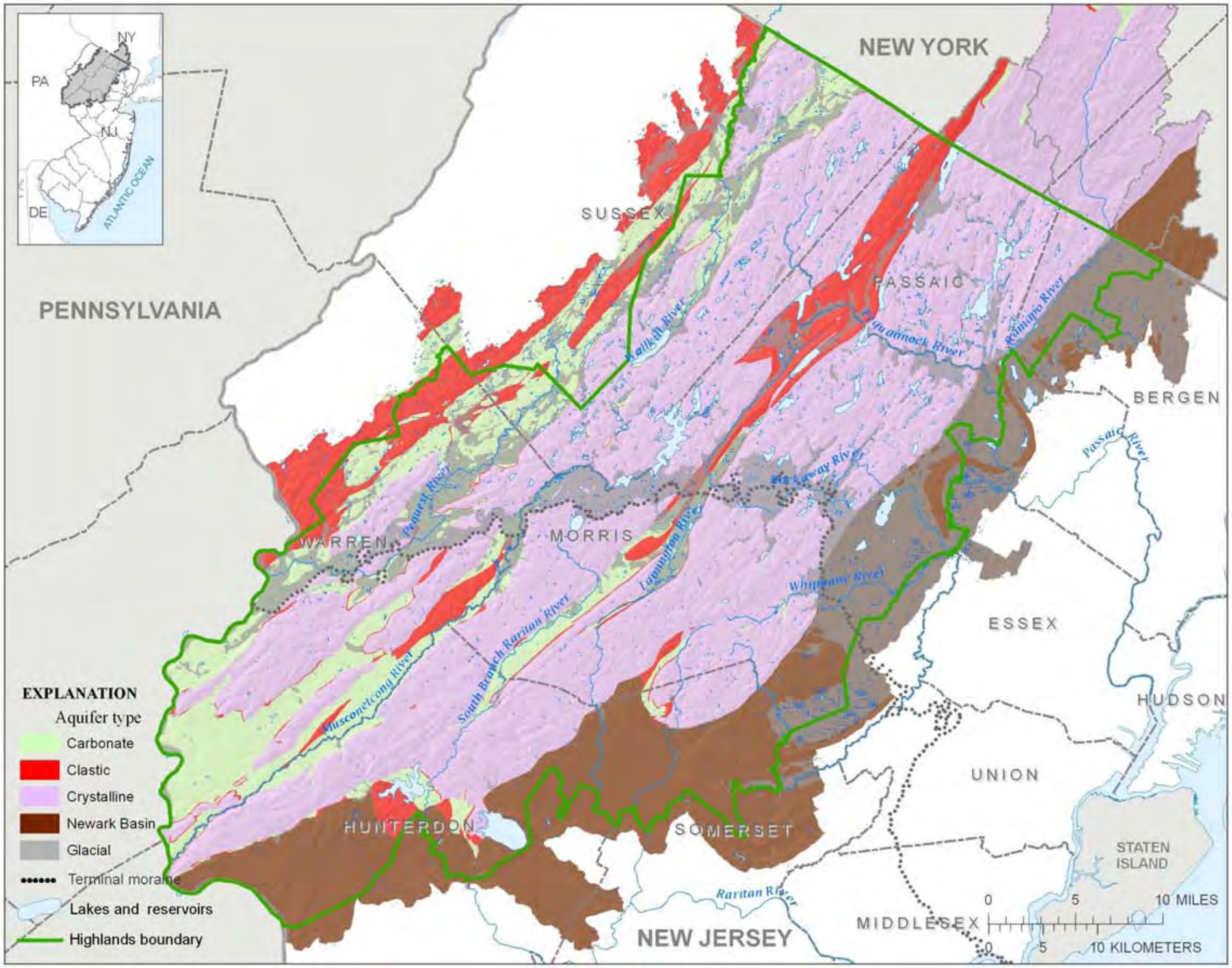
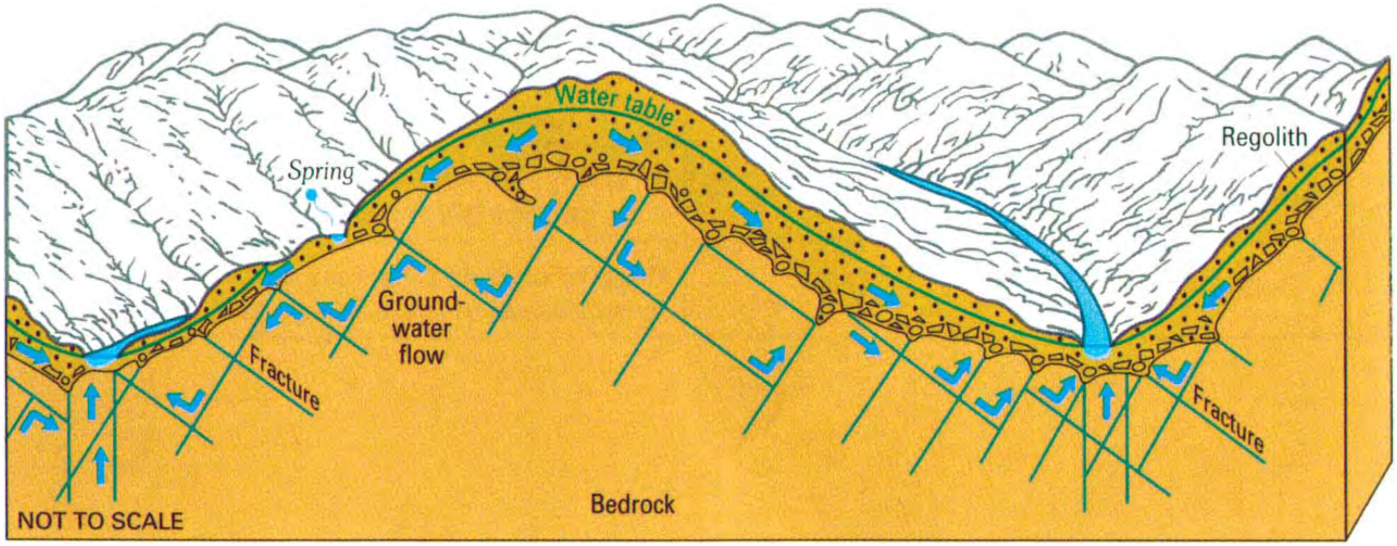
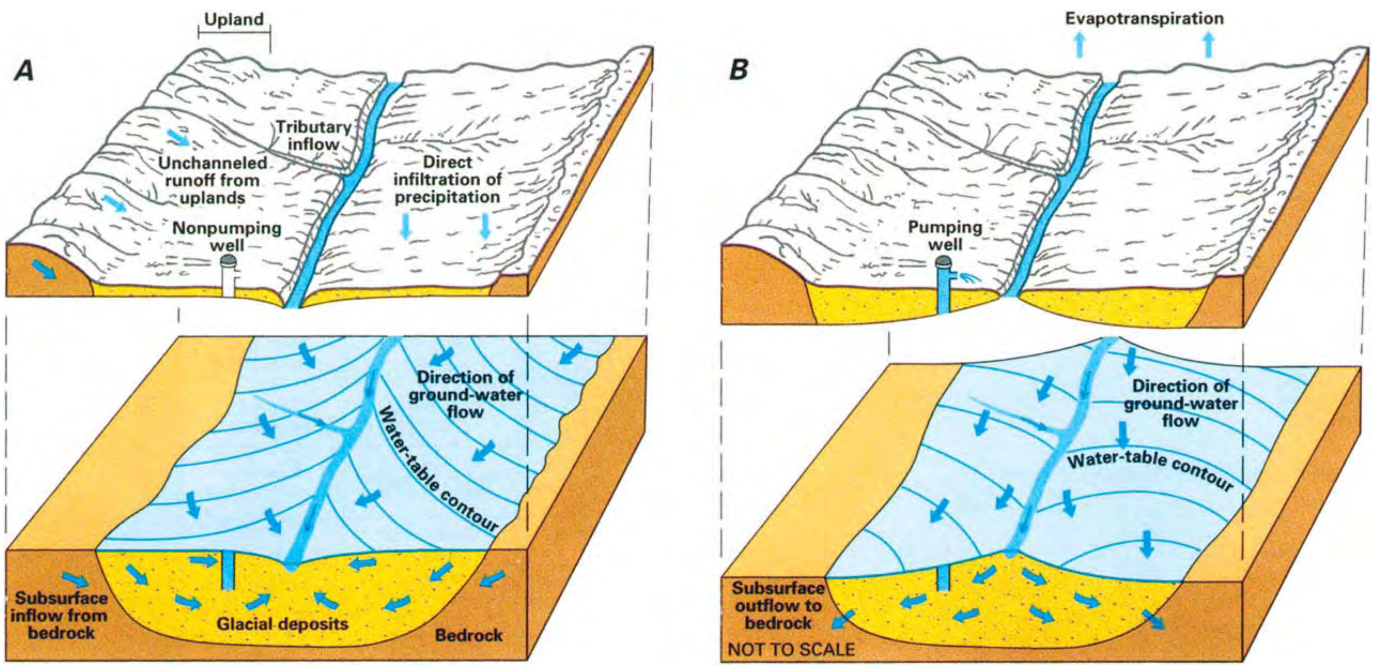


Figure 1. Generalized Aquifer Type, New Jersey Highlands



Groundwater Recharge and Flow Within Highlands Bedrock Aquifers.



Groundwater Recharge and Flow Within Highlands Glacial Aquifers.

Crystalline aquifers are composed of crystalline metamorphosed sedimentary and igneous rocks of pre-Cambrian age and are the uppermost (surficial) aquifer in approximately 57% of the area within the Highlands Region. Rock types consist primarily of coarse-grained gneiss, schist, and granite of various mineral compositions. Fine-grained metamorphic slates are common in the New York state part of the study area. These rock types are most resistant to erosion, forming upland regions and providing the highest elevations and relief typical of Highlands topography. They have limited capacity for large wells and primarily support domestic water supplies for individual residences.

Carbonate aquifers are composed predominantly of Paleozoic age limestone and dolomite formations and are exposed over 17% of the surface area within the Highlands Region. These rock types are less resistant to erosion, are subject to dissolution and therefore are found on valley floors interspersed between more resistant crystalline and clastic rocks that form valley walls. They can provide significant water supplies, including some of the most prolific wells in the Highlands Region.

Clastic aquifers are composed of Paleozoic age sedimentary sandstone, shale conglomerates and quartzite, and are exposed over more than 8% of the Highlands Region surface area. These rock types overlay carbonates in some valleys; with the more resistant rocks forming predominant northeast-southwest trending ridges known locally as Green Pond, Bearfort, Kanouse and Bellvale Mountains.

Newark Basin aquifers of Mesozoic age are exposed over 17% of the Region, primarily to the east and south of the carbonate, clastic and crystalline formations that are typical of the Highlands Province. These rocks are predominantly red sandstones and shales. Conglomerates (particularly near the Ramapo border fault), basalt, and diabase units are also present. These formations support wells of variable size, generally supplying more water than crystalline aquifers, but less than carbonate or glacial valley aquifers.

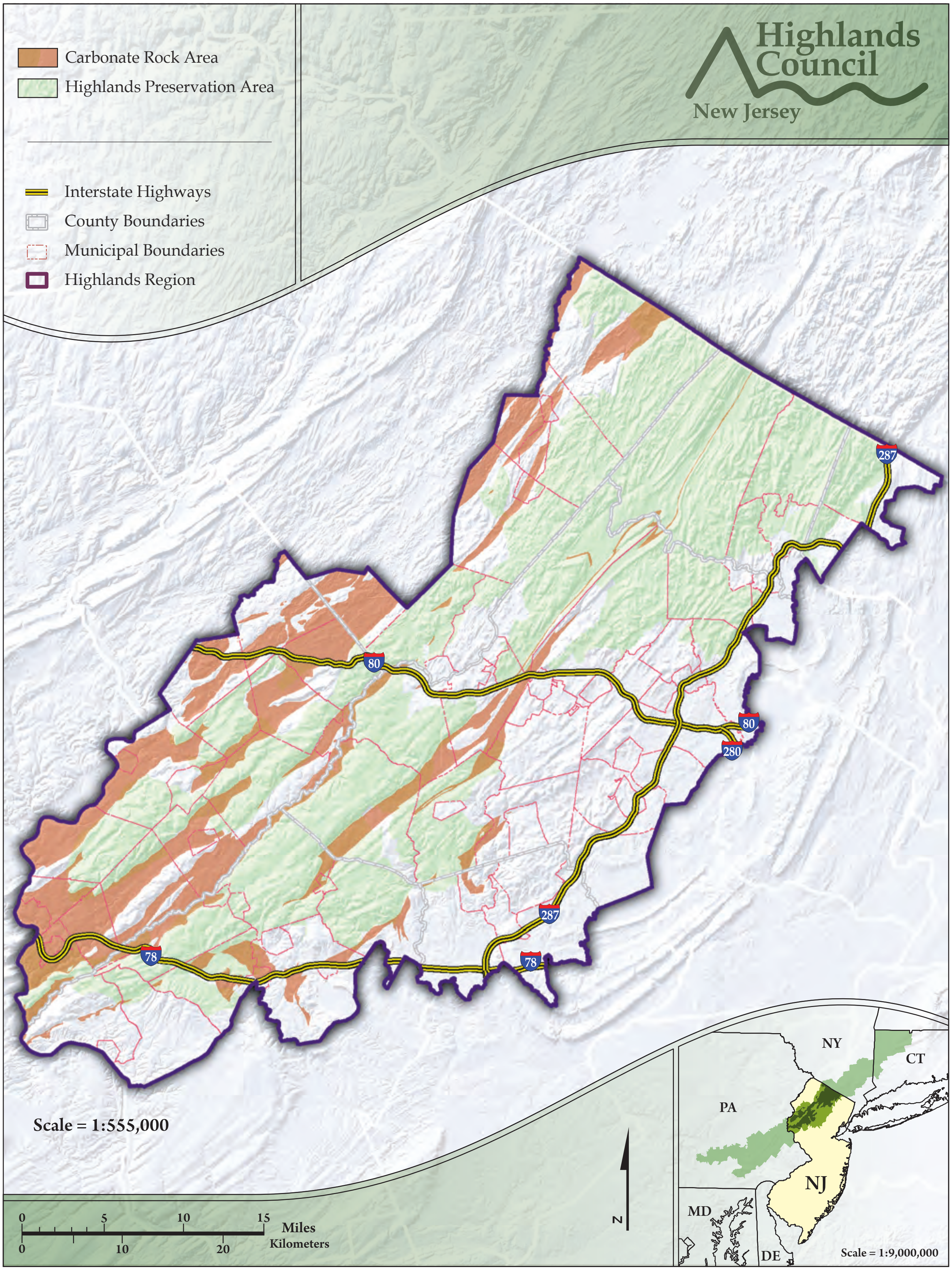
Glacial aquifers are the youngest geological formations, composed mainly of unconsolidated sand, silt and gravel of Pleistocene age, and form narrow belt-like deposits of small areal extent. The aquifers can comprise channels up to 300 feet thick and provide significant storage and yields of ground water. The largest channels are generally found where the glacial material filled a pre-existing river valley, and are known as valley fill or buried valley aquifers. These overlay both Newark Basin and Highlands Province aquifers.

KARST TOPOGRAPHY

Karst is a type of land surface, or topography, which is formed at the surface of carbonate rock formations when water dissolves the rock over time. This process causes surface depressions and the development of such features as sinkholes, sinking streams, enlarged bedrock fractures, caves, and underground streams. Sinking streams and sinkholes direct surface water runoff into karst aquifers with little or no attenuation of any transported contaminants. Stormwater basins, septic system leaching fields and sewers may also contribute contaminants directly to ground water through karst features. In addition to ground water concerns, communities in karst areas must contend with safety concerns as sinkholes can have damaging effects to large manmade objects.1 The Highlands Region has several large areas with carbonate rock formations, usually river valleys such as the Musconetcong, South Branch of the Raritan and Lamington, and karst features exist in some – but not all – of these areas.

There is no available map of karst topography, as these features develop over time and are difficult to map through remote sensing. Therefore, the Highlands Council relied upon existing New Jersey Geologic Survey and United States Geological Survey data to map areas of the Highlands Region that are underlain by carbonate rocks (see http://www.state.nj.us/dep/njgs/geodata/index.htm#geology). These areas collectively are referred to as the Carbonate Rock Area (see Carbonate Rock Area figure), and the map is the most current and reliable depiction of the areas that may contain karst topography.

CARBONATE ROCK AREA



Management of development activities in carbonate rock areas is necessary to address the potential problems that are common to karst areas. The site assessment and design process can be modified for karst areas to allow applicants, municipalities and the Council to identify any karst concerns at a site and to incorporate appropriate design features in order to minimize future sinkhole (or other karst feature) formation, damage to development, and the potential for ground water contamination.

PRIME GROUND WATER RECHARGE AREAS

This section addresses the mapping of prime ground water recharge areas. By mapping relative recharge capacity, the Highlands Council can identify land areas that are more efficient for recharge (i.e., have the highest recharge rates and provide the greatest recharge volumes in the least amount of land area) and therefore should be given priority as a critical support feature for surface and ground water resource protection.

Ground water recharge provides water to aquifers and, indirectly, to surface waters. Aquifers are used for water supply, and surface waters support both human water uses and aquatic ecosystems. Estimating the relative recharge rates of various land areas provides a way by which the most critical ground water recharge areas can be identified and therefore, better protected through various mechanisms including zoning, development regulation and land preservation.

The New Jersey Geological Survey (NJGS) developed a method for ground water recharge mapping, based on the New Jersey Geological Survey Report GSR-32 – A Method for Evaluating Ground-Water-Recharge Areas in New Jersey (GSR-32) that is the only available method to differentiate recharge rates among land areas within single watersheds or subwatersheds. As such, it can be used to determine which land areas can be considered "prime" ground water recharge areas on a relative basis.

Existing GSR-32 results from NJGS (using the 2002 land use/land cover) were used to test various approaches to ranking land areas within each HUC14 subwatershed of the Highlands Region based on ground water recharge. Based on this analysis, the Highlands Council has defined "Prime Ground Water Recharge Areas" as those areas that most efficiently provide 40 percent or more of the total recharge volume for each HUC14 subwatershed, using the GSR-32 with 2002 land use/land cover data. These areas would be considered a high priority for enhanced protection. Remaining land areas that also contribute to ground water recharge at a lower rate should continue to be protected through NJDEP stormwater management regulations and local ordinances, which require that post-construction ground water recharge be at least equal to pre-construction recharge. The New Jersey Water Supply Authority (NJWSA) assisted the Highlands Council in mapping prime ground water recharge areas based on this method.

Ground water recharge results from the movement of water from the land surface through soils, past the root zone of plants and down through the unsaturated (vadose) zone to a point where the water fills the pore spaces in soils and bedrock, known as the "saturated zone", where the infiltrating water is then considered to be ground water. Some ground water eventually reaches aquifers, which are defined as geologic formations that can yield economically significant quantities of water to wells or springs. Ground water recharge measures the total quantity of recharge to both aquifer and non-aquifer ground water resources, as aquifer recharge is just one component of overall ground water recharge.

Aquifers discharge to surface waters over time, unless their waters are intercepted by wells for human use. The remaining, non-aquifer ground water will also discharge to surface waters. In both cases, ground water is a fundamental factor in sustaining ecosystem health by helping to maintain flow to streams that support aquatic and other ecosystems, as well serving as a direct source of water supply for a wide variety of human uses, including potable water, industrial, agricultural and recreational supplies. Ground water resources are critical to the Highlands Region. Later sections of this Technical Report address the quantification of water availability for human and ecological uses.

Recharge can be reduced through changes in soil permeability (e.g., increased impervious surface, soil compaction), soil aspect (e.g., slope, surface roughness), and vegetative cover. Recharge can be contaminated by a wide variety of intentional discharges (e.g., septic systems), accidental discharges (e.g., spills) and incidental discharges (e.g., fertilizer and pesticide applications that penetrate past the root zone).

Although the NJDEP 2004 stormwater regulations provide for protection of recharge volumes from land development changes, damages to the most productive recharge areas can still result from inadequate recharge assumptions during the design process, soil compaction during and after construction, poor recharge system maintenance, and other means. The Highlands Act also emphasizes the need to protect ground water resources, and therefore, prime recharge areas are appropriate to be included in the definition of critical environmental areas. The most efficient recharge areas have been identified and included as a priority for protection from alteration through a combination of fee simple acquisition, easements and development regulation.

A number of methods are available for assessing ground water capacity by watershed or subwatershed (e.g., Posten, 1984; Rutledge, 1998; Low Flow Margin and others discussed later in this Technical Report). These methods provide watershed-based values for recharge during various climatic conditions. Unfortunately, these methods cannot define the recharge in specific portions of a specific watershed, to provide a sense of which land areas have higher or lower recharge rates. Only one method is currently available for estimating relative ground water recharge capacity by land area in New Jersey. This method was first published in 1993 by the NJDEP-New Jersey Geological Survey as GSR-32 (NJDEP, 2005b), and was last updated in electronic spreadsheet form in 2005. GSR-32 estimates recharge capacity per land "polygon" – each discrete land area – with a uniform combination of soils type, land cover and precipitation.

NJGS estimated ground water recharge results based on 1995/97 land use/land cover data for the Highlands Region using GSR-32 at two different precipitation levels – annual average precipitation and drought of record precipitation (1964-1966 for New Jersey). The recent availability of 2002 land use/land cover data made possible the creation of a new ground water recharge analysis for the entire Highlands using GSR-32. The 1995/97 GSR-32 results were used to test several different mapping methods. The selected method was then used to develop 2002 GSR-32 results to provide information for the Highlands Regional Master Plan.

METHODOLOGY

According to Charles (1993), the GSR-32 method is to be used "for estimating ground water recharge (the volume of water transmitted to the subsurface through soils) rather than aquifer recharge (recharge to geologic formations which can yield economically significant quantities of water to wells or springs). Ground water recharge is critical to aquifers, wetlands, streams and lakes. The method is useful for evaluating the effect of present and future land uses on these resources." GSR-32 uses precipitation, surface runoff, evapotranspiration and soil moisture deficit information to estimate recharge rates. As such, the method is highly dependent on available information regarding soils, precipitation patterns and land cover. The focus is on differentiating the recharge capacity of various land areas within a geographic area. With the polygon-based calculations of recharge rates, the various lands within a larger area can then be ranked. Several ranking methods can be used, depending on the analytical purpose.

GSR-32 mapping prepared by the New Jersey Geologic Survey (NJGS), available at http://www.nj.gov/dep/njgs/geodata/dgs02-3.htm was used to develop modeling scenarios as a preliminary step in the development of a Highlands method for mapping prime recharge areas.

It would not be appropriate to use the 1995/97 results for the Regional Master Plan, given that the 2002 land use/land cover maps from NJDEP is now available. Lands developed since that time would not be reflected in the 1995/97 version. Such land would most likely be shown as having a higher recharge rate than their 2002 land use would indicate, unless the development was regulated to achieve a post-construction recharge rate that is at least equal to the pre-construction rate. The 2002 land use/land cover data actually used in determining prime recharge areas will reflect changes through March 2002. Even using the most recent data available, lands developed since 2002 are not identified as such. For these reasons, updates will be needed through the conformance process and future aerial photographic surveys, to ensure that the maps of Prime Ground Water Recharge Areas are as up to date as possible.

The method illustrated in the HUC14 Drought Ground Water Recharge (GWR) Volume Rank figure was used to develop a map of ground water recharge using GSR-32 and the most updated GIS data available. Data issues include:

- NJDEP 2002 land use/land cover data were used. This GIS coverage is available from the NJDEP GIS data web site at www.nj.gov/dep/gis/lulc02shp.html.
- Soils information came from two sources. For most counties, the SSURGO data base of the USDA Natural Resources Conservation Service was used. These files are available from NJDEP at www.nj.gov/dep/gis/soilsshp.html. However, no SSURGO data were available for Warren County, as this information is under development. NJDEP provided its previously developed soils coverage for Warren County, which is the same as what was used for its 1995/97 GSR-32 maps.
- Precipitation coverage was provided by the NJGS, along with the most updated GSR-32 method.

As stated above, a series of ranking methods to map ground water recharge areas were developed for use in determining the Prime Ground Water Recharge Areas. These maps are described below, with commentary on their utility for this purpose, and are provided as a series of corresponding figures in Appendix A to this report, illustrating the various recharge scenarios considered in this analysis, results for certain watersheds used as examples to test the scenarios. (Note: surface waters and wetlands are depicted on these recharge areas in white as having no recharge rate, based on the GSR-32 method, because most such areas discharge ground water and the identification of areas and times when this is not true requires extensive field information.)

Highlands Area Ground Water Recharge (GWR) Quintile Rank[1] determines the relative rank of ground water recharge rates across the entire Region, by quintile of recharge rates using annual average recharge rates and provides a useful visual tool to show that average recharge rates vary widely across the Highlands (from zero to nearly 24 inches per year), and have clear sub-regional patterns, with the south-central and northwestern Highlands showing the greatest concentrations of top-quintile scores. However, recharge to a subwatershed in the northern Highlands provides no water to a subwatershed in

[1] Quintiles are formed by taking the highest and lowest recharge scores and dividing the results into five groups with equal recharge ranges. GSR-32 does not provide recharge estimates for wetlands, hydric soils and open waters (which usually are discharge areas), and therefore these areas are given a zero score.

the south. Therefore the delineation of prime recharge areas using this ranking approach would not be protective of the water supplies for each stream system or aquifer.

Highlands Area Drought Ground Water Recharge (GWR) Quintile Rank reflects a similar Highlands-wide ranking of recharge rates, using precipitation values from the 1964-1966 drought of record. The difference is illustrated in the legend, where the top rate in this map is significantly lower than the top rate in the previous figure (i.e., 16.5 inches, versus 23.87 inches). Some significant differences are evident in the recharge patterns regionally. The top recharge quintile is uncommon, and occurs predominantly in the northern Highlands, while much of the Region is in the third and fourth quintiles, showing a far greater evenness than in the previous scenario. This pattern shift may be caused by the use of soil moisture deficits as a factor considered in the GSR-32 method. It is to be expected that soil moisture deficits would increase during droughts, to different extents based on the soil type.

- HUC14 Ground Water Recharge (GWR) Quintile Rank is similar to the first scenario, which illustrates Highlands Area Ground Water Recharge (GWR) Quintile Rank, but the quintile ranks are determined based on the recharge rates within each HUC14 subwatershed.[2] As such, the pattern shown for the highest quintile shifts significantly. This approach defines prime recharge areas that would be protective of each localized stream system, because it identifies the highest recharge rates for each HUC14. However, this approach can be misleading if any single recharge rate is either dominant or highly limited within a HUC14. Far more or less land area can be contained in any one quintile under such circumstances.
- HUC14 Drought Ground Water Recharge (GWR) Quintile Rank is similar to the second (drought of record) scenario in terms of precipitation, but like the HUC14 Ground Water Recharge (GWR) Quintile Rank approach, it is based on HUC14 subwatersheds. It reflects recharge during a highly constrained period, when stream flows are most likely to be stressed by low base flow from ground water supplies.
- HUC14 Ground Water Recharge (GWR) Volume Rank is significantly different from the prior approaches, in that it ranks land area polygons by the extent to which they contribute to the most efficient 20 percent of recharge volume, and then to each successive 20 percent of recharge volume. Recharge volume is derived by multiplying the recharge rate of each land polygon (in inches per year) by the total area of that polygon (in acres) and applying a conversion factor, yielding values in "million gallons per year." The advantage of this approach is that the HUC14 is divided into five areas of equal recharge volume. It allows for the identification of those areas that contribute a target percentage of the total HUC14 recharge most efficiently – these areas would be considered "prime" recharge areas.
- HUC14 Drought Ground Water Recharge (GWR) Volume Rank is similar to the previous volume rank approach, but uses drought recharge values. As with the other drought recharge scenario, there are pattern differences from the approach that uses average recharge rates.

Four HUC14 subwatersheds were chosen as examples to demonstrate the differences between the six recharge ranking methods shown above, and were extracted from the figures discussed above. These HUC14 subwatersheds were chosen due to their diverse recharge area patterns, i.e., relatively uniform to highly diverse, rather than to show differences among various Highlands sub-regions. The first of these figures (provided in Appendix A) shows the location of the four example subwatersheds. The next four figures show all six ranking methods for each example HUC14 subwatershed. The three figures that follow these ranking method maps show all four HUC14 subwatersheds for the three non-drought

[2] For this analysis, the HUC14 subwatershed is used as the basic geographic area, as the smallest watershed size that has been routinely delineated within the Highlands Region. There are 183 HUC14 subwatersheds wholly or partially within the Highlands Region as established by the Highlands Act.

ranking methods. The results of this comparison are as follows for each of the four example HUC14s:

- Franklin Pond Creek HUC14: This subwatershed shows limited top-quintile recharge from the figures illustrating regional quintile ranking. Results from HUC14 quintile ranking show a more diverse pattern, but still with little representation from the top quintile, indicating that only a small portion of the HUC14 subwatershed recharges at or near its top rate. The results from the HUC 14 volume ranking show more land in the top rank, showing the land areas that provide the best 20 percent of recharge volume. The average and drought recharge patterns are somewhat different for these last two, but not markedly so.
- Pohatcong Creek (Springtown to Merrill Creek): This subwatershed shows almost no top-quintile recharge from the regional quintile ranking, and a very uniform recharge pattern dominated by third-quintile recharge. Results from the HUC14 quintile ranking show a slightly more diverse pattern, with almost all land within the top two quintiles. This indicates that nearly the entire HUC14 subwatershed recharges at or near the top rate for that subwatershed. The results from the HUC 14 volume ranking show much more differentiation among land areas, based on contribution to volume. The average and drought recharge patterns are somewhat different for these last two, but again, not markedly so.
- Raritan River South Branch (Stonemill Gage to Califon): This subwatershed shows extensive recharge in the top two quintiles from the regional quintile ranking. Reflecting this generally uniform pattern, results from the HUC14 quintile ranking show a less diverse pattern, with even more representation from the top quintile, indicating that much of the HUC14 subwatershed recharges at or near its top rate. Again, the results from the HUC 14 volume ranking show a more diverse pattern of recharge, with far less land at the top rank than for the quintile rank maps. The average and drought recharge patterns are different for the volume rankings, especially in the southern portion on both sides of the stream channel.
- Mulhockaway Creek: Of the four example areas, this subwatershed shows the greatest diversity of recharge ranks in the regional quintile ranking, with very little difference between average and drought recharge patterns. Results from the HUC14 quintile ranking also show a diverse pattern, but somewhat less so. The results from the HUC 14 volume ranking show a very different pattern, with the top recharge ranks located primarily in the northern section of the subwatershed and almost non-existent in the southern section, perhaps reflecting the significant difference in geology north and south of Spruce Run Reservoir. The average and drought recharge patterns are somewhat different for the volume rankings, but not markedly so.

Based upon the individual HUC14 examples, the comparison of each using various modeling scenarios provides a useful comparison as discussed below:

- Highlands Area GWR Quintile Rank: the differences among the four subwatersheds in regional quintile ranks show very different patterns and dominant quintiles in each. This emphasizes the difficulty of defining prime ground water recharge areas on a regional basis, where some subwatersheds would have none and others would have high percentages, despite the need of each subwatershed for recharge.
- Highlands Area HUC14 GWR Quintile Rank: ranking recharge areas by rate quintile in each HUC14 subwatershed provides a somewhat more balanced view of recharge among subwatersheds, with each having lands in the various rank quintiles. However, patterns still vary a great deal. Watersheds may have very large or very small areas at the top rate, resulting in a more or less diverse pattern and scope of prime recharge areas in the map.
- Highlands Area HUC14 Volume Rank: the use of volume ranking provides a more distinctdifferentiation of areas within the HUC14 subwatershed. Each area has significant lands in

each of the five ranks.

DEFINING PRIME GROUND WATER RECHARGE AREA

The results discussed above were used to clarify the choices among ranking methods for the purpose of mapping Prime Ground Water Recharge Areas (see figure Prime Recharge Areas). Findings include:

- Regional ranking systems, whether for annual average or drought recharge (as in the first two figures in this series), will result in prime recharge area maps that will not protect recharge sufficiently in many HUC14 subwatersheds, due to the significant sub-regional differences in recharge rates.
- HUC14 quintile ranking systems, whether for annual average or drought recharge (as in the third and fourth figures in this series), may result in prime recharge area maps that protect significantly different amounts of recharge in the 183 HUC14 subwatersheds, due to the different patterns among high and low recharge rates within each HUC14.
- HUC14 volume ranking systems, whether for annual average or drought recharge (as in the fifth and sixth figures in this series), will result in prime recharge area maps that protect equal amounts of recharge in the 183 HUC14 subwatersheds.

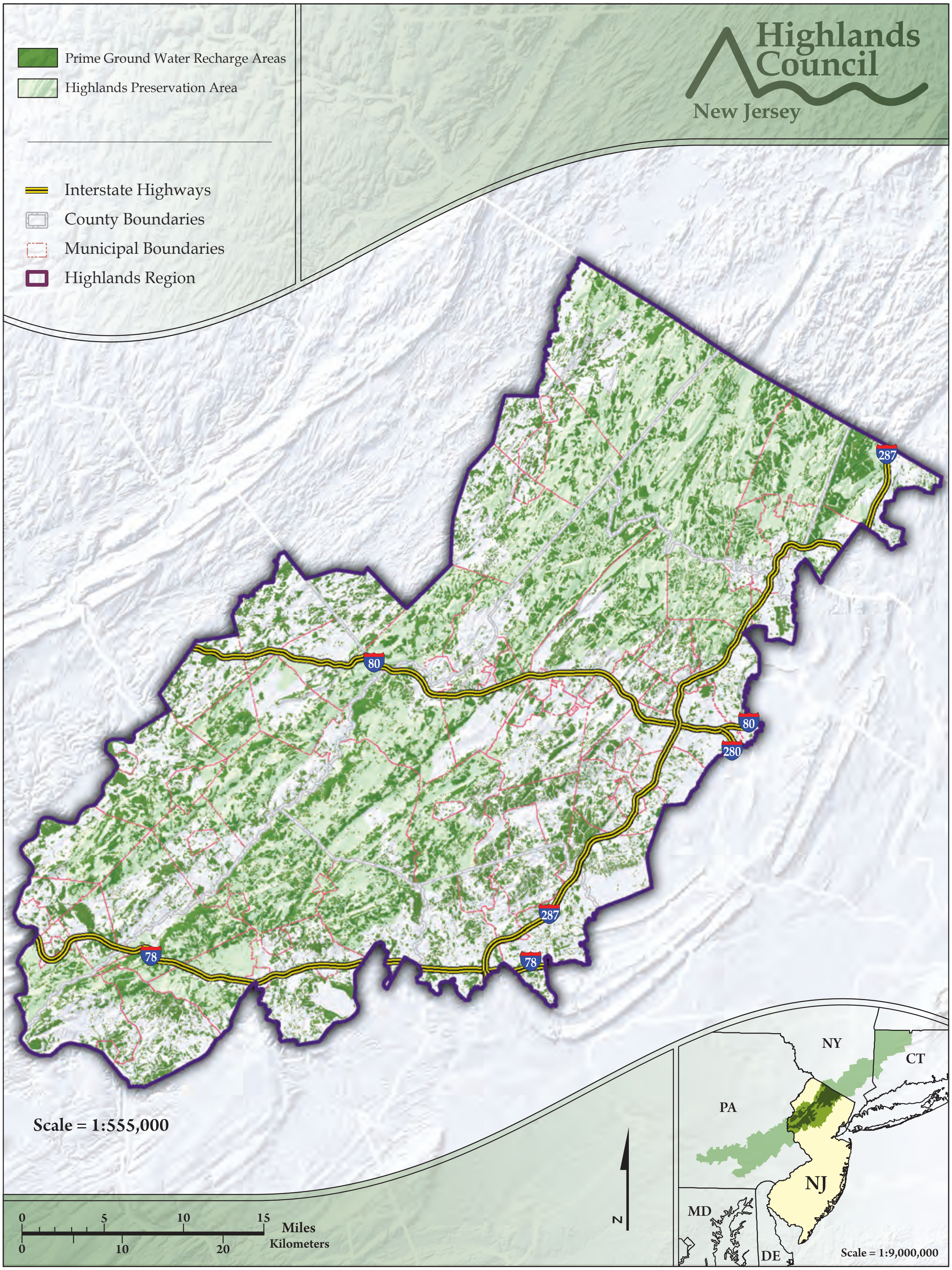
Recognizing the need to maintain ground water resources for both human and ecological uses is based in part on an assumption that recharge volumes are to be maintained for each HUC14. It is therefore appropriate to use HUC14 subwatersheds as the basis for mapping Prime Ground Water Recharge Areas. Because stream ecosystems, to which ground water moves as base flow have all evolved to require the flows and flow patterns provided by normal recharge patterns, it is also appropriate to protect equal proportions of recharge volumes in each HUC14 subwatershed.

The final question relating to the definition of Prime Ground Water Recharge Areas is what volume threshold to use in the ranking process. Few examples are available from other regions, though the Raritan Basin Watershed Management Project used a threshold of 30 percent (NJWSA, 2004). Given the Highlands Act goals related to water resource protection, the Highlands Council method defines Prime Ground Water Recharge Areas as those lands within a HUC14 subwatershed that most efficiently provide 40 percent of total recharge volume for that HUC14 subwatershed, as defined using a GSR-32 analysis available based upon the 2002 land use/land cover. Given that aquifers and streams are most stressed during drought periods, and that the Highlands Council method for defining available water supplies focuses upon dry period flows, it is appropriate to use the GSR-32 drought recharge estimates as the basis for mapping.

The method illustrated in the HUC14 Drought Ground Water Recharge (GWR) Volume Rank figure, as shown in Appendix A was determined to be the appropriate basis for mapping the Prime Ground Water Recharge Areas for each HUC14 subwatershed, using the two top ranks, representing the top 40% as the threshold for inclusion.

The table called Highlands Ground Water Recharge Volume by HUC14 shows the results of the HUC14 Drought Ground Water Recharge Volume Rank method based on 2002 Land Use Land Cover data but showing only the top two quintiles, representing the most efficient recharge areas contributing 40 percent of the total recharge volume during a drought period. These areas are defined as the Prime Ground Water Recharge Areas for the Highlands Region and serves as the baseline in the Regional Master Plan. Estimates of prime water recharge by volume for each HUC14 within the Highlands Region is provided in the table Highlands Ground Water Recharge Volume by HUC 14 Subwatershed Based on GSR-32 Method, 2002 Land Use Land Cover.

PRIME GROUND WATER RECHARGE AREAS



Highlands Ground Water Recharge Volume by HUC 14 Subwatershed Based on GSR-32 Method, 2002 Land Use Land Cover			
HUC 14	Subwatershed Name	Watershed Management Area	Total Volume of Drought GWR BG/year
02020007010010	Wallkill R/Lake Mohawk(above Sparta Sta)	02	1.25
02020007010020	Wallkill R (Ogdensburg to SpartaStation)	02	0.85
02020007010030	Franklin Pond Creek	02	0.93
02020007010040	Wallkill R(Hamburg SW Bdy to Ogdensburg)	02	1.67
02020007010050	Hardistonville tribs	02	0.75
02020007010060	Beaver Run	02	0.79
02020007010070	Wallkill R(Martins Rd to Hamburg SW Bdy)	02	1.10
02020007020070	Papakating Creek (below Pellettown)	02	1.22
02020007030010	Wallkill R(41d13m30s to Martins Road)	02	0.95
02020007030030	Wallkill River(Owens gage to 41d13m30s)	02	0.46
02020007030040	Wallkill River(stateline to Owens gage)	02	0.59
02020007040010	Black Ck(above/incl G.Gorge Resort trib)	02	0.75
02020007040020	Black Creek (below G. Gorge Resort trib)	02	2.05
02020007040030	Pochuck Ck/Glenwood Lk & northern trib	02	0.71
02020007040040	Highland Lake/Wawayanda Lake	02	0.68
02020007040050	Wawayanda Creek & tribs	02	1.98
02020007040060	Long House Creek/Upper Greenwood Lake	02	1.11
02030103010010	Passaic R Upr (above Osborn Mills)	06	1.59
02030103010020	Primrose Brook	06	0.90
02030103010030	Great Brook (above Green Village Rd)	06	1.04
02030103010040	Loantaka Brook	06	0.49
02030103010050	Great Brook (below Green Village Rd)	06	0.38
02030103010060	Black Brook (Great Swamp NWR)	06	0.78
02030103010070	Passaic R Upr (Dead R to Osborn Mills)	06	0.71
02030103010080	Dead River (above Harrisons Brook)	06	0.77
02030103010090	Harrisons Brook	06	0.61
02030103010100	Dead River (below Harrisons Brook)	06	0.67
02030103010110	Passaic R Upr (Plainfield Rd to Dead R)	06	0.59
02030103010180	Passaic R Upr (Pine Bk br to Rockaway)	06	0.01
02030103020010	Whippany R (above road at 74d 33m)	06	1.02
02030103020020	Whippany R (Wash. Valley Rd to 74d 33m)	06	1.03
02030103020030	Greystone / Watnong Mtn tribs	06	1.01
02030103020040	Whippany R(Lk Pocahontas to Wash Val Rd)	06	0.73
02030103020050	Whippany R (Malapardis to Lk Pocahontas)	06	0.67
02030103020060	Malapardis Brook	06	0.40
02030103020070	Black Brook (Hanover)	06	0.74
02030103020080	Troy Brook (above Reynolds Ave)	06	0.89
02030103020090	Troy Brook (below Reynolds Ave)	06	0.29
02030103020100	Whippany R (Rockaway R to Malapardis Bk)	06	0.30
02030103030010	Russia Brook (above Milton)	06	1.19
02030103030020	Russia Brook (below Milton)	06	0.71
02030103030030	Rockaway R (above Longwood Lake outlet)	06	1.01
02030103030040	Rockaway R (Stephens Bk to Longwood Lk)	06	1.12
02030103030050	Green Pond Brook (above Burnt Meadow Bk)	06	0.87
02030103030060	Green Pond Brook (below Burnt Meadow Bk)	06	0.83
02030103030070	Rockaway R (74d 33m 30s to Stephens Bk)	06	1.08
02030103030080	Mill Brook (Morris Co)	06	0.62
02030103030090	Rockaway R (BM 534 brdg to 74d 33m 30s)	06	0.73
02030103030100	Hibernia Brook	06	1.16
02030103030110	Beaver Brook (Morris County)	06	1.84
02030103030120	Den Brook	06	1.12
02030103030130	Stony Brook (Boonton)	06	1.65
02030103030140	Rockaway R (Stony Brook to BM 534 brdg)	06	0.62
02030103030150	Rockaway R (Boonton dam to Stony Brook)	06	0.67
02030103030160	Montville tribs.	06	0.94
02030103030170	Rockaway R (Passaic R to Boonton dam)	06	0.67
02030103040010	Passaic R Upr (Pompton R to Pine Bk)	06	0.26
02030103050010	Pequannock R (above Stockholm/Vernon Rd)	03	0.77
02030103050020	Pacock Brook	03	0.95
02030103050030	Pequannock R (above OakRidge Res outlet)	03	1.49
02030103050040	Clinton Reservior/Mossmans Brook	03	2.04
02030103050050	Pequannock R (Charlotteburg to OakRidge)	03	2.80
02030103050060	Pequannock R(Macopin gage to Charl'brg)	03	1.13

Highlands Ground Water Recharge Volume by HUC 14 Subwatershed Based on GSR-32 Method, 2002 Land Use Land Cover			
HUC 14	Subwatershed Name	Watershed Management Area	Total Volume of Drought GWR BG/year
02030103050070	Stone House Brook	03	0.96
02030103050080	Pequannock R (below Macopin gage)	03	2.25
02030103070010	Belcher Creek (above Pinecliff Lake)	03	0.85
02030103070020	Belcher Creek (Pinecliff Lake & below)	03	1.45
02030103070030	Wanaque R/Greenwood Lk(aboveMonks gage)	03	2.49
02030103070040	West Brook/Burnt Meadow Brook	03	2.04
02030103070050	Wanaque Reservior (below Monks gage)	03	3.22
02030103070060	Meadow Brook/High Mountain Brook	03	0.95
02030103070070	Wanaque R/Posts Bk (below reservior)	03	1.51
02030103100010	Ramapo R (above 74d 11m 00s)	03	0.93
02030103100020	Masonicus Brook	03	0.36
02030103100030	Ramapo R (above Fyke Bk to 74d 11m 00s)	03	1.00
02030103100040	Ramapo R (Bear Swamp Bk thru Fyke Bk)	03	0.91
02030103100050	Ramapo R (Crystal Lk br to BearSwamp Bk)	03	1.13
02030103100060	Crystal Lake/Pond Brook	03	1.01
02030103100070	Ramapo R (below Crystal Lake bridge)	03	1.32
02030103110010	Lincoln Park tribs (Pompton River)	03	1.29
02030103110020	Pompton River	03	0.94
02030103140010	Hohokus Bk (above Godwin Ave)	04	0.53
02030103140020	Hohokus Bk(Pennington Ave to Godwin Ave)	04	0.90
02030103140040	Saddle River (above Rt 17)	04	1.65
02030105010010	Drakes Brook (above Eyland Ave)	08	1.22
02030105010020	Drakes Brook (below Eyland Ave)	08	0.86
02030105010030	Raritan River SB(above Rt 46)	08	0.53
02030105010040	Raritan River SB(74d 44m 15s to Rt 46)	08	0.84
02030105010050	Raritan R SB(LongValley br to 74d44m15s)	08	2.09
02030105010060	Raritan R SB(Califon br to Long Valley)	08	2.31
02030105010070	Raritan R SB(StoneMill gage to Califon)	08	1.51
02030105010080	Raritan R SB(Spruce Run-StoneMill gage)	08	0.71
02030105020010	Spruce Run (above Glen Gardner)	08	2.03
02030105020020	Spruce Run (Reservior to Glen Gardner)	08	0.60
02030105020030	Mulhockaway Creek	08	2.08
02030105020040	Spruce Run Reservior / Willoughby Brook	08	1.65
02030105020050	Beaver Brook (Clinton)	08	0.99
02030105020060	Cakepoulin Creek	08	1.78
02030105020070	Raritan R SB(River Rd to Spruce Run)	08	1.10
02030105020080	Raritan R SB(Prescott Bk to River Rd)	08	1.12
02030105020090	Prescott Brook / Round Valley Reservior	08	1.21
02030105040020	Pleasant Run	08	1.45
02030105040030	Holland Brook	08	1.67
02030105050010	Lamington R (above Rt 10)	08	0.75
02030105050020	Lamington R (Hillside Rd to Rt 10)	08	1.35
02030105050030	Lamington R (Furnace Rd to Hillside Rd)	08	0.78
02030105050040	Lamington R(Pottersville gage-FurnaceRd)	08	1.46
02030105050050	Pottersville trib (Lamington River)	08	0.85
02030105050060	Cold Brook	08	0.97
02030105050070	Lamington R(HallsBrRd-Pottersville gage)	08	2.08
02030105050080	Rockaway Ck (above McCrea Mills)	08	2.73
02030105050090	Rockaway Ck (RockawaySB to McCrea Mills)	08	0.74
02030105050100	Rockaway Ck SB	08	1.83
02030105050110	Lamington R (below Halls Bridge Rd)	08	0.90
02030105060010	Raritan R NB (above/incl India Bk)	08	0.98
02030105060020	Burnett Brook (above Old Mill Rd)	08	1.09
02030105060030	Raritan R NB(incl McVickers to India Bk)	08	1.20
02030105060040	Raritan R NB(Peapack Bk to McVickers Bk)	08	1.25
02030105060050	Peapack Brook (above/incl Gladstone Bk)	08	1.04
02030105060060	Peapack Brook (below Gladstone Brook)	08	0.80
02030105060070	Raritan R NB(incl Mine Bk to Peapack Bk)	08	1.32
02030105060080	Middle Brook (NB Raritan River)	08	0.96
02030105060090	Raritan R NB (Lamington R to Mine Bk)	08	1.03
02030105070010	Raritan R NB (Rt 28 to Lamington R)	08	1.04
02030105120050	Middle Brook EB	09	1.09
02030105120060	Middle Brook WB	09	0.65

Highlands Ground Water Recharge Volume by HUC 14 Subwatershed Based on GSR-32 Method, 2002 Land Use Land Cover			
HUC 14	Subwatershed Name	Watershed Management Area	Total Volume of Drought GWR BG/year
02040105040040	Lafayette Swamp tribs	01	0.50
02040105040050	Sparta Junction tribs	01	1.45
02040105040060	Paulins Kill (above Rt 15)	01	1.07
02040105050010	Paulins Kill (Blairstown to Stillwater)	01	2.19
02040105060020	Delawanna Creek (incl UDRV)	01	1.44
02040105070010	Lake Lenape trib	01	0.62
02040105070020	New Wawayanda Lake/Andover Pond trib	01	1.36
02040105070030	Pequest River (above Brighton)	01	1.39
02040105070040	Pequest River (Trout Brook to Brighton)	01	1.00
02040105070050	Trout Brook/Lake Tranquility	01	1.16
02040105070060	Pequest R (below Bear Swamp to Trout Bk)	01	0.38
02040105080010	Bear Brook (Sussex/Warren Co)	01	0.82
02040105080020	Bear Creek	01	1.05
02040105090010	Pequest R (Drag Strip--below Bear Swamp)	01	0.82
02040105090020	Pequest R (Cemetary Road to Drag Strip)	01	0.95
02040105090030	Pequest R (Furnace Bk to Cemetary Road)	01	1.25
02040105090040	Mountain Lake Brook	01	0.76
02040105090050	Furnace Brook	01	0.94
02040105090060	Pequest R (below Furnace Brook)	01	1.08
02040105100010	Union Church trib	01	1.02
02040105100020	Honey Run	01	1.22
02040105100030	Beaver Brook (above Hope Village)	01	1.02
02040105100040	Beaver Brook (below Hope Village)	01	1.17
02040105110010	Pophandusing Brook	01	0.74
02040105110020	Buckhorn Creek (incl UDRV)	01	1.92
02040105110030	UDRV tribs (Rt 22 to Buckhorn Ck)	01	0.89
02040105120010	Lopatcong Creek (above Rt 57)	01	1.00
02040105120020	Lopatcong Creek (below Rt 57) incl UDRV	01	1.12
02040105140010	Pohatcong Creek (above Rt 31)	01	1.36
02040105140020	Pohatcong Ck (Brass Castle Ck to Rt 31)	01	1.63
02040105140030	Pohatcong Ck (Edison Rd-Brass Castle Ck)	01	1.37
02040105140040	Merrill Creek	01	0.58
02040105140050	Pohatcong Ck (Merrill Ck to Edison Rd)	01	0.91
02040105140060	Pohatcong Ck (Springtown to Merrill Ck)	01	0.74
02040105140070	Pohatcong Ck(below Springtown) incl UDRV	01	0.60
02040105150010	Weldon Brook/Beaver Brook	01	0.89
02040105150020	Lake Hopatcong	01	1.84
02040105150030	Musconetcong R (Wills Bk to LkHopatcong)	01	0.56
02040105150040	Lubbers Run (above/incl Dallis Pond)	01	0.99
02040105150050	Lubbers Run (below Dallis Pond)	01	1.30
02040105150060	Cranberry Lake / Jefferson Lake & tribs	01	0.62
02040105150070	Musconetcong R(Waterloo to/incl WillsBk)	01	0.72
02040105150080	Musconetcong R (SaxtonFalls to Waterloo)	01	1.18
02040105150090	Mine Brook (Morris Co)	01	0.74
02040105150100	Musconetcong R (Trout Bk to SaxtonFalls)	01	1.11
02040105160010	Musconetcong R (Hances Bk thru Trout Bk)	01	2.10
02040105160020	Musconetcong R (Changewater to HancesBk)	01	2.92
02040105160030	Musconetcong R (Rt 31 to Changewater)	01	1.17
02040105160040	Musconetcong R (75d 00m to Rt 31)	01	0.76
02040105160050	Musconetcong R (I-78 to 75d 00m)	01	2.08
02040105160060	Musconetcong R (Warren Glen to I-78)	01	0.86
02040105160070	Musconetcong R (below Warren Glen)	01	0.79
02040105170010	Holland Twp (Hakihokake to Musconetcong)	11	0.67
02040105170020	Hakihokake Creek	11	2.06
02040105170030	Harihokake Creek (and to Hakihokake Ck)	11	1.54
02040105170040	Nishisakawick Creek (above 40d 33m)	11	0.85
02040105170050	Nishisakawick Creek (below 40d 33m)	11	0.97

Ground water recharge zones are designated within the Highlands Region as Prime Ground Water Recharge Areas account for 232,854 acres (126,636 acres of the Preservation Area and 106,221 acres of the Planning Area), or 27 percent of the Highlands Region.

- The Land Use Capability Zone Map divides the Prime Ground Water Recharge Areas among the Protection Zone, the Conservation Zone (CZ), the Existing Communities Zone (ECZ) and the Environmentally Constrained Sub-zones of the Existing Community Zone and Conservation Zone as shown in the table below entitled *Distribution of Prime Ground Water Recharge Areas by Land Use Capability Zone.*

Distribution of Prime Ground Water Recharge Areas by Land Use Capability Zone				
Zone and Sub-zone	**Total Acres**	**PGWRA Acreage**	**Percentage of Zone in PGWRAs**	**Percentage of Total PGWRA in Zone**
Protection Zone	469,462	158,392	33.74	68.13
Conservation Zone (not environmentally constrained)	70,474	4,357	6.18	1.87
CZ Environmentally Constrained Sub-zone	120,485	38,611	32.04	16.58
Existing Community Zone (not environmentally constrained)	146,011	737	0.50	0.32
ECZ Environmentally Constrained Sub-zone	32,231	30,757	95.42	13.21

**Excludes Lake Community Overlay Zone*

MANAGEMENT OF PRIME GROUND WATER RECHARGE AREAS

Changes in anthropogenic factors greatly affect the degree of infiltration and water quality within a ground water recharge area by changing the ecological, geological and hydro-geological constraining factors. Because anthropogenic changes are influenced largely by socio-economic forces they can be controlled through the regulatory process and through the use of engineering techniques or a combination of both, as discussed below.

Water quality can be regulated through the establishment of water quality standards which set specific concentration limits on potential contaminants to prevent water quality degradation. By establishing water quality standards, regulators can limit the type of land use activity and its density within ground water recharge areas to those that do not violate these standards. One of the more widely used water quality standard is for nitrate concentrations in ground water (e.g., the RMP standards for septic system densities). Another approach to water quality protection is to regulate specific types of pollutant sources, as is done in the RMP wellhead protection requirements.

Land use can be controlled through adoption of rules and ordinances to regulate or prohibit certain land use activities, establish development densities, require scientific studies to evaluate a development's potential impact, and provide the necessary and appropriate measures to protect and enhance infiltration and water quality. Listed in the table below entitled *Summary of County and Municipal Ground Water Recharge Regulations* are examples of county level and local regulations designed to manage Prime Ground Water Recharge Areas, as identified through a search of legal databases available to the Highlands Council.

Summary of County and Municipal Ground Water Recharge Regulations	
County/Municipality	**Regulation**
Augusta, GA	Restricts or prohibits certain land use activities and regulates septic system densities nitrate using ground water quality standards and sets storm-water performance standards
Borough of Ringwood, NJ	Standard wellhead protection ordinance
The Cape Cod Commission, MA	Model Aquifer Protection Bylaw: Establishes an Aquifer Protection Overlay District which prohibits certain land use activities, requires permitting for certain land use activities and for any construction that renders 10,000 square feet impervious, establishes Nitrogen based ground water quality standards, and sets storm-water performance standards
Fauquier County, VA	Establishes an Aquifer Protection Overlay District which prohibits certain land use activities, requires permitting for certain land use activities and for any construction that renders 10,000 square feet impervious, establishes Nitrogen based ground water quality standards, and sets storm-water performance standards
Middlesex County, NJ	Recommends "Site Specific Recharge Analysis" and that municipalities adopt an Aquifer Protection Overlay District to be managed through wellhead protection regulations. Evaluates aquifers based on quality.
Montville, NJ	Modification of Land Use ordinance to include wellhead protection regulations prohibiting certain land use activities and requires a site specific hydro-geologic study
Mountain Lakes, NJ	Prohibits certain land use activities and requires a "Ground Water Management Plan" detailing site hydrogeology and other factors.
Readington Township, NJ	Standard wellhead protection and storm-water regulations.

The most common method to manage Prime Ground Water Recharge Areas is through the use of zoning regulations that restrict or prohibit specific land use activities that are considered potential contaminant sources based upon their Standard Industrial Classification Code. These zoning regulations are most commonly applied in an Aquifer Protection Overlay District or Zone established through a Wellhead Protection Ordinance. To manage infiltration within a Prime Ground Water Recharge Area, all of the counties and municipalities listed above require conformance with storm-water performance standards. Nitrogen based water quality standards are employed by Augusta, GA, The Cape Cod Commission, MA and Fauquier County, VA to regulate septic system densities. Site specific hydro-geologic or recharge analysis studies were only recommended or required by Middlesex County, NJ, Montville, NJ and Mountain Lakes, NJ. Thus, as summarized above, it very common for county and local regulators use a combination of zoning, wellhead protection and storm water regulations and nitrogen based water quality standards to manage Prime Ground Water Recharge Areas.

However, a few counties and municipalities have adopted aquifer recharge ordinances or have included within their wellhead protection ordinances language that specifies the maximum percentage of impervious coverage allowed within a ground water recharge area. The primary goal of impervious coverage limits is to allow for controlled development within prime ground water recharge areas while protecting natural infiltration. This goal is supplemented by an embedded requirement in the regulations to implement Best Management Practices to maximize water infiltration and to maintain and possibly enhance water quality. The table below entitled *County/Municipal Regulation of Impervious Coverage in Aquifer Protection Zones* represents a sampling of county and municipal impervious coverage limits:

County/Municipal Regulation of Impervious Coverage in Aquifer Protection Zones	
County/Municipality	**Allowable Percentage of Impervious Coverage**
Boonton, NJ	15 percent
Fremont, NH	10 percent
Hillsdale, NJ	20 percent to 38 percent
Montville, NJ	50 percent Restricted Aquifer Zone, 40 percent Prime Aquifer Zone
Princeton, NJ	A sliding scale from 14 percent to 61 percent
Rye, NH	35 percent
Stratham, NH	20 percent

The designation of impervious coverage limits within Prime Ground Water Recharge Areas attempts to balance the pressures of development with that of the protection of ground water resources. However, this balancing act is fraught with inconsistencies. As shown above, the maximum percentage of impervious cover varies widely from municipality to municipality and from state to state. Impervious coverage limitations range from a low of 10 percent in Fremont, New Hampshire to a high of 61 percent in Princeton, New Jersey. The lack of uniformity with respect to impervious coverage standards suggests that these standards are derived at the local level in response to local factors and are not established by any regional regulatory authority or regional analysis. Further, a review of these ordinances reveals that the rationale used to establish impervious coverage standards is either not stated or is based upon a patchwork of local zoning regulations and storm-water-derived engineering methods and procedures. This indicates that there are no established, overarching, scientifically-based methods and procedures to determine the appropriate extent of impervious coverage. Additionally, the lack of a clear regionally accepted standard suggests that impervious coverage standards are based more upon local socio-economic conditions than purely environmental concerns.

A review of available information from the Center for Watershed Protection indicates that at this time there are no studies regarding impervious surface limitations on ground water recharge areas. The Center's primary focus is on the destructive impacts of high flow periods rather than on low flow periods, though they do emphasize the need to maintain the volume and quality of recharge. RMP requirements address these issues regarding maintenance of recharge volume, mitigation at 125% for disturbance of Prime Ground Water Recharge Areas, and control of potential pollutant sources in the same manner as for wellhead protection areas. A review of the Coastal Area Facility Review Act [CAFRA (N.J.S.A. 13:19)] regulations, addressing percent impervious surface in certain areas find that these regulations, similar to the Center for Watershed Protection recommendations, are based on impacts of runoff on surface waters, rather than on recharge impacts. There are no NJDEP regulations that address impervious surface limitations in ground water recharge areas.

Therefore, management of Prime Ground Water Recharge Areas needs to be implemented in two ways – through municipal planning that maximizes protection by proper zoning, and on a site-specific basis to address variations in local anthropogenic, ecological, geological and hydro-geological conditions. Ordinances for wellhead protection and storm-water, and standards such as impervious coverage limits based upon community character or surface water impacts are not appropriate to manage Prime Ground Water Recharge Areas. This is because these ordinances and standards lack the necessary guidance or appropriate scientific methods that can be applied to site-specific conditions associated with ground water recharge.

HIGHLANDS REGION SOLE SOURCE AQUIFERS

The federal Safe Drinking Water Act (Section 1424) defines a Sole Source Aquifer area as "an area that has an aquifer which is the sole or principal drinking water source…and which, if contaminated would create a significant hazard to public health." The documentation required for designation of these Sole Source Aquifers provides information about extent, topography, hydrogeologic characteristics, ground water use and quality of the aquifers in question. It also provides information on public water suppliers and population served at the time designation was completed. This section provides a summary of the information characterizing these aquifers that was provided in the petitions for Sole Source Aquifer status. USEPA has designated five Sole Source Aquifers or Aquifer Systems located wholly or partially within the Highlands Region, or receiving water from the Highlands, as shown on the figure titled Highlands Sole Source Aquifers). The designations occurred primarily during the 1980s. The designated Sole Source Aquifers in the Highlands include:

- Buried Valley Aquifer
- Highlands Basin Aquifer System
- Northwest New Jersey 15 Basin Aquifer System
- Upper Rockaway River basin Area Aquifer System
- Ramapo River Basin Area Aquifer System

The primary purpose of the Sole Source Aquifer designation was to provide an enhanced level of review of projects and decisions that have the potential to harm the quality or quantity of drinking water resources of those aquifers. Federal funding cannot be used for any project that may contaminate the designated aquifer or create a significant hazard to public health.

BURIED VALLEY AQUIFER SYSTEM

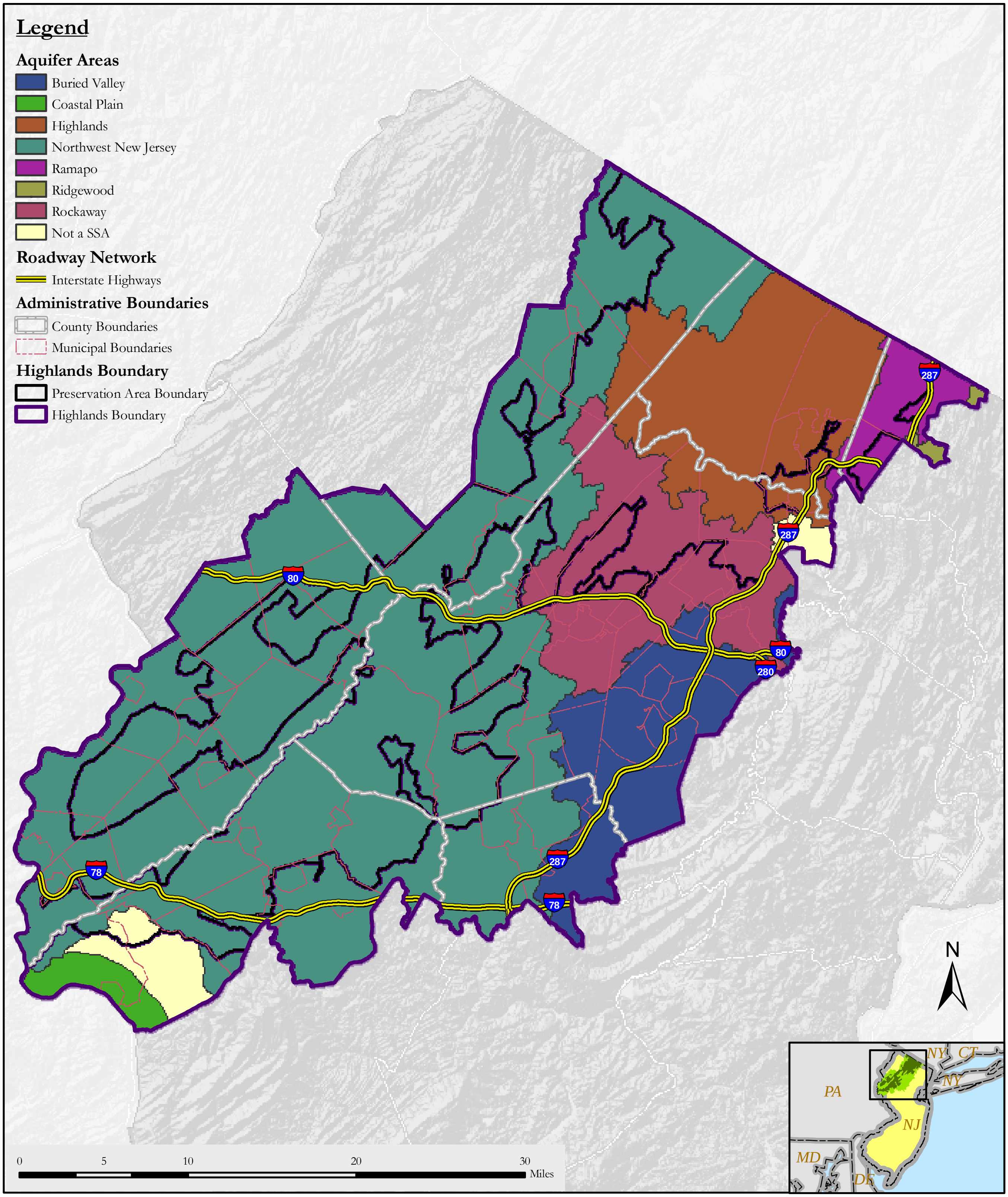
The Buried Valley Aquifer System area was the first Sole Source Aquifer designation in New Jersey, in 1980. It lies in portions of Morris, Union, Essex and Somerset Counties. The Buried Valley Aquifer System is largely located in the Piedmont Province. Only its stream flow source zone is in the Highlands.

The boundary of the area was defined as the Central Basin of the Passaic River Watershed. The area is bordered on the north by Hook Mountain and by a line that roughly bisects Montville. The western boundary is defined by the trace of the Ramapo Fault and the beginning of the Highlands Physiographic Province.

Two different types of aquifers occur in the area. One of regional extent underlies the entire area and is comprised of consolidated rocks of Triassic age. The other consists of unconsolidated rocks of Quaternary age in buried valley or valley fill deposits of sand or sand and gravel. Ground water flows from upland areas underlain by Triassic rocks into lowland areas underlain by the Quaternary unconsolidated deposits. Under natural conditions ground water discharges into streams and swamps that drain low areas. Because ground water flows from the Triassic age rocks into the unconsolidated deposits, the two types of aquifers are hydraulically interconnected and comprise a single ground water system. Most water pumped for public supply in the service area of the Buried Valley aquifer system is derived from the unconsolidated deposits.

Although evidence exists that the entire valley fill aquifer system of the Rockaway, Whippany and Passaic River watersheds are directly connected and therefore function as a single hydrologic system, a system of sub-regions are present.

Highlands Sole Source Aquifer Areas



Regional Master Plan, July 2008

Highlands Council
New Jersey

Sources:
New Jersey Highlands Council, 2006

Recharge area is delineated by valleys and the upland areas that drain into them. Ground water flow generally begins in higher areas, flows toward the valleys into unconsolidated, stratified deposits occupying valley floors and then discharges through into streams, swamps or lakes. Interception through well pumpage in the valley may result in induced infiltration of surface water into the aquifer. The recharge source zone is defined by the recharge to regional flow of the Buried Valley Aquifer System and the land area is the same as that of the aquifer system. Precipitation occurring within this area recharges the ground water reservoir that lies below it. There is little or no ground water connection with adjacent basins under natural conditions. However, extreme withdrawal in adjacent areas might influence the boundary of natural recharge for the basin. The contribution of precipitation to ground water varies within the basin and its overall amount or local extent is unknown. Where well withdrawals are great along reaches of the Passaic River, "reverse" recharge occurs with water flow from the river to the aquifer.

Water quality from Precambrian wells is generally good. Hardness ranges from soft, less than 50 parts per million (ppm) of dissolved minerals to moderately hard (60-120 ppm); pH ranges from slightly acidic to slightly alkaline. Iron occurs in objectionable quantities in some areas. Water from Watchung basaltic rocks is usually hard, ranging from 60 to more than 180 ppm. Some wells also have high sulfate, iron and manganese levels.

The Passaic River drains the Buried Valley Aquifer System. Combined low flow at Two Bridges, where the river leaves the ground water basin, is about 40 cubic feet per second (cfs) or 26 MGD. The Pompton River joins the Passaic at Two Bridges and increases the low flow to 115 cfs or 75 MGD. In 1970, diversions amounted to 320 MGD, which indicates the extent to which the surface water supplies have been utilized. It appears that surface water supplies are not an alternative supply for the area presently served by ground water. There were no economically feasible alternative drinking water sources identified which could replace the Buried Valley Aquifer System.

HIGHLANDS BASIN AQUIFER SYSTEM

The boundary of this system is defined by the outer boundary of the Wanaque and Pequannock River watersheds within the Passaic River Basin. The rock formations of the region are composed of Precambrian metamorphic and intrusive igneous rocks, with Paleozoic sandstones and conglomerates. Quaternary glacial deposits are found in the valleys and the lower slopes of the hills. The Wisconsin glaciation removed the soils and overburden from the bedrock, which is relatively unweathered. With the exception of pockets of impermeable till, the entire land surface in the drainage basin acts as the recharge area.

The water table in the Highlands Aquifer System area occurs at depths up to 40 feet below the land surface on the hilltops, intersecting the land surface in valleys. It is contiguous with the upper surface of streams, lakes and swamps.

The ground water quality in this system is generally very good, but varies due to differences in the composition of the rock, pattern of ground water movement from recharge to discharge, and length of time that the water is in contact with the various rock types. Water from the Precambrian and Paleozoic ranges from soft to moderately hard, low in total dissolved solids and slightly alkaline. The low mineral content is due to the highly insoluble nature of the minerals comprising these rocks. In the Quaternary deposits, the water is moderately hard and low in dissolved solids. The water can be slightly acidic to slightly alkaline.

The Highlands Aquifer System is thought to be vulnerable to contamination from numerous sources (e.g., on-site septic disposal, stormwater runoff). The thin soils, high permeability of glacial deposits, and fractured bedrock contribute to the vulnerability and potential spread of contamination. This is complicated by the fact that most of the bedrock wells in the area penetrate more than one water producing zone, having different hydraulic heads. This penetration causes short-circuiting of natural ground water flow and potentially, swifter spread of contamination.

Much of the land in the Highlands Aquifer System area is within the watersheds for the City of Newark and North Jersey District Water Supply Commission water supply reservoirs. The dispersed nature of the population, mountainous terrain, and hardness of the Precambrian bedrock would preclude the construction of a large public distribution system in most of the designated area. Therefore, alternate sources of drinking water were not apparent, necessitating protection of the Highlands Basin Aquifer System under the Sole Source Aquifer Program.

NORTHWEST NEW JERSEY 15 BASIN AQUIFER SYSTEM

The total area of the 15 Basin Aquifer System is approximately 1,735 square miles. Boundaries of the aquifer system are defined by drainage basin divides, streams which serve as discharge points, and the northern boundary of the Coastal Plain Province where it crosses the Millstone River Basin. The Delaware River constitutes the western boundary of the Sole Source Aquifer System area above Phillipsburg. The area encompassed by the 15 Basin Aquifer System includes portions of the Valley and Ridge, Highlands and Piedmont Physiographic Provinces.

The portion of the Highlands Province within the petition area includes Precambrian gneiss, intrusive rocks, and an outlier of Paleozoic sedimentary strata. Ridges are comprised of igneous and metamorphic rocks, with valleys underlain by limestone and shale.

Local flow systems are recharged at topographic high areas and discharge at topographic low areas. It is likely that recharge occurs over the entire petition area, excluding discharge areas (e.g., seepage into water bodies, flow to pumping wells).

The rate of recharge is probably greater where glacial till is thin or discontinuous and weathered bedrock is exposed, or where sand and gravel deposits are at the land surface. The direction of ground water flow is generally down and toward river valleys in uplands, and up and toward streams in the valley bottoms.

All formations in the Highlands transmit water due at least in part to secondary openings. Formations of Kittatinny Limestone contain solution cavities that permit conduit flow. Quaternary glacial deposits exist over much of the Highlands, extending from Morristown to Belvidere. Quaternary stratified drift deposits in the area are predominantly shallow (less than 100 feet) and tend to provide water storage that recharges underlying bedrock formations, or small community and domestic supplies. Upland areas are generally covered by a thin veneer of glacial till, usually less than 20 feet thick.

However, valleys can be filled with up to 350 feet of stratified glacial drift deposits. There are 24 stratified drift deposits of considerably greater thickness, such as those in the Wallkill and Whippany River Basins. Sands and gravels within these deposits can be very productive. The water table occurs on hilltops at depths of 20-40 feet below the land surface and intersects the land surface in valleys, where it is coincident with upper surface of streams, lakes and swamps.

Ambient ground water quality within the designated area varies considerably, though it is largely suitable as a drinking water supply following disinfection treatment. Purveyors are required to report the type of treatment they provide prior to delivering water to customers. Most in this area provide no treatment or disinfection only. Purveyors must monitor supplies to ensure they meet Federal and State standards. An absence of treatment indicates ambient ground water quality exceeds such standards. Localized contamination has resulted in well closings.

Variations in water quality are attributed mainly to differences in composition of rocks, pattern of ground water movement, and length of time that water is in contact with various rock types.

There are no identified alternate sources with existing infrastructure that are able to provide the same quantity of water as the 15 Basin Aquifer System. Potential alternate sources have constraints that prohibit their use, including lack of sufficient capacity, infrastructure, permits, or contracts required to allow use as alternative sources for the 15 Basin Aquifer System. The remaining sources include Spruce Run and Round Valley Reservoirs and the D&R Canal.

In addition, interconnections are reported as insufficient to deliver alternate supplies to purveyors in the system. Water distribution systems would need to be constructed to supply approximately 275,000 people, utilizing domestic wells, throughout the 1,735 square mile area. Construction of necessary interconnections between purveyors in different basins and water distribution systems to service that population would require tremendous capital investment. The topography and geology would also make such construction extremely difficult.

UPPER ROCKAWAY RIVER BASIN AREA AQUIFER SYSTEM

The area includes 13 municipalities in Morris County within the Rockaway River drainage basin, above the Boonton Reservoir. These include Boonton Town and Township, Denville, Dover, Jefferson, Mine Hill, Mountain Lakes, Randolph, Rockaway Borough and Township, Roxbury, Victory Gardens and Wharton.

Public water supply systems supplied an estimated 90,000 persons within these 13 municipalities at the time of the Sole Source Aquifer petition. Within the Upper Rockaway River drainage basin, individual wells drawing from the unconsolidated aquifer deposits and bedrock aquifers supply an estimated 30,000 persons with 2.7 MGD. The unconsolidated Quaternary aquifer supplies greater than 75% of the potable water in the area.

The unconsolidated Quaternary aquifer system of the Rockaway River drainage basin can be divided into two sub-basins - the Upper Rockaway and Lower Rockaway River, which are separated by the Boonton Reservoir. This system is situated partly in the Highlands, and partly in the Piedmont province. Stratified deposits were formed as streams reworked material carried by ice. Thickness of the Wisconsin stratified deposits vary from shallow to about 150 feet. Faulting is important, as fractures in bedrock formations can increase their permeability.

In 1976, approximately 9.5 MGD was withdrawn for public supply from the unconsolidated Quaternary aquifer. In addition to supplying potable water to the area's population, the aquifer is an important source of stream flow to the Rockaway River system, which drains to the Boonton Reservoir and the Passaic River. Four municipalities in Hudson, Essex and Bergen counties are serviced by the Boonton Reservoir. The Passaic Valley Water Commission also withdraws water from the Passaic River at a downstream location to service its customers.

Most ground water flows into the Rockaway River Basin Area. A small portion flows south into the Lamington River. Deposits along these two rivers constitute separate ground water flow schemes. Water moves through the bedrock aquifer by means of secondary permeability created by fractures. Water moves from high to low areas and into unconsolidated deposits. These deposits naturally discharge to surface water, mainly the Rockaway River.

Stratified drift deposits are highly permeable, and the bulk of the unconsolidated Quaternary aquifer system is recharged directly from precipitation on outcrop areas of these unconsolidated deposits. The

Rockaway River and its tributaries would recharge the aquifer through river sediments during drought periods. Inflow of surface water to these deposits occurs where heavy pumping reverses ground water flow, inducing recharge from the river to the aquifer.

Recharge from crystalline rock underlying Quaternary deposits is likely small compared to recharge from direct precipitation. Some consolidated rock upland areas recharge the aquifer, and some discharge to the surface through streams, seeps and springs which tend to dry up during droughts. This indicates limited storage potential in the upland rock aquifers.

Exchange between the river and underlying aquifers was considered especially important since surface water rights are held by Jersey City and ground water rights by municipalities in Morris County. In general, it seems that ground water discharge to streams is increasing in the upper part of the river upstream of Mill Creek; whereas downstream the river is recharging the ground water system.

The Alamatong Well Field, located on the Black (or Lamington) River in Randolph and Roxbury Townships, was developed by Morris County Municipal Utilities Authority. The well field is about 600 acres in size and reportedly had an estimated yield of 5-7 MGD. The well field taps Wisconsin stratified drift deposits, which are at least 160 feet thick.

Precambrian rock types found in the region include Franklin Limestone, Pochuck Gneiss, Losee Gneiss and Byram Gneiss. From a water supply perspective, permeability of rocks is low except where faulting, fracturing and weathering have developed secondary permeability. Recharge areas for Precambrian formations are in outcrop areas at the highest elevations. The general flow pattern is from these areas to the river.

Paleozoic rocks are confined to a narrow belt in the north and northwestern part of the Rockaway Valley service area. Within the service area, only sandstone units of Green Pond Conglomerate are used for water supply purposes. Recharge to these formations is mostly derived from direct precipitation on outcrop areas. In places where drift deposits overlie bedrock, recharge is from percolation through drift deposits.

Triassic formations including sandstone, shale and basalt underlie most of the Lower Rockaway River Drainage Basin. Near outcrop areas where recharge occurs, water in deposits is unconfined. In low-lying areas, glacial or recent deposits of clay and silt may act as confining layers. Fracturing in shale beds contributes most of the permeability. This area is contained within the Buried Valley Sole Source Aquifer System, described below.

More than 50% of drinking water for the aquifer service area is supplied by the Aquifer System. There are no economically feasible alternative drinking water sources that could replace the Rockaway Aquifer System.

RAMAPO RIVER BASIN AQUIFER SYSTEM

Thirty percent of the Ramapo River Basin Aquifer System land area is in New Jersey, including parts of Passaic and Bergen Counties. The remaining upstream area is in New York State. The aquifer area consists of hydraulically connected aquifers contained within the Ramapo River Basin. The Ramapo River Basin is part of the Passaic River drainage system. The basin is part of the Appalachian Highlands division that includes several physiographic provinces, including parts of the Highlands.

Aquifers include a highly productive valley fill aquifer in the Ramapo and Mahwah River valleys, and a bedrock aquifer that underlies the eastern portion of the Ramapo River Basin, east of the Ramapo River in New Jersey and the Mahwah River in New York.

Various rock types, ranging in age from Precambrian to Holocene, crop out in the Ramapo River basin. Crystalline rocks of Precambrian age underlie the majority of the basin area west of the Ramapo River in New Jersey. These rocks are mostly granite-like gneisses. These gneisses are part of the mountainous northeast belt across northern New Jersey comprising the Highlands. The Ramapo Mountains mark the southeast border of the Highlands Physiographic Province.

The Newark Group of Late Triassic age crops out in a northeast trending belt along the Delaware River to the New York State line. From Pompton Lakes north to the New Jersey-New York State line, the Newark Group underlies the entire area east of the Ramapo River to the Hudson River. There are two parts of the Newark Group in this area. The Brunswick Formation in the Ramapo River Basin is largely sandstone and conglomerate containing interbedded shale. The Triassic igneous rocks, including the extrusive Watchung Basalt of the Newark Group and intrusive diabase are commonly called trap rock.

Unconsolidated rocks of Quaternary age mantle the bedrock almost everywhere in the basin. These surficial deposits consist of unstratified and stratified drift deposited by the Wisconsin glacier and its melt waters during the Quaternary Period. Holocene alluvial deposits occur along stream channels to a lesser extent.

This drift cover on gneiss is generally thin, and bedrock exposures are numerous, particularly on steep slopes and summits. It is somewhat thicker on Triassic rocks, in some places more than 100 feet thick. In the New Jersey part of the basin, extensive deposits of stratified drift, chiefly sand and gravel occur. Because of their widespread surface coverage, they transmit water downward to underlying rock aquifers and laterally to streams. Where saturated thickness of these deposits and permeability are sufficient, they serve as aquifers. Stratified drift in the Ramapo valley forms the most productive aquifer in the basin.

Other extensive deposits of stratified drift occur in areas of Franklin Lake and Campgaw, and in the lowland between Ramsey and Mahwah. Most of the stratified drift around Franklin Lake forms a plain between the First and Second Watchung Mountains that extends from the Ramapo valley to the northwest and east of the lake. The lowland from Ramsey to Mahwah is largely covered with stratified drift. This lowland belt connects with the belt of stratified drift along the Ramapo River near the New York-New Jersey State line.

The principal stream in the basin is the Ramapo River, rising near Monroe, New York. Just downstream from the New York-New Jersey State line, the Ramapo is joined by the Mahwah River from the east. The Ramapo then flows in a generally southwesterly direction to Pompton Lake. Emerging from Pompton Lake, it flows south to the Pequannock River to form the Pompton River. The Pompton River flows into the Passaic River at Two Bridges.

Both occurrence and availability of ground water vary considerably according to the geologic materials underlying different parts of the area. Ground water generally occurs under unconfined conditions throughout the basin. Virtually all ground water in the basin originates as local precipitation. After moving through aquifers, ground water discharges to tributary streams, the Aquifer System, or is withdrawn by wells.

Virtually all ground water in the Brunswick Formation, especially in shale beds, occurs in interconnecting fractures. The most important fractures, with respect to transmitting ground water, are generally vertical joints. Locally, fractures resulting from faulting may be most important water bearers. Typically, ground water in sufficient quantities for domestic purposes can be obtained nearly everywhere in the Brunswick Formation from wells that are 100 to 200 feet deep.

Ground water in the Watchung Basalt also occurs mainly in fractures, with some in vesicular zones, containing cavities within the rock. The most productive water bearing parts of basalt are probably in or near contact with the Brunswick Formation.

Naturally occurring seepage from the Ramapo River during flood stage is considered to be a major source of recharge to valley fill aquifer. The recharge induced from the river by withdrawal of water from wells tapping the aquifer is also important.

Water from Precambrian gneiss is characteristically low in dissolved solids, soft to moderately hard, and acidic to neutral. In comparison, water from the Brunswick Formation contains moderate amounts of dissolved solids, is moderately to very hard, and neutral to slightly alkaline. Water from Quaternary sand and gravel deposits contains moderate amounts of dissolved solids, is moderately hard, and neutral to slightly alkaline.

WATER AVAILABILITY FROM GROUND WATER AND UNREGULATED STREAM FLOWS

The Highlands Act requires that the Regional Master Plan address, among other things, the protection, enhancement and restoration of water resources and ecosystems. Therefore, human uses of water (both ground and surface) must take place within the context of ecological protection. Because every human use of water has the potential to affect ecological resources, methods to estimate the availability of water supplies for human use must address the acceptability of those impacts on Highlands ecological resources.

One critical factor in defining potential growth areas within the Highlands Region is the availability of water for human use for a variety of purposes – domestic, agricultural, industrial, commercial and recreational. Water availability can be divided into two, interrelated components: ground water availability and surface water availability. They are interrelated because ground and surface waters are really the same resource, separated by time and space. Ground water supports stream flows through the year, and comprises 100 percent of natural stream flow during dry periods (these stream reaches where ground water moves to the streams are defined as "gaining stream reaches"). Surface waters not only rely on ground water for these "base flows" but also can be a source of ground water, when surface waters recharge ground waters along stream reaches where the ground water table is below the stream's elevation ("losing stream reaches"). Because most Highlands areas depend entirely on ground water supplies, the primary focus for water availability will be on ground water, which is the topic of this section. However, surface water availability based on reservoir systems is also a critical issue (especially in terms of providing the potable water supply to the densely populated areas outside of the Highlands Region) and is addressed in the Surface Water Availability section of this Technical Report.

Various policy decisions affect the final determination of what water is "available." Based on these policy decisions, in some areas water uses may already exceed available supply, some areas may have no remaining water available for additional human uses, and some may have "available" water that can support increases in human use. In turn, water availability will drive or constrain, in part, the potential for future development and redevelopment within various areas of the Highlands. Assessment and apportionment of the water availability of Highlands watersheds and subwatersheds will help to maintain, enhance and restore stream habitat and ecological health while addressing the sometimes competing demands for ground water supply needs.

One of the major objectives of the Regional Master Plan is to promote consistency among municipal, county and state levels of government so that local zoning and land use decisions are consistent with state resource protection policies which are necessary to determine "the amount and type of human development and activity which the ecosystem of the Highlands Region can sustain." (N.J.S.A. 13:20-11.a(1)(a)) Toward that end, the Regional Master Plan looks to establish limits on the type and intensity of land uses and uses of water that are based on the quality, limitations and sustained protection needs of Highlands ground and surface water resources, among other issues. For these reasons, water availability is a critical factor in determining the "type and intensity" of Highlands land use patterns and the sustainable capacity of natural systems to support that use.

ESTIMATING GROUND WATER CAPACITY AND AVAILABILITY

The determination of water availability relies first on a definition of "Ground Water Capacity" – the natural ability of a subwatershed to support stream flow over time, during varied climatic conditions. It is then necessary to determine how much of that capacity can be provided to human use without harm to other ground water users, the aquatic ecosystems or downstream water users. This new value can be considered the total "Ground Water Availability." Existing and projected uses are then subtracted from current uses to determine "Net Water Availability," which is the amount of water that is available (if any) for human use beyond the quantities already being used, or the amount by which current needs already exceed water availability.

A major challenge faced by the Highlands Council is that New Jersey currently lacks a commonly accepted method that can be uniformly applied across the Highlands Region for determining Ground Water Capacity or Ground Water Availability. The 1996 New Jersey Statewide Water Supply Plan (NJDEP, 1996a) uses a method (20% of annual average recharge) that was considered applicable to regional aquifers (e.g., Buried Valley, Piedmont or Coastal Plain); many parts of the Highlands are underlain by localized aquifers that may be more limited. In addition, this method was based on an empirical comparison of known aquifer problems to statistics on existing use levels. Under the current NJDEP regulatory system, water allocation decisions for surface waters are based on safe yield models, which in turn exist only where reservoir storage is available to ensure availability during drought periods. Most large ground water withdrawals are regulated case-by-case using pump tests and analyses, with consideration only to localized impacts on other users and on aquatic ecosystems. In areas where significant historical use has strained aquifer supplies, aquifer models may be used to regulate future water withdrawals (e.g., the Central Passaic Buried Valley Aquifers, the Ramapo Aquifer). While this system has a regulatory history dating from 1981, it is not sufficient for the Regional Master Plan. The Highlands Council must address land use capacity and patterns regionally, including the availability of water supplies, prior to the availability of aquifer models or local aquifer tests that support the permitting program. This regional analysis is intended to provide a larger context for evaluating the cumulative impacts associated with individual water uses.

A second major challenge is that no commonly accepted method exists in New Jersey for directly relating stream flow requirements to ecological integrity. A growing body of research exists that points to the need for methods that address a larger variety of flow statistics than just the traditional low flow threshold, but insufficient research has been performed in New Jersey to apply these approaches at this time. There are several models that may have applicability once further research is conducted, but at this time the available models make significant assumptions about the link between stream flows and aquatic ecosystems. There is a major need for a long-term commitment to evaluating the ecological flow needs of streams. However, for purposes of Regional Master Plan development the Highlands Council must rely on currently available data and methods. These methods are based on concepts from recent ecological research and current scientific principles regarding instream flow protection needs.

The New Jersey Highlands Council retained the services of the USGS New Jersey Water Science Center to provide expert technical support to the Highlands Council on developing appropriate methods to assess ground water capacity in the Highlands Region. The Highlands Council worked with NJDEP (including the New Jersey Geological Survey) and USGS to understand water availability in the Highlands Region. The USGS analyses helped inform subsequent policy decisions regarding surface and ground water protection requirements and available water supply, which in turn can be used by the Highlands Council to establish sustainable limits to growth within the Highlands Region.

The ground water capacity analyses utilized various statistical methods and analytical models. The analysis of water budgets and availability, and the relationship of both to the capacity of watersheds to support sensitive ecological resources and human uses are highly complex. Models are needed to help address these issues, because no direct methods exist for measuring the impacts on aquatic ecosystems of changes in hydrologic conditions due to water uses. Models are simplifications of real world conditions, and as such help to make complex decision making feasible. The methods were developed for use in watershed-based analyses of water availability; they were tested in the Highlands Region to determine their viability for application in the resource assessment and land use capacity map.

The Highlands Council recognizes that models are decision aids, not decision determinants. Therefore, results from the selected model or models must be applied in conjunction with policies and with the results from other analyses (e.g., ecological resource assessments, identification of open space preservation goals and priorities, growth pattern preferences) before an ultimate estimate of water availability can be developed. Any approach for estimating water availability must be capable of using model results in concert with additional policies and decision-making factors that may further constrain Ground Water Availability.

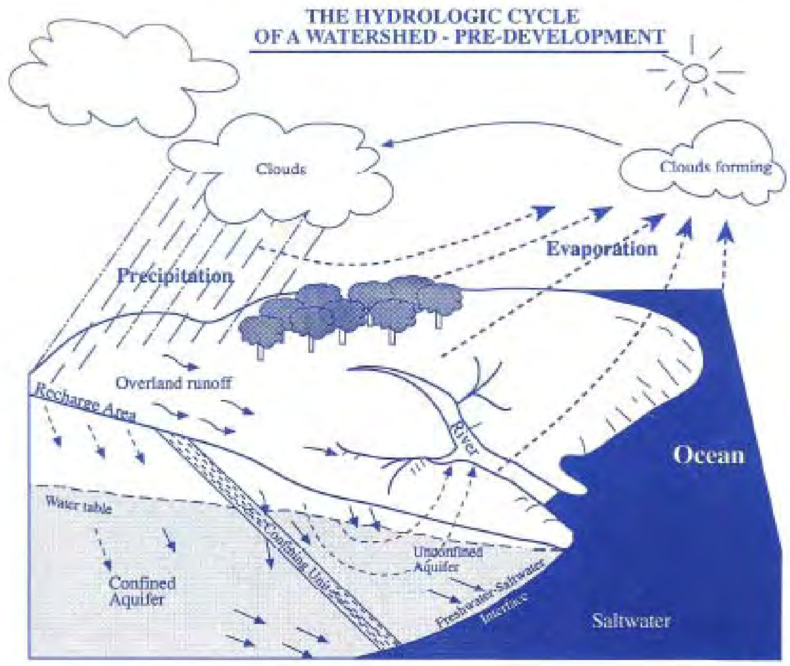
LEVEL OF ANALYSIS

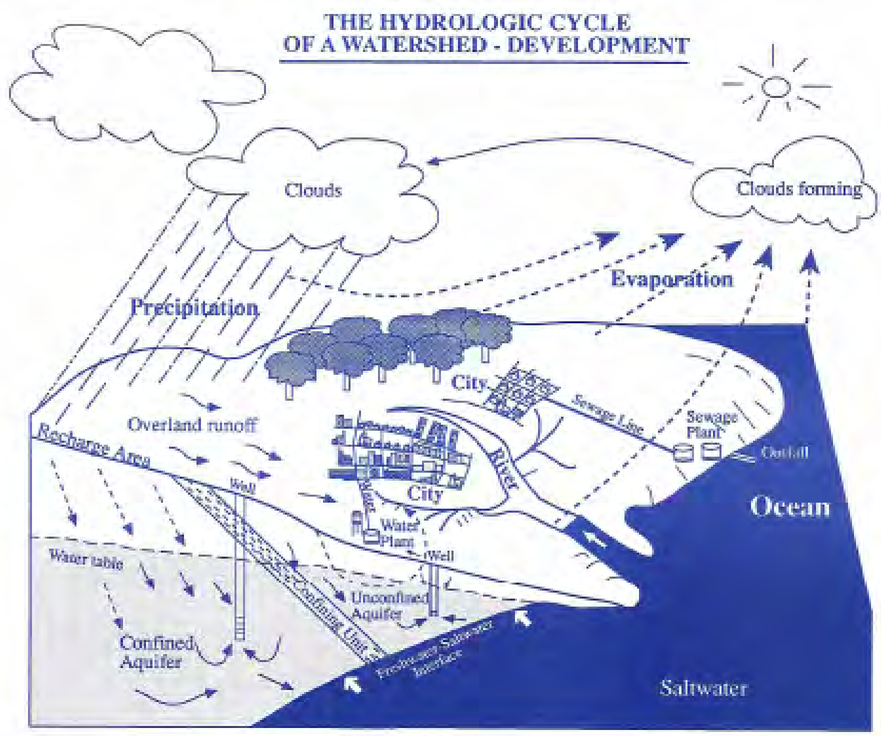
The availability and sustainability of Highlands' water resources are based on the physical characteristics of the Region's watersheds that directly determine their ability to store and transmit water and on the consumptive amount and transport of water that is withdrawn. This assessment evaluates water capacity and demand in 183 HUC14 subwatersheds entirely or partially within the Highlands Region, ranging in size from approximately three to 21 square miles. Hydrologic Unit Codes, as defined by the USGS in New Jersey (Ellis and Price, 1995), are used to identify the boundaries and the geographic area of drainage basins for the purpose of water data management.

Some water availability issues extend beyond the HUC14 subwatershed scale. If so desired, it is feasible for the Highlands Council to group subwatersheds for analysis at a larger scale, such as all the subwatersheds contributing to a surface water reservoir, or the subwatersheds upstream of a subwatershed area in deficit. Each issue can be addressed on the scale most appropriate to the issue, using HUC14 subwatersheds as the smallest study area.

RELATIONSHIP BETWEEN STREAM FLOWS AND RECHARGE

Any water availability method relies on an understanding of the watershed budget. For any watershed area, the natural water budget is dependent on precipitation as an input. The water is then partitioned over time into runoff (overland flow to surface water bodies), infiltration and recharge (movement of water through soils to the saturated zone, and to aquifers), and evapotranspiration (movement of water to the atmosphere due to evaporation from the land surface, and transpiration from plants). See the figure titled *The Hydrologic Cycle of a Watershed – Pre-development and Development* (from NJDEP, 1996a). Evapotranspiration can remove roughly half of total precipitation from a watershed (NJWSA, 2000b). Infiltration to ground water eventually returns to surface water bodies, creating base flow. Human activity modifies the natural water budget in many ways, including both direct water use and wastewater returns, and changes in land cover that can reduce evapotranspiration, increase runoff or decrease infiltration/recharge. These anthropogenic impacts can in turn modify or stress both aquatic and terrestrial ecosystems. A significant component of water availability analyses is determining the extent to which the impacts of existing and projected human water uses and hydrologic changes are acceptable, regarding both ecosystems and other human water uses.





Source NJDEP 1996a

Natural stream flows have several components, which can be affected by other factors in developed watersheds (NJDEP, 1996a). For natural watersheds, the primary components are runoff (precipitation that moves immediately across the land surface into surface waters), interflow (precipitation that percolates into the ground and flows rapidly through shallow layers to streams within hours to days) and base flow (precipitation that recharges ground water and aquifers and then discharges to streams after a longer period). Base flow is ground water discharge that provides water to streams during all periods, but is the sole natural flow in extensive dry periods (see figure Mean Annual Base Flow). Base flow in a natural stream system will, over time, be essentially equal to total ground water recharge, and therefore recharge is a major factor in the analysis of Ground Water Availability.

Unfortunately, it is impossible to measure watershed recharge directly; it can only be estimated. Recharge occurs over much of the land surface within a watershed, varying with soil, slope, land cover, precipitation patterns and volumes, etc. Recharge rates vary across the landscape and over time. Therefore, it is standard practice to estimate recharge by relying on surrogate measures, primarily base flow. Complications arise from doing so, especially in developed and developing watersheds where human land and water uses have altered the natural hydrologic system.

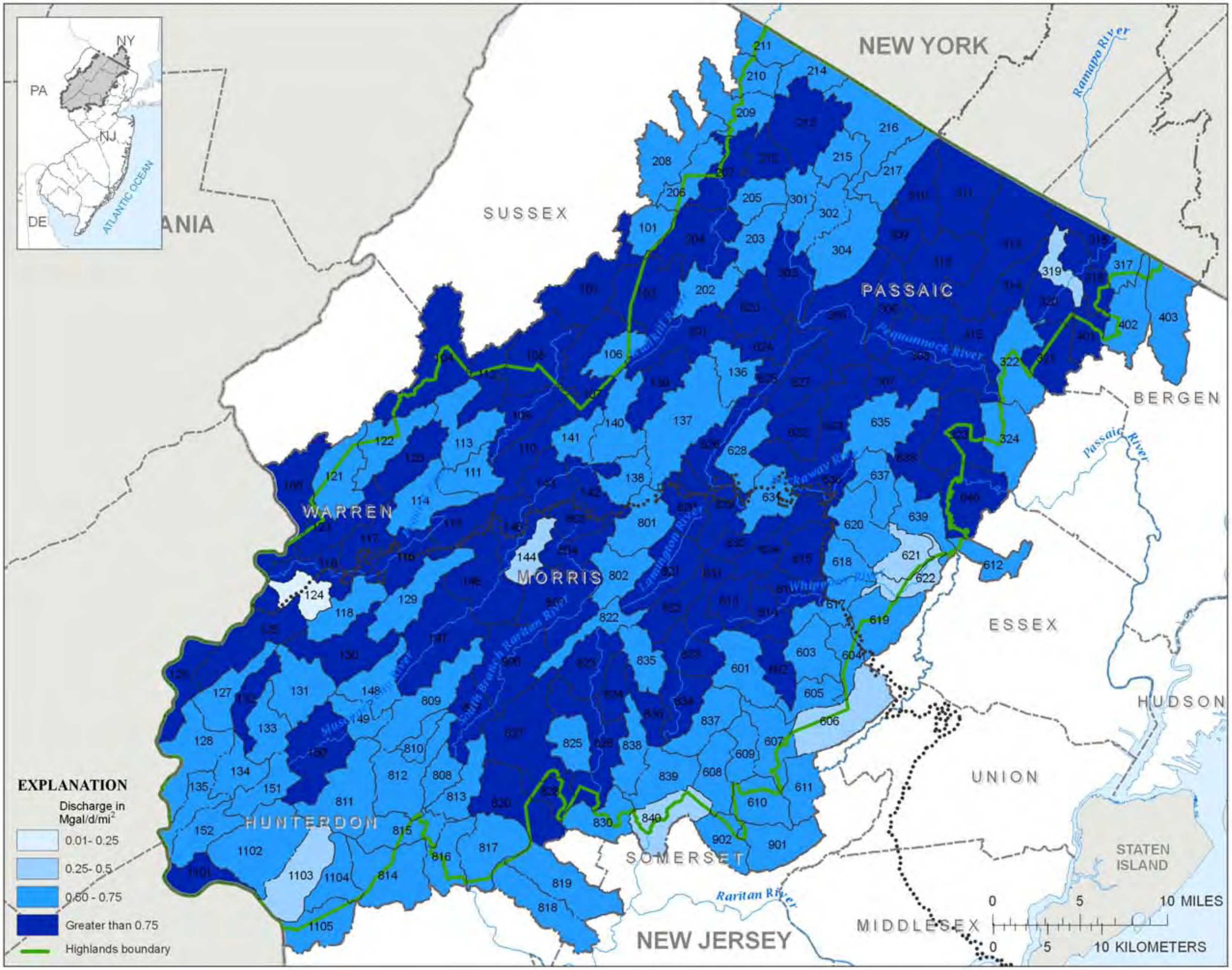
Base flow can be modified in developed watersheds by a variety of factors, including ground water withdrawals (which reduce the flow of ground water to the stream), surface water withdrawals or reservoir storage (which directly reduce stream flows), release of impounded waters from reservoirs to the stream, discharge of used water to the streams (from wastewater treatment plants and return flows from agriculture, industry and recreation), and recharge losses from land use and land cover changes. Despite these effects, the use of base flow can, if carefully analyzed to exclude human impacts to the maximum extent possible, provide a sound estimate of ground water recharge, and therefore a sound basis for estimating ground water capacity and water availability.

It should be clear from the discussion above that in a watershed with unregulated flows (i.e., no upstream impoundment that can alter the timing and magnitude of stream flows), additional consumptive or depletive uses[3] of ground water will reduce base flow in streams to which those ground waters usually flow. The assumption is that the base flow reduction will occur on a 1:1 basis over time, unless the ground water is replaced in kind. While there may be situations where the 1:1 reduction estimate varies, USGS studies, including one in the Highlands (USGS, 1997 and USGS, 2003b) have reached this general conclusion and it is a useful conservative assumption.

IMPACTS OF LAND COVER ON STREAM BASE FLOWS

Deforestation and the creation of impervious and semi-impervious cover, related to new development and to new agricultural development, can reduce both evapotranspiration and recharge, and therefore greatly increase runoff. New stormwater management regulations require continued recharge at pre-construction rates, but this requirement does not fully control the new runoff created by reduction in the rate of evapotranspiration. Conversely, reforestation has been noted in several areas of New Jersey, as previously farmed areas are allowed to re-establish forest cover. This process can increase both recharge and evapotranspiration, and therefore reduce runoff. Improved understanding of how each of these factors affects recharge, stream base flows and water availability would be valuable.

[3] Consumptive uses are those that result in evaporation of the water. Depletive uses are those that physically transfer the water to another watershed. Both result in loss of water to the originating watershed.



Mean Annual Base Flow, New Jersey Highlands

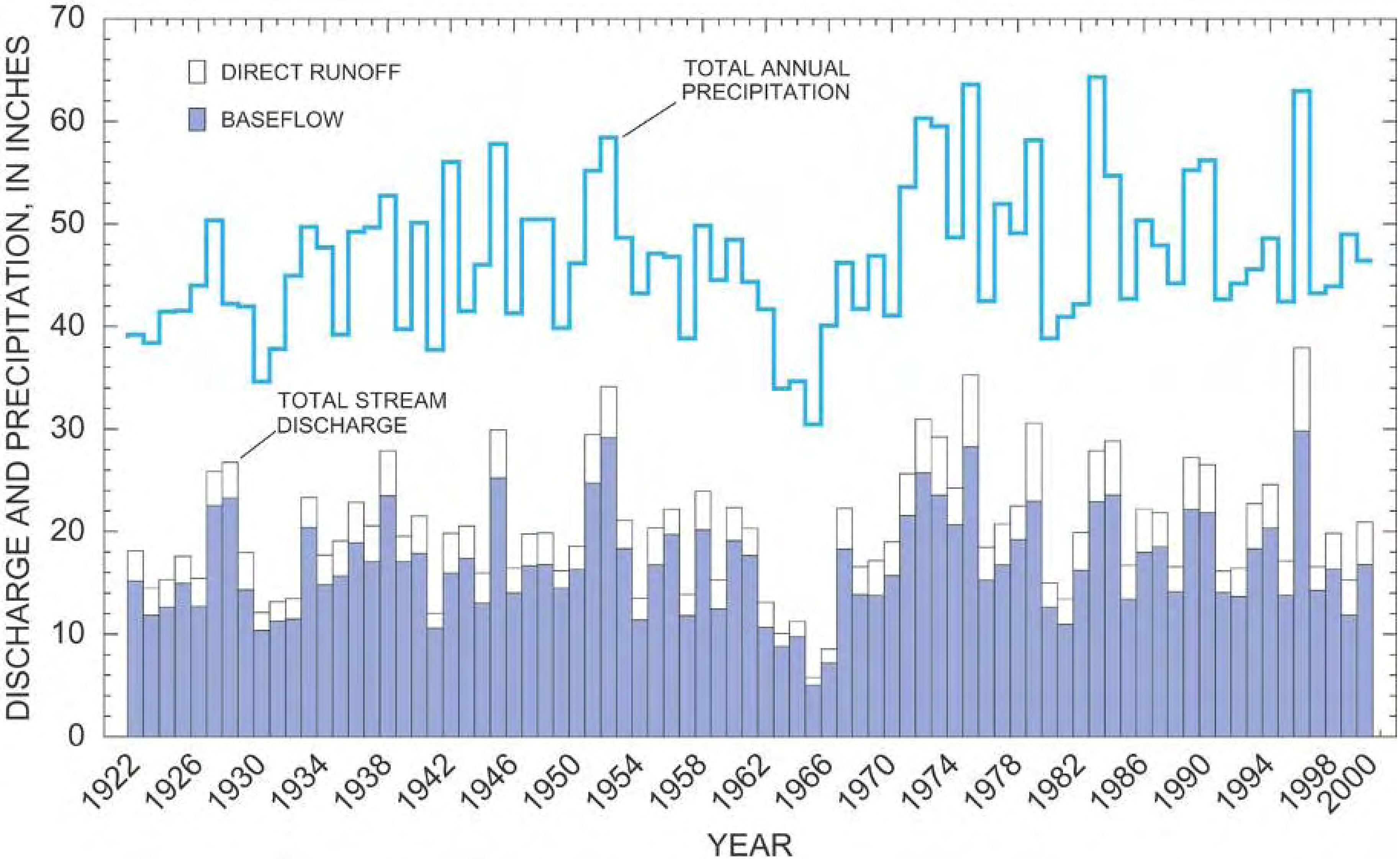
None of these processes are directly measurable. There is no method of directly relating changes in land uses to changes in recharge, and of changes in recharge to changes in base flow by area or time. Recharge to ground water is not uniform across a subwatershed. Movement of that ground water to aquifers also is not uniform. The addition of land uses within a subwatershed will therefore have different impacts on recharge depending on what previous land cover existed, where the new land uses are, the nature of the land uses, the extent to which recharge is artificially maintained to match pre-construction rates, etc. The flow of recharge water to streams is also variable with location, time, season and climatic event. Streams in some cases recharge ground water (losing stream reaches), and in other cases receive flow from ground water (gaining stream reaches). Increased land development reduces recharge rates and volumes. As such, there is a strong conceptual case that increased land development should result in decreased stream base flow, but two USGS studies of long-term base flow trends in New Jersey (Brandes and others 2005, and Walker and others 2005) have failed to find statistically significant base flow trends related to increased impervious cover. The reasons for this lack of correlation are not clear, and require additional study. It should be noted that these studies did not rule out such a link. It is acknowledged that in the future, an improved understanding of this issue over time would allow for a more robust water availability modeling approach.

SELECTION OF WATER AVAILABILITY METHOD

The following methods were considered for use by the Highlands Council in determining available water supplies. Some of these methods are described in Annear (2004) a report of the Instream Flows Council, and were considered due to their potential applicability to the Highlands Region. The selected methods and their application are then described in more detail in the following sections.

Stream base flow is a low flow statistic that can be used to estimate Ground Water Capacity within a basin. Base flow in a natural watershed consists of the ground water that discharges to its stream system. Base flow is an indicator of the water-yielding capacity of the aquifer or aquifers and the ability of the stream to sustain flow. Under natural conditions, the amount of stream flow composed of base flow is determined by (and roughly equal to) the amount of water recharging the ground water by precipitation, the infiltration capacity of the soil and the underlying aquifers' ability to store and transmit water. As introduced above, the proportions of stream flow composed of base flow and runoff can be modified by land use changes that reduce evapotranspiration, reduce recharge to ground water and increase surface runoff. Withdrawal of water from wells can also influence the amount of ground water available to discharge to streams.

The annual variability in precipitation a watershed receives can have a significant effect on annual totals of stream discharge, particularly during very dry and wet periods. An example of how stream base flow is influenced by annual fluctuations of precipitation in the Highlands Region is shown graphically in the figure entitled Annual Variability of Stream Discharge, Base Flow and Runoff in Relation to the Annual Variability in Precipitation for the Pequest River at Pequest, New Jersey. Annual stream flow for a period of 80 years, recorded at a gaging station on the Pequest River at Pequest, in Warren County, New Jersey, is compared to local annual precipitation for the period. Approximately half of the precipitation that falls on the watershed leaves the watershed as stream discharge; the remainder is lost mainly to evapotranspiration. Of note in this figure is the annual variability in the amount of base flow due to the annual variability in precipitation. Because of this variability, a base flow frequency distribution evaluating a range of recurrence intervals is used to show how Ground Water Capacity varies based on climatic conditions.



Annual Variability of Stream Discharge, Base Flow, and Runoff in Relation to the Annual Variability in Precipitation for the Pequest River at Pequest, New Jersey

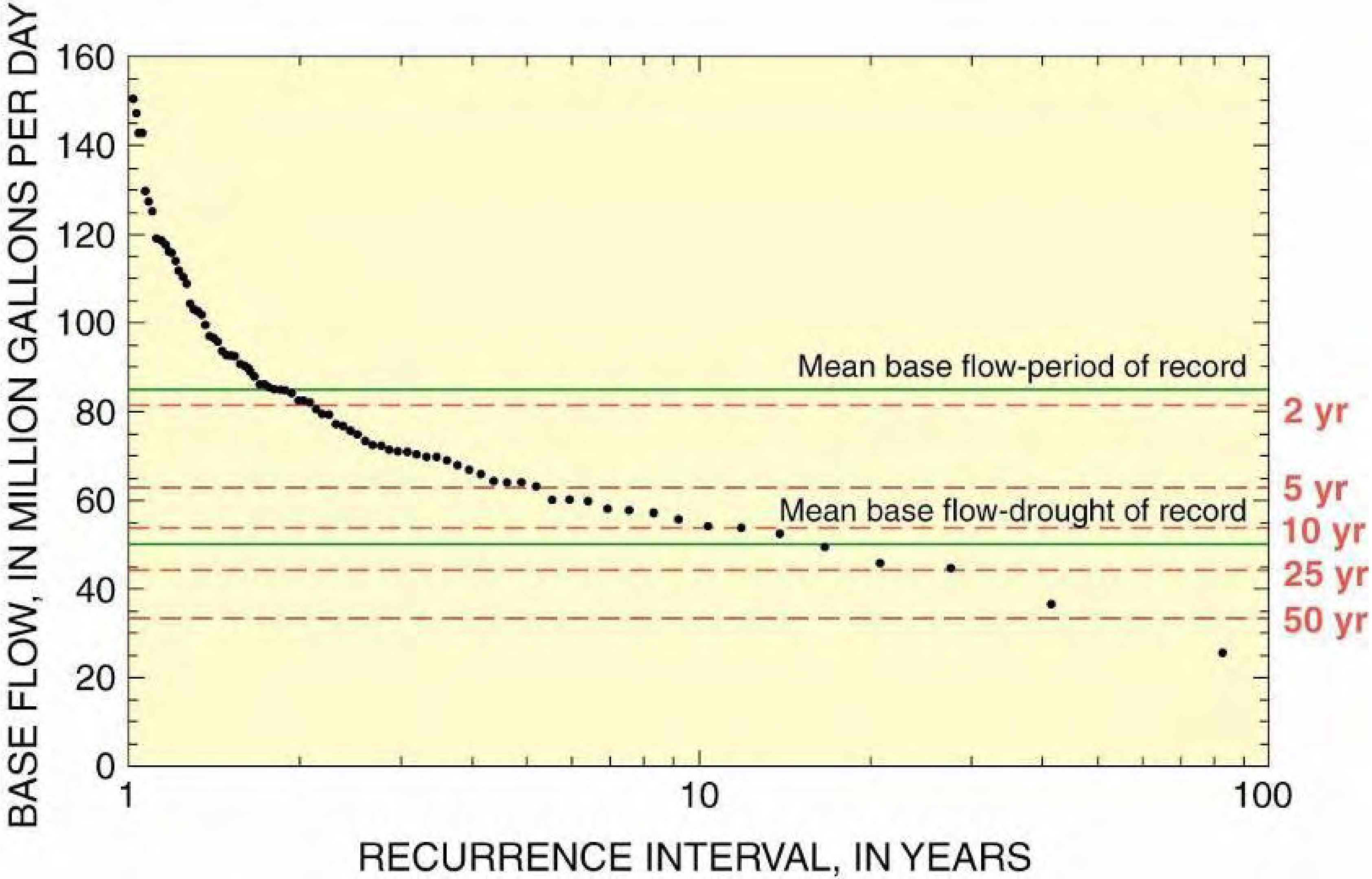
The 1-year annual base flow recurrence interval is equivalent to the long-term mean (average) base flow. The 2, 5, 10, 25 and 50-year annual base flow recurrence intervals represent a range of climatic conditions from relatively wet (two-year recurrence interval) to very dry (50-year recurrence interval). A recurrence interval is generally the average time, expressed in years, between occurrences of a hydrologic event such as a specified low flow. The term does not imply a regular cyclic occurrence. For example, an event with a two-year recurrence interval can be expected every two years on average, or with a probability of 50% every year. The 5, 10, 25 and 50-year recurrence interval base flows have probabilities of 20%, 10%, 4% and 2%, respectively, of occurring every year. However, any two years in sequence can have any recurrence interval base flows.

The distribution of base flow recurrence interval statistics with respect to mean base flow for the period of record and the 1960's drought of record is shown graphically in the figure titled *Distribution of Flow Statistics at a Typical Gaging Station*. For this particular basin the amount of base flow ranges from slightly more than 80 million gallons per day (MGD) at the two-year (wet) recurrence interval to about 34 MGD at the 50-year recurrence interval. The mean base flow for the 1960's drought of record is about 50 MGD.

Base flow recurrence intervals are not commonly used as the basis for defining how much water can be removed from a watershed. The Delaware River Basin Commission (DRBC, 1999) uses base flow (the low flow that has a twenty five-year return period) as a threshold for depletive/consumptive ground water uses in Southeastern Pennsylvania. The method assumes that depletive/consumptive ground water uses will reduce base flow, including during drought periods, but seeks to limit the potential impacts to acceptable levels.

More commonly, a specific base flow recurrence interval is used to establish a passing flow requirement for surface water withdrawals (e.g., prohibiting withdrawals when stream flows are less than or equal to that base flow) or to establish a maintenance flow requirement for a surface water storage facility (e.g., requiring releases to the stream system below a reservoir whenever stream flow is less than or equal to that base flow).

A base flow recurrence interval method could not used directly to define available water. Rather, a determination would be needed whether use of a specific base flow, or a percentage of a specific base flow, could be used as an indicator of total ground water supplies. Base flows may be zero or positive values, and so Ground Water Capacity would also range from zero to positive values. Application of a percentage to use of the base flow recurrence interval would result in a lower value, which could be considered Ground Water Availability. The current consumptive and depletive uses are then subtracted from the Ground Water Availability to determine Net Water Availability. This value could be negative or positive indicating a deficit or surplus, respectively. The Highlands Council would then need to apply additional policy considerations to determine how much of the Net Water Availability will actually be made available for additional human use, if any.



Distribution of Flow Statistics at a Typical Gaging Station

LOW FLOW MARGIN OF SAFETY METHOD

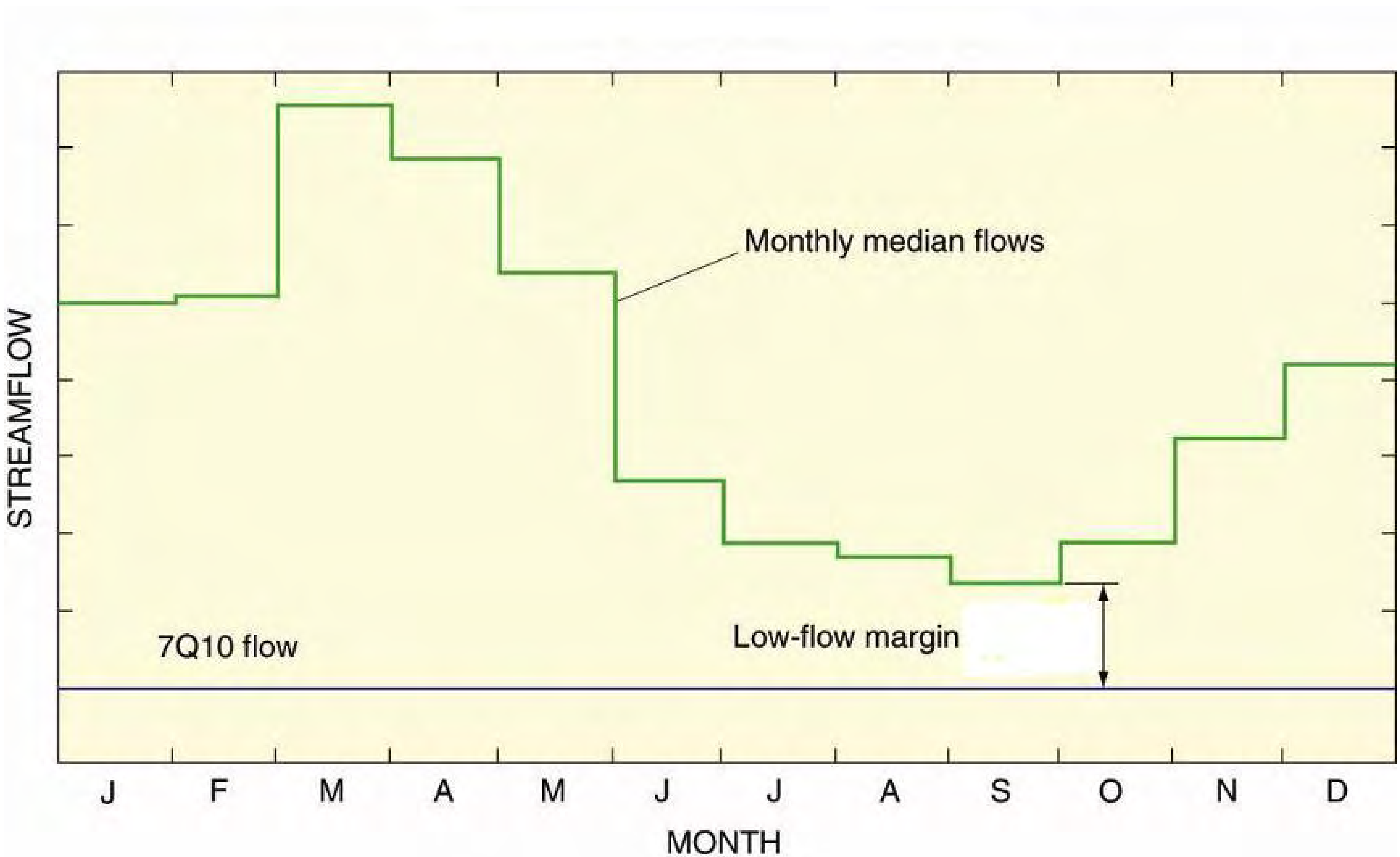
This method was developed by NJDEP for the purpose of defining water capacity based on a margin between two stream low flow statistics, used to help define limits on Ground Water Capacity that are based on a basic understanding of ecological stresses. It derives the September median flows and the 7Q10 (using a base flow analysis process as described above), for each HUC14 subwatershed using data from streams in a relatively unaltered state. The 7Q10 is the lowest total flow over seven consecutive days during a ten year period, a low flow statistic that has been used in quantifying passing flow requirements. The 7Q10 is also often used to define an extreme low flow condition for water quality based effluent limits applied to wastewater discharges. A critical flow regime for aquatic ecosystems is the lowest monthly flow, which in New Jersey and the Highlands tends to occur most years in September. The "Low Flow Margin" is the difference between the two, which will always be either a positive sum or zero, and is used to reflect Ground Water Capacity, or the natural ability of the watershed to support base flow. The "Low Flow Margin of Safety" or Ground Water Availability would then be derived by multiplying this value by a selected percentage or percentages to represent the portion of the Low Flow Margin that is considered available for human consumption (absent other constraints). Finally, estimates of consumptive and depletive water uses are subtracted from the Ground Water Availability to determine Net Water Availability.

It is critical to note that each stream will always have a positive Low Flow Margin or Ground Water Capacity (i.e., September median flows will always be greater than 7Q10), due to the nature of these statistics, with 7Q10 being indicative of a more severe condition. However, this Low Flow Margin value does not necessarily equate to a positive value for <u>Net</u> Water Availability. The application of a percentage to Ground Water Capacity, the subtraction of consumptive/depletive water uses, and the implications of Highlands Council policy decisions can significantly subtract from the Low Flow Margin. Based on this method, the analysis of a HUC14 shows "what would be" if there was not such flow impacts within or upstream of a HUC14 subwatershed. The final value for Net Water Availability under this method is "what should be." Similar to the Base Flow Recurrence Interval, Net Water Availability may be positive, zero or negative.

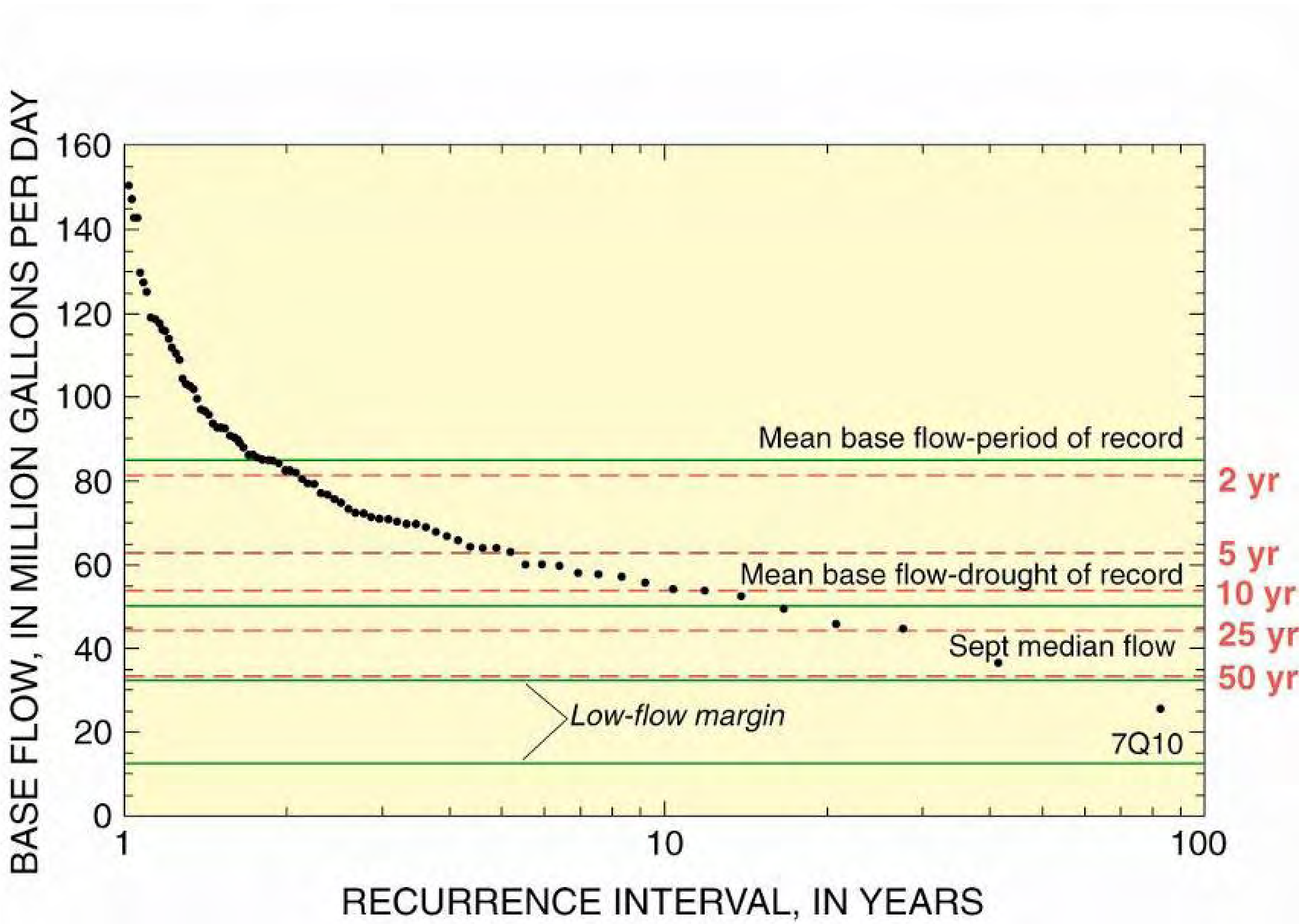
It should be noted that in some basins, anthropogenic factors result in the alteration of stream base flow. Dams may decrease or eliminate it; sewer plant discharges or reservoir releases may supplement it. These and other factors can be considered in making planning decisions regarding protection of water supply and a stream's ecological integrity.

An example of the low flow margin for a typical stream based on the difference between the streams 7Q10 and September median flows is shown in the figure entitled *The Low Flow Margin*. Estimates of Ground Water Capacity in million gallons per day (MGD), based on the calculated low flow margin is shown in comparison to the base flow recurrence interval statistics for the Pequest gage (see the figure *Comparison of Low Flow Margin with Base Flow Recurrence Intervals at a Typical Gaging Station*). One advantage to this method is that results from watersheds with minimal changes can be extrapolated or interpolated to all HUC14 subwatersheds.

The Low Flow Margin method has not previously been used for water availability analyses. NJDEP will be using this method in its update of the New Jersey Statewide Water Supply Plan.



The Low-Flow Margin



Comparison of the Low-Flow Margin with Base Flow Recurrence Intervals at a Typical Gaging Station

AQUIFER MODELS

Where available, aquifer models can provide a more complete understanding of ground water systems. In the Highlands, the available models are generally focused on specific regional aquifers, not entire watersheds, such as the Central Passaic Valley, Ramapo Valley, Upper Rockaway Valley, Lamington/Flanders Valleys and Germany Flats. However, no models exist for Precambrian ground water units or many other aquifers. Therefore, the use of ground water models can provide useful information for the derivation of water capacity using other methods, but cannot in aggregate provide region-wide estimates of water availability.

AQUATIC BASE FLOW

The New England Flow Policy was developed by the New England Field Office of the US Fish and Wildlife Service as an interim policy in 1981 "to address regional energy and water supply initiatives" for defining minimum stream flow needs in New England; it is still in use (USF&WS, 1999). The flow policy uses the Aquatic Base Flow (ABF) Method to identify instream flow needs. ABF utilizes the <u>median</u> of all mean August stream flows for a stream as the target for the "summer instantaneous stream flow", because August is viewed as the month of greatest stress to aquatic organisms due to low stream flows, depleted dissolved oxygen and high water temperatures in New England. Other flow targets are used in other periods of the year (February for fall spawning fish, and April/May for instream and overbank spawning species and channel integrity). There are two approaches, one of which uses natural stream flow data for watersheds that have a minimum drainage area of 50 square miles, with a period of record for each monitoring station of at least 25 years with good to excellent quality, a "basically free flowing or unregulated stream, and median monthly flow values calculated by taking the median of monthly average flows for the period of record." (USF&WS, 1999)

It should be noted that the New England Flow Policy itself states that the "USFWS has designated the median flow for August as the Aquatic Base Flow" but the 2002 version of the *Questions and Answers on the New England Flow Policy* states that "Median monthly flow values were calculated by taking the median of monthly mean flow." The two statements could be construed as different, as a true median of August stream flows would determine the middle (median) value of all August flows in the period of record, while the median of all August <u>mean</u> flows requires the calculation of mean (average) flows for each August in the period of record and determination of the median of <u>those</u> values. The latter approach will yield a higher flow target than the former, because daily stream flows most often are approaching or at base flow levels, with higher, short term peaks related to precipitation events. Each day of higher flow affects determination of a median value less than it affects the average (mean). However, for the purpose of this methods comparison, the definition of ABF in the *Questions and Answers on the New England Flow Policy* is assumed to be correct because it was written after the original 1981 memorandum and is specifically intended to clarify the uses of the New England Flow Policy.

In the absence of adequate flow data from the specific stream, ABF has a default flow release target of 0.5 cubic feet per second per square mile ($ft^3/s/mi^2$) is needed to protect native aquatic organisms during the low flow summer months (1.0 and 4.0 $ft^3/s/mi^2$ is needed during the fall/winter and spring, respectively). The New England Flow Policy recommends that this approach is most appropriate when "the project is relatively straightforward; the waters are not over-allocated to uses such as water supply, hydropower or irrigation; a single flow recommendation is sufficient; the administrative process is straightforward; time and cost constraints are significant issues; and a goal of the parties involved is to minimize risk and provide certainty during the regulatory process." Available water would then be determined by subtracting the ABF target flow from the daily flow, as the flow policy requires that instantaneous flows exceed the ABF values.

The ABF method is especially applicable to surface water diversions such as impoundments for water supply or hydroelectric power (the latter being a common occurrence in New England); the policy specifically states "USFWS personnel shall recommend that the instantaneous flow releases for each water development projects be sufficient to sustain indigenous aquatic organisms throughout the year." (USF&WS, 1999) Only surface water diversions have the ability to regulate instantaneous flow releases. A surface water diversion lacking impoundment storage has a "safe yield" essentially equal to zero, because the availability of sufficient stream flows during a severe drought cannot be guaranteed. Impoundments provide both for water supply during dry periods and for the ability to maintain stream flow through releases. The ABF method provides a target for downstream releases. Because ground water diversions affect base flow year round and cannot be tailored to provide different base flows at different times of the year, New England states have recognized that the utility of the ABF methods is primarily for surface water diversions. Some technical studies have reviewed the potential application to basins with ground water diversions (USGS, 2003b), but the method apparently is not used for the regulation of ground water allocations.

The ABF is based on New England hydrology and is applicable at the stream reach scale. It was developed in the Connecticut River basin and then expanded to the New England area. The default values are not directly applicable to other regions (Annear, 2004). Therefore, its use in the Highlands would require development of a Highlands-specific approach using Highlands data. One significant issue is whether, in which circumstances and how the ABF results can be transferred to watersheds that are either without flow gaging stations or are regulated by upstream impoundments, as the method "does not address geomorphology and natural hydrologic variability" (Annear, 2004). The New England Flow Policy documentation specifically states that it is not appropriate to use long-term gaging records from an unregulated stream to develop simulated unregulated flow records for a nearby gaged stream for the purpose of developed stream-specific ABF values. (USF&WS, 1999) Because the Regional Master Plan is a regional document, the estimates of ground water capacity and availability must be regional in the extent of their coverage. The current ABF method assumes that ungaged streams will all have the same characteristics, and therefore applies a single default value to all.

PERCENT OF ANNUAL AVERAGE FLOW (TENNANT)

The Tennant method (see Dunbar, et al. and Annear, 2004) utilizes percentages of mean annual flow in order to recommend seasonally adjusted instream flows necessary for maintaining healthy aquatic habitat conditions, as summarized in the table entitled *Tennant Method*. The method was developed based on information from several areas of the United State, and has been used since the 1950's in the Ohio and Delaware River Basin, and is considered applicable to the river segment scale where there is little or no competition for water; (Annear, 2004) recommends that site-specific studies based on other methods be used where there are complex flow trade-offs.

Tennant Method
Relationship between Aquatic Habitat Conditions and Mean Annual Flow for Small Streams

Aquatic habitat condition for small streams	Percentage of Q_{MA}, Apr to Sept	Percentage of Q_{MA}, Oct to Mar
Outstanding	60	40
Excellent	50	30
Good	40	20
Fair	30	10
Poor	10	10
Severe degradation	<10	<10

Q_{MA} = Mean annual discharge

The "good" flow is implied to mean the flow needed to maintain a healthy aquatic ecosystem during summer low flows. The "good" flow is calculated by multiplying the mean annual flow in the basin by 0.40 (40 percent) to estimate the mean monthly flow during that stress period. The good flows may then be divided by the basin area to come up with "good" flows per square mile (cubic feet per second per square mile, $ft^3/s/mi^2$). The mean of area-adjusted flows has been estimated by others as 0.67 $ft^3/s/mi^2$. In accordance with the Tennant methodology, this value is then subtracted from the mean (not the median) September flow per square mile to yield water availability for that month.

The application of a single flow regime (such as the 40% "good" flow in the preceding table) is not necessarily protective of the aquatic habitat; as stated in directives for using the Tennant method, it "…can and should be used to recommend different flows at different times of year to follow the natural hydrograph".

In northern New Jersey, stream flow is at its highest in the spring and at its lowest during late summer and early fall. Therefore, the "good" summer stream flows provided by the Tennant method may be higher than would be appropriate in New Jersey. Directives for using the method indicate that it must be used in conjunction with "a sound knowledge of the hydrology and ecology of the river in question." If the method is to be applied to streams where no stream flow data exists for natural flows, care needs to be taken in its application.

This method's strength is that it is inexpensive and easy to conduct. However, directives for using the method indicate that it must be used in conjunction with "a sound knowledge of the hydrology and ecology of the river in question." If the method is to be applied to streams where no stream flow data exists for natural flows, care needs to be taken in its application.

A limitation of the Tennant method is the requirement of having a continuous stream flow record to analyze. Application of the Tennant method to stream flow records at sites with altered flow conditions influences subsequent calculations and results. Capacity values identified at a deficit are from regulated sites. Discharge numbers from these stations are artificial and are a function of upstream regulation. They do not reflect natural base flow conditions. Conversely, applying an average mean flow calculated from a group of pristine basins to other basins, particularly those that have regulated flows (e.g., Pequannock River at Macopin, Wanaque River at Awosting, Wanaque River at Wanaque, Ramapo River at Pompton Lakes, Rockaway River below Boonton Reservoir) is not technically sound. This assumes all basins have the same physical characteristics, which is not the case.

RANGE OF VARIABILITY (RVA) METHOD

RVA is based on two concepts – first, that riverine ecosystems are best preserved by protecting the natural variability in flows or "natural flow paradigm", rather than assuming that protection of minimum stream flows alone is required to support healthy aquatic communities, and second, that since we will never completely understand what the ecosystem can tolerate, an adaptive management approach should be taken to define an adequate flow regime. This system is considered useful for diagnostic and monitoring purposes (Annear, 2004).

RVA is a multi-step process involving characterization of the range of flows using 32 indicators of hydrologic alteration; selecting flow management targets; designing a system to attain the selected targets; implementation and monitoring; annual revisiting of the above steps; and incorporation of new information and revising the overall program as needed. The Nature Conservancy has developed a statistical method to be used in conjunction with RVA know as "Indicators of Hydrologic Alteration" (IHA) to characterize flow regimes (Nature Conservancy, 2006).

Five attributes are included in IHA: the magnitude of flow, frequency of events, such as floods, duration of such events, timing of flow events, and the rate of change indicating how quickly the flow changes. The required data collection and other input parameters for the model make this approach impractical in terms of time limitations for adoption of a RMP, but provide a potential next step in RMP implementation. The current efforts to determine base flow will help in developing this or any other enhancements to the Highlands instream flow protection program. It should be noted that the NJDEP/USGS Hydro-ecological Integrity Model (or Ecological Flow Goals approach) is a variation on RVA. A critical question regarding this method is whether and how it can be applied regionally, given that many Highlands stream systems lack flow monitoring gauges.

HYDROECOLOGICAL INTEGRITY ASSESSMENT PROCESS (ECOLOGICAL FLOW GOALS METHOD)

The United States Geological Survey New Jersey Water Science Center (USGS) and the NJDEP are currently evaluating new methods to assess regional water availability that are protective of the ecological integrity of freshwater aquatic ecosystems (Henriksen and others, 2006). The intent is to develop new methods that can be used to assess the effects of water withdrawals on stream flow and ecological health in streams that are highly dependent on natural flow regimes (Poff and others, 1997 and Olden and Poff, 2003). This approach is not an ecological model per se, but rather assumes the ecological benefits of maintaining a relatively natural flow regime.

The Hydroecological Integrity Assessment Process (HIP) is comprised of a users' manual and a set of assessment software that includes the New Jersey Hydrologic Assessment Tool (NJHAT, also known as the Ecological Flow Goals Method). This tool uses nationally available USGS continuous stream flow data to calculate a set of ecologically relevant hydrologic indices (ERHIs). ERHIs are stream flow indices that characterize elements of the flow regime that most significantly affect biological health and ecological sustainability. The major elements of the flow regime include the magnitude, timing, frequency, duration and rate of change of stream flow under low-flow, high-flow and average conditions. NJHAT then assesses water availability by evaluating hydrologic changes against selected thresholds ranges in these indices.

NJHAT allows for assessment of water availability within selected threshold ranges by evaluating changes in specified ERHIs that may be altered by changes in land use such as urban development and other anthropogenic processes including flow regulations, diversions, withdrawals and returns (Poff and Ward, 1989; Olden and Poff, 2003). These impact thresholds can represent an upper or lower limit of ecological sustainability in streams. Localized issues related to water use, such as effects of water withdrawal for consumption, effects on the sustainability of freshwater aquatic ecosystems, and contamination threats, would place further stress on the resource.

This method is still under development and therefore has not been used in a regulatory setting. USGS developed the general model and is testing it for NJDEP use. NJDEP is considering the policy issues inherent in the method that must be addressed prior to regulatory use. The method is fundamentally different from historic methods, in that it addresses change to a range of flow conditions, including high and low flows, and to flow frequency. Historically, the primary focus has been on maintaining low flows only, for downstream water uses and ecosystems. The value of the method is that it determines natural stream flow dynamics and allows for a determination of when stream flow falls outside the acceptable limits based on these dynamics as a result of water use. The method is highly data intensive and may, to an extent, be site specific. It is not available as a region-wide analytical tool at this time.

In developing the method, NJHAT was first used to calculate 171 ERHIs for a group of 94 New Jersey USGS stream gage sites using daily and peak flow records. These gage sites were selected as representing the least hydrologically impaired sites. A New Jersey stream classification tool classifies any stream into one of the four stream types. The four classes of streams identified in New Jersey are characterized by the relative degree of skewness of daily flows (low = stable flow, high = flashy flow) and frequency of low-flow events (low = high base flow; high = low base flow).

Thus, streams belonging to stream class A are semi-flashy with moderately low baseflow, class B streams are stable with high base flow, class C streams are moderately stable with a moderately high base flow, and class D streams are flashy with a low base flow (Henriksen and others, 2006). Following this, a series of Principal Components Analyses were conducted to identify the most significant ERHIs that are associated with 10 sub-components of the flow regime (magnitude – low, average, high; frequency – low, high; duration – low, high; timing – low, high; rate of change – average) for each of the stream types. A matrix was produced by identifying, for each stream type, the indices that are most significant for each of the 10 sub-components of the flow regime. Significant indices were derived by assessing the loading pattern on significant principal components. Loadings of the hydroecological indices on each significant principal component were used to identify indices that explain dominant patterns of hydrologic variation provided by the indices. Because principal-components axes by definition are orthogonal, indices from significant secondary and tertiary principal-component axes also were selected to ensure that the chosen indices are relatively independent from one another and to identify surrogate indices for later comparisons (Olden and Poff, 2003).

Surrogate indices were also identified, i.e., other indices within each sub-component that are collinear with the indices of interest (Henriksen and others, 2006). The ten primary and surrogate indices for this stream type are listed in the table titled *Primary and Surrogate Indices for Stream Type "C"*.

The indices produced by HIP can be defined as either temporal or spatial (Henriksen and others, 2006). Temporal indices are typically calculated from a long-term multi-year daily flow record from a single stream gage. For example, index MA24 – variability (coefficient of variation) of January flow values – uses the standard deviation for January mean flow values in each year over the entire flow record and divides the standard deviation for each year by the mean for each January in that year and the median of these values are the index. Therefore, there are calculated values for each year for the entire flow record to calculate upper and lower percentile limits. Spatial indices, however, do not produce a range of values from which percentile limits can be calculated. For example, MA5 (skewness) is defined as the mean for the entire flow record divided by the median for the entire record. This calculation results in a single value, therefore, upper and lower percentile limits cannot be calculated. One approach to generating percentile limits for spatial indices is to calculate the 25th and 75th percentile values of the respective index values for all sites for a given stream type. This approach works in most circumstances and provides a statistically defensible option for establishing limits around an index value as an alternative to identifying a surrogate temporal index.

WETTED PERIMETER METHOD

The wetted perimeter approach focuses on submerged stream width in riffles as a critical ecological indicator, and is used to determine fish food availability (Big Hole River Foundation, 2005). By maximizing the wetted perimeter of riffles, enough food and habitat is assumed to be available for a healthy aquatic community to survive in the river as a whole. The minimum stream flow required for habitat protection is assumed to be where increases in stream flow no longer produce large increases in wetted perimeter. This typically occurs when water covers the streambed to the bottom of the bank.

Wetted perimeter is simply a physical measure of how wet the streambed is. Studies show that it is directly proportional to the crop of food available to fish, and therefore, to the ecological carrying capacity of the stream.

Wetted perimeter is measured as a variable that changes with the flow rate of water. Because stream beds come in complex shapes, wetted perimeter does not increase in a simple, linear way as the flow of water

Primary and Surrogate Indices for Stream Type "C"

Index	General Definition	Specific Definition	Index Type	Primary or Surrogate
DL16	Low flow duration - Pulse Duration	Combine the average pulse duration for each year for flow events below a threshold equal to the 25th percentile value for the entire flow record. DL16 is the median of the yearly average durations.	Temporal	Primary
DH11	High flow duration - annual maximum of 1-day moving average flows divided by the median for the entire record.	Compute the maximum of a 1-day moving average flow for each year. Dl11 is the mean of these values divided by the median for the entire record.	Temporal	Primary
FH3	Frequency of high flow events - high flow pulse count	Compute the average number of days per year that the flow is above a threshold equal to three times the median flow for the entire record. FH3 is the median of the annual number of days for all years.	Temporal	Surrogate
FL1	Frequency of low flow events - low flow pulse count	Compute the average number of flow events with flows below a threshold equal to the 25th percentile value for the entire flow record. FL1 is the median number of events.	Temporal	Primary
MA24	Magnitude of average flows - Variability (coefficient of variation) of monthly flow values	Compute the standard deviation for January in each year over the entire flow record. Divide the standard deviation by the mean for each month. The median of these values across all years is the MA24.	Temporal	Primary
MH14	Magnitude of high flow events - Median of annual maximum flows	Compute the annual maximum flows from monthly maximum flows. Compute the ratio of annual maximum flow to median annual flow for each year. MH14 is the median of these ratios.	Temporal	Primary
ML3	Magnitude of low flow events - median minimum flow for March for all years	Compute the minimums for each March over the entire flow record	Temporal	Primary
RA6	Rate of change of average flows.	Compute the log10 of the flows for the entire flow record. Compute the change in log of flow for days in which the change is positive for the entire flow record. RA6 is the median of these values.	Temporal	Primary
TH3	Timing - high flow events - Seasonal predictability of non-flooding.	Computed as the maximum proportion of a 365-day year that the flow is less than the 1.67 year flood threshold and also occurs in all years. Accumulate non-flood days that span all years. TH3 is maximum length of those flood free periods divided by 365 days.	Spatial	Primary
TL1	Timing - low flow events - Julian date of annual minimum	Determine the Julian date that the minimum flow occurs for each water year. Transform the dates to relative values on a circular scale (radians). Compute the x and y components for each year and average them across all years. Compute the mean angle as the arc tangent of y-mean divided by x-mean. Transform the resultant angle back to Julian date.	Spatial	Surrogate

increases. A graph of wetted perimeter vs. stream flow will show inflection points where the wetted perimeter changes abruptly with small changes in flow. Measurement of channel cross-sections in the target streams, usually at a riffle section, is necessary during multiple stream flow levels to conduct this method; the method is appropriate at the river reach scale in streams "with well-defined riffle and pool sequences" (Annear, 2004).

Other factors complicate using the wetted perimeter method alone as a guide to stream flows. Riparian vegetation loss, loss of shade, widening and shallowing of the stream channel all result in a rise in water temperature, especially at low flows. This affects fish food – and fish – viability. Incising of a stream channel due to stormwater runoff can constrain the stream channel. A critical question regarding this method is whether and how it can be applied regionally, given the need for intensive stream-specific data.

R2CROSS METHOD

In this method, the minimum flow necessary to maintain acceptable habitat for fish and macroinvertebrates in critical areas (such as riffles) is determined using the wetted perimeter, water depth and water velocity of a stream (Montana Water Trust, 2006). During the summer, all three hydrologic requirements must be met. During winter flows only two of the three requirements must be met. These requirements are made to account for seasonal variability that occurs in most unregulated systems. By protecting the physical characteristics of habitat in such critical areas, it is assumed that other types of habitats, such as pools and runs, will also be protected.

The R2Cross instream flow method uses field measurements (slope, depth, distance from stake, velocity) from a stream transect and links these to the natural environment, based on two biological assumptions; first, that fish are the species most sensitive to minimum instream flows in coldwater ecosystems and second, that riffles are a critical component to healthy aquatic ecosystems. As nearly all Highlands streams are cold water aquatic ecosystems, this assumption may be applicable here.

In addition to the hydrologic physical parameters measured, biological observations can be used as part of the R2Cross method. A fish and aquatic invertebrate sample are suggested for each stream reach. This biologic information is separate from the R2cross hydrologic modeling but can be considered in making instream flow recommendations. As with the Wetted Perimeter method, this method requires the collection and analysis of significant stream-specific data and therefore may not be practical as a regional planning tool.

CONSIDERATIONS FOR METHOD SELECTION

Determining an acceptable method for estimating water availability relies on numerous considerations. The method must be capable of identifying where subwatersheds, watersheds and river basins are already stressed due to existing ground water consumptive and depletive water uses, and where they are not (i.e., the method should not assume that current conditions are necessarily acceptable conditions). The method must be capable of yielding initial results that can then be reassessed based on policy decisions. These policy decisions will consider applicable statutes (e.g., Highlands Act policies for base flow maintenance in the Preservation Area, protection of existing surface water safe yields, water needs of extraordinary ecological areas). The method must also establish a baseline for water availability that will not change based on the impacts of future land uses and water uses (e.g., no "sliding scale" as conditions change, as ecological sustainability requirements do not).

It should also be noted that the Highlands Council intends to continue to move forward in refining its estimates of water availability, in assessing the adequacy of stream flow for both water supply and ecological protection purposes, and that the Regional Master Plan will be revised periodically to accommodate this goal.

Conducting the analysis at the subwatershed (HUC14) level is critical to the protection of small streams. The subwatershed results can then be aggregated to watershed (HUC11) and river basin (HUC8) levels to determine impacts on the larger streams and rivers. Final answers on water availability can only be determined when the results from every level of aggregation are combined and evaluated. For example, a large river could have ample flows from its full watershed, but the small streams of one tributary subwatershed could be severely impaired due to excessive ground water withdrawals. Conversely, a subwatershed could have ample flows, but contribute to a downstream subwatershed that has severe impairment due to excessive withdrawals. Because HUC11 results cannot be disaggregated to the HUC14 level without significant additional analyses, the HUC14 level was selected for baseline analysis.

It is important to note that the flows of the watershed upstream of a reservoir may have already been allocated, even though they remain in the stream. NJDEP is responsible for issuing and enforcing water allocation permits and setting safe yields and passing flows for reservoirs. One issue that must be considered is the extent to which existing stream flows (the current hydrologic regime) are critical to protecting the safe yields of reservoirs through restrictions on net increases in consumptive and depletive water uses upstream of the reservoirs. In other cases, some additional consumptive and depletive water uses would be acceptable without compromising safe yields. In either case, the safe yields are already determined, and these safe yields are the only legally recognized determinant of "surface water available capacity."

There may be instances where a finding that there is Net Water Availability will be overshadowed by the need to protect highly sensitive ecosystems. As such, the preservation of those ecosystems would reduce development potential and acknowledge that the water must be fully "reserved" to address the ecosystem protection goals of the Highlands Act.

It is acknowledged that in addition to constraints on water availability, the Regional Master Plan will include a variety of other policies that will protect, enhance and restore water resources and ecosystems. Habitat preservation, development regulations, water management policies, land management improvements, and restoration options are all to be considered for augmenting water consumption policies in support of the goals of the Highlands Act.

Where Net Water Availability is a positive value, the water could potentially be available for future human uses (e.g., agriculture, potable water, industry) and will help determine the type and intensity of development that is sustainable. Where Net Water Availability is negative, the Regional Master Plan can establish restrictions on future growth and/or consider other options for restoring flows in that HUC14 (e.g., water conservation, recharge augmentation) to reduce depletive and consumptive water uses and their impacts.

SELECTION OF METHOD FOR ASSESSING WATER CAPACITY

No method is currently available to the Highlands Council that provides a direct, causative and measurable relationship between aquatic ecosystem integrity and stream flows that can be applied across the entire Highlands Region. For this reason, the Highlands Council decided to focus on the severity and duration of low flows as a reasonable surrogate for ecosystem impacts.

The method selection was driven by a several critical factors, including:

- The need for a method that can be applied to every HUC 14 subwatershed in the Highlands Region, using available data; and

- The limited schedule, which made the collection of field information and research infeasible at this time. However, there may be significant benefit from pursuing future research (such as for the Range of Variability, R2Cross or wetted perimeter methods) after completion of the Regional Master Plan to improve water availability estimates over time.

The other methods discussed above were not used at this time for one or more of five reasons:

- Provide less defensible results than the existing methods;
- Methodological issues that make the applicability to Highlands issues unclear;
- Not applicable across the entire Highlands Region given available information;
- Not applicable directly to the issue of water availability; or
- Not feasible within the Regional Master Plan development schedule.

Based on the methods and data available, the Low Flow Margin method was selected by the Highlands Council as the primary tool for assessing Ground Water Capacity in every Highlands subwatershed (HUC14). This method required policy decisions regarding how much of the Low Flow Margin can safely be withdrawn while protecting water uses (ecological and human) supported by stream flows during a critical flow period.

As discussed above, both the Tennant and ABF methods were developed primarily for the assessment of surface water diversions (water supply or hydroelectric), with the ABF being used by the U.S. Fish and Wildlife Service to address surface water diversions on New England streams. This point is critical, as passing flows from surface water diversions can be altered to meet specific, instantaneous stream flow requirements, and impoundments can be required to release water (flow augmentation) to keep stream flows above specified targets. Because ground water diversions affect base flow over long periods and cannot be tailored to provide different base flows at different times of the year, the utility of these methods is primarily for surface water diversions. More research would be needed regarding the potential application to basins with ground water diversions.

Any direct comparison of methods needs to be based on a full understanding of what the values calculated actually represent. The statistical low flow methods used by USGS calculate a value that represents an estimate of base flow generated within each HUC14 using extreme low flow statistics over a long period of record. This is used as an initial estimate of Ground Water Capacity, some portion of which may be available for use. As discussed, the Low Flow Margin approach assumes that only a percentage of the Ground Water Capacity, minus current/full allocation consumptive and depletive uses, will be available in the future. The Low Flow Margin provides an estimate of how much ground water contributes to the stream flow, while the Tennant and ABF methods estimate how much stream flow should be provided through releases from surface water impoundments. Therefore, the results are not directly comparable without adjustment.

The table titled *Comparison of Water Capacity Determined from the Low Flow Margin of Safety Method to that of the Tennant and the New England Base Flow Method* provides examples of the LFM, Tennant and ABF method (with the last using the 0.5 $ft^3/s/mi^2$ default for summer instantaneous stream flow and deducting this volume from the Q_{MSep}, which is the mean of the September monthly means (based on the daily discharges for each September) for the period of record at the selected gaged stations. September was used rather than the ABF method target month of August, as September is most often the critical flow month for the Highlands. As indicated, the mean Low Flow Margin (LFM_{100}) is 0.31 $ft^3/s/mi^2$ (cubic feet per second per square mile), which is markedly lower than the September mean flow minus ABF, of 0.42 $ft^3/s/mi^2$. The LFM_{100} (representing the maximum estimated base flow that could be allocated for use) in 22 of 25 basins is smaller than the ABF-derived values. The use of percentages of the low flow margin as threshold values and the deduction of water use from that value, as intended by the Council, will only further reduce the amount of Ground Water Availability using the Low Flow Margin Method and increase this difference.

Any comparison of the water sustainability versus ecological flow requirement results must be accompanied by sufficient analysis so the results from pristine basins and altered basins are well understood. Even then, the comparison may not be valid. Factors such as soils, geology, basin area and basin slope can influence stream flow and need to be accounted for when any such comparison is performed. The variation in values for the results presented in the water capacity comparison table above may be explained through further analysis of just such factors. For example, there is significant variation in the individual values for LFM_{100} and Tennant flows. This variation may be a result of basin characteristics correlated with basin low flows, accounted for in the regressed values of the Low Flow Margin, but not in the calculated Tennant flows. The Tennant method determines low flow conditions by taking a percentage (40% for "good" summer flow) of the mean annual flow. Mean annual flow is comprised of base flow and other flow components (e.g., storm flow and bank storage). The Low Flow Margin is essentially an expression of base flow (the low flow condition with no contribution from direct runoff). This difference in use of the components used in the flow analysis will also cause variation in the values for the two methods.

This comparison of the LFM water capacity with the ABF and Tennant ecological flows provides information on whether there is a "surplus" or "deficit" in the stream, but without benefit of the numerous "guidance of policy" determinations included in the Council's overall approach to determining water availability, as discussed above. The application of a single flow regime (such as the 40% "good" flow) is not necessarily protective of the aquatic habitat; as stated in directives for using the Tennant method, it "…can and should be used to recommend different flows at different times of year to follow the natural hydrograph".

As discussed above, a limitation of the Tennant method is the requirement of having a continuous stream flow record to analyze. Application of the Tennant method to stream flow records at sites with altered flow conditions influences subsequent calculations and results. Applying an average mean flow calculated from a group of pristine basins to other basins, particularly those that are regulated is not technically sound. This assumes all basins have the same physical characteristics, which is not the case. Discharge numbers from these stations are artificial and are a function of upstream regulation. They do not reflect natural base flow conditions. As with the Tennant method, one significant issue for the New England Aquatic Base Flow Method (ABF) is whether, in which circumstances and how the ABF results can be transferred to watersheds that are either without flow gaging stations or are regulated by upstream impoundments. Because the Regional Master Plan is a regional document, the estimates of Ground Water Availability must be regional in the extent of their coverage.

The Base Flow Recurrence Interval and Low Flow Margin of Safety apply stream flow statistics, basin characteristics and water use to estimate water capacity for each of the 183 HUC14 subwatersheds. Both use stream low flow statistics to estimate the probable amount of water in streams from ground water discharge through a range of climatic and watershed conditions. Due to the use of reference drainage basins, the low flow statistics represent conditions that are as close to natural as possible within the region (that is, flows that are not subject to control by upstream flow control structures, such as reservoirs, or other significant human effects on flows). With the support of the USGS, the Highlands Council conducted a detailed analysis of base blow. Results of the study are reported at the HUC14 level to provide a detailed analysis of stream base flow. The current and future consumptive and depletive water use are then provided as indicators of use-related stress in each of the Highlands subwatersheds. This analysis helps identify HUC14 subwatersheds where reduced recharge and increased water

Comparison of Water Capacity Determined from the Low Flow Margin of Safety Method to That of the Tennant and the New England Aquatic Base-Flow Method. [Q_{MA}, mean annual discharge; Q_{MSep}, mean of the September mean discharges; Q_{MedSep}, median September discharge].

Station ID	Station Name	Drainage Area	Beginning period of record	Ending period of record	Station Type	Q_{MA} $ft^3/s/mi^2$	Q_{MSep} $ft^3/s/mi^2$	Q_{MedSep} $ft^3/s/mi^2$	Q_{710} $ft^3/s/mi^2$	LFM_{100} $ft^3/s/mi^2$	LFM_{80} $ft^3/s/mi^2$	LFM_{60} $ft^3/s/mi^2$	Q_{MSep} - Mean $Tennant_{good}$ (.67) $ft^3/s/mi^2$	Q_{MSep} - ABF (.50) $ft^3/s/mi^2$
01368000	Wallkill River near Unionville, NY	140	1938	1980	Gage	1.55	0.76	0.29	0.06	0.22	0.18	0.13	0.09	0.26
01379000	Passaic River near Millington, NJ	55.4	1980	2003	Gage	1.69	0.93	0.29	0.04	0.25	0.20	0.15	0.26	0.43
01379773	Green Pond Brook at Picatinny Arsenal, NJ	7.65	1983	2003	Gage	1.78	0.72	0.45	0.08	0.37	0.30	0.22	0.05	0.22
01380500	Rockaway River above Reservoir at Boonton, NJ	116	1938	2003	Gage	1.98	1.04	0.52	0.12	0.39	0.32	0.24	0.37	0.54
01381400	Whippany River near Morristown, NJ	14	1964	2002	Gage	2.05	1.19	0.51	0.17	0.35	0.28	0.21	0.52	0.69
01381500	Whippany River at Morristown, NJ	29.4	1922	2003	Gage	1.86	1.19	0.68	0.30	0.38	0.31	0.23	0.52	0.69
01384500	Ringwood Creek near Wanaque, NJ	19.1	1935	2003	Gage	1.73	0.68	0.17	0.02	0.15	0.12	0.09	0.01	0.18
01385000	Cupsaw Brook near Wanaque, NJ	4.37	1935	1957	Gage	1.78	0.70	0.11	0.00	0.11	0.09	0.07	0.03	0.20
01386000	West Brook near Wanaque, NJ	11.8	1935	1978	Gage	2.03	0.90	0.25	0.05	0.20	0.16	0.12	0.23	0.40
01386500	Blue Mine Brook near Wanaque, NJ	1.01	1935	1957	Gage	2.26	0.77	0.10	0.00	0.10	0.08	0.06	0.10	0.27
01387450	Mahwah River near Suffern, NY	12.3	1959	1994	Gage	1.97	0.75	0.24	0.05	0.19	0.15	0.11	0.08	0.25
01387500	Ramapo River near Mahwah, NJ	120	1904	2003	Gage	1.90	0.93	0.36	0.09	0.27	0.22	0.16	0.26	0.43
01390500	Saddle River at Ridgewood, NJ	21.6	1955	2003	Gage	1.55	0.89	0.44	0.10	0.34	0.27	0.20	0.22	0.39
01396500	South Branch Raritan River near High Bridge, NJ	65.3	1919	2003	Gage	1.88	1.10	0.70	0.33	0.37	0.30	0.22	0.43	0.60
01396660	Mulhockaway Creek at Van Syckel, NJ	11.8	1977	2003	Gage	1.70	0.86	0.42	0.16	0.26	0.21	0.16	0.19	0.36
01398500	Nb Raritan River near Far Hills, NJ	26.2	1922	2003	Gage	1.82	1.03	0.57	0.11	0.46	0.37	0.28	0.36	0.53
01399500	Lamington (Black) River near Pottersville, NJ	32.8	1922	2003	Gage	1.70	0.99	0.61	0.15	0.46	0.37	0.28	0.32	0.49
01399510	Upper Cold Brook near Pottersville, NJ	2.18	1973	1995	Gage	1.76	0.81	0.55	0.11	0.44	0.35	0.26	0.14	0.31
01403150	West Branch Middle Brook near Martinsville, NJ	1.99	1979	2003	Gage	1.73	0.95	0.11	0.02	0.10	0.08	0.06	0.28	0.45
01443500	Paulins Kill at Blairstown, NJ	126	1922	2003	Gage	1.57	0.84	0.43	0.13	0.30	0.24	0.18	0.17	0.34
01445000	Pequest River at Huntsville, NJ	31	1940	1961	Gage	1.51	0.82	0.39	0.07	0.32	0.26	0.19	0.15	0.32
01445500	Pequest River at Pequest, NJ	106	1922	2003	Gage	1.49	0.86	0.47	0.18	0.29	0.23	0.17	0.19	0.36
01446000	Beaver Brook near Belvidere, NJ	36.7	1923	2003	Gage	1.43	0.75	0.35	0.05	0.29	0.23	0.17	0.08	0.25
01456000	Musconetcong River near Hackettstown, NJ	68.9	1922	1973	Gage	1.73	1.24	0.75	0.17	0.58	0.46	0.35	0.57	0.74
01457000	Musconetcong River near Bloomsbury, NJ	141	1904	2003	Gage	1.70	1.12	0.74	0.32	0.42	0.34	0.25	0.45	0.62
	Mean for 25 gaged drainage basins					1.76	0.92	0.42	0.12	0.31	0.24	0.18	0.25	0.42
	Median for 25 gaged drainage basins					1.73	0.89	0.43	0.10	0.30	0.24	0.18	0.22	0.39

withdrawals may impair ecological resources, or conversely those HUC14 subwatersheds that can support some level of withdrawal with acceptable changes in stream flow. The subwatershed analysis permits aggregation of HUC14 subwatershed results to any larger watershed scale. The whole is the sum of its parts; the stream discharge within a HUC11 watershed is the sum of the stream discharges in its nested HUC14 subwatersheds. Because HUC11 results cannot be disaggregated to the HUC14 level without significant additional analyses, the HUC14 level was selected for baseline analysis.

A pilot study using Ecological Flow (EcoFlow) Goals analysis was implemented to examine the complete stream flow regime within four relatively undeveloped Highlands basins to assess the changes in stream flow from surface or ground water withdrawals that could cause significant ecological impacts. While this method is still in development, the results help provide some context for selecting thresholds for application in the Low Flow Method.

Therefore, the results of the NJ Hydroecological Assessment Tool (EcoFlow Goals), Baseflow Recurrence Interval analysis and other information can be used to help determine the appropriate "margin of safety" to use when applying the Low Flow Margin method, but are not relied upon directly for the regional analysis.

GROUND WATER CAPACITY TECHNICAL ANALYSES

This section provides detailed information on the statistical methodology used for the Low Flow Margin and the Base Flow Recurrence Interval. A full description and results of the EcoFlow Goals Pilot study is also presented.

The Base Flow Recurrence Interval and Low Flow Margin methods require a comprehensive statistical analysis of low flow measurements and the basin characteristics to evaluate Ground Water Capacity. The Highlands Council worked in cooperation with the USGS New Jersey Water Science Center to develop low flow statistics for these methods in each of the 183 HUC14 subwatersheds. USGS provided estimates of the base flows based on actual data from streams with long-term flow monitoring data (25 with continuous records and another 96 with partial records), in watersheds that have limited water flow impacts and statistically significant declines in stream flow over time. For the Base Recurrence Interval method, the following values were estimated: mean annual base flow, drought of record base flow, annual base flow for the 2, 5, 10, 25 and 50-year recurrence intervals, the 7Q10, and the September median flow. The Low Flow Margin method utilizes two of these values, and is simply calculated as the September median flow minus the 7Q10 flow.

In most cases, however, the 121 gaged watersheds were not equivalent to HUC14 subwatersheds, nor did they provide complete coverage of the Highlands. In these instances, the results from these gaged watersheds were used to create base flow estimates for each HUC14 subwatershed, based on similarities between the characteristics of the gaged stream watersheds and the target HUC14 statistical programs were used to estimate the values of missing data and to create complete hydrographs (stream flow tables) for watersheds that lacked continuous monitoring data or are ungaged. The two methods used most commonly to estimate statistics for ungaged sites are the drainage area ratio method and regression equations. The drainage area ratio method is most appropriate for use when the ungaged site is near a stream gaging station on the same stream (nested). Regression equations can be used to obtain estimates for most ungaged sites. Both were used in this analysis.

Techniques used to estimate these statistics for continuous record gaging stations and low flow partial record stations are outlined below.

LOW FLOW STATISTICS FOR GAGED BASINS

The USGS operates two types of stations for which low flow statistics in gaged basins were estimated. These include stream flow gaging stations and low flow partial record (LFPR) stations. The methods used to estimate stream flow statistics at data collection stations differ depending on the type of station. Continuous records of stream flow are obtained at stream flow gaging stations. Stream flow statistics are determined directly from the records for these stations. Stream flow gaging stations provide flow data at regular intervals throughout the day. The data, usually collected at 15 minute intervals, are used to compute daily mean flow values.

Low flow partial record stations are often established where stream flow information is needed, but either:

- It is not physically or economically feasible to continuously monitor stream flows at the location, or
- The amount or accuracy of the stream flow information needed does not require continuous monitoring at the location

At LFPR stations, a series of stream flow measurements is made during independent low flow periods when all or nearly all stream flow is from ground water discharge. Typically a minimum of eight base flow measurements made over a four year period provide an adequate amount of data to establish a correlation between low flow conditions at a continuous record gaging station and those at the low flow station.

Stream flow at gaging stations is affected by changes in climate; natural factors such as river processes, sedimentation, beaver dams, water-diversion trends, wastewater discharge trends, and other human activities. Stream flow at some gaging stations has changed over time as a result. Gaging stations with long periods of record reflect more of the inherent long-term variability of stream flow. Therefore, stream flow statistics are evaluated on the basis of length of record and on the climatic conditions during the period of record to account for those changes.

For these reasons, only 25 continuously gaged sites with a minimum of twenty years of record were considered to ensure an adequate compilation of data. Flow data collected at regulated streams were not included in the analysis, to ensure that the flow data used are those that best represent natural flows. Sites at which upstream returns (e.g. wastewater treatment facility discharges) accounted for a significant portion of the calculated low flow statistic were also excluded from the analysis for the same reason. Additionally, sites in close proximity to either significant ground water withdrawals or surface water diversions were examined in further detail. Low flows at continuous sites of this type were examined for statistically significant decreasing trends in low flow discharge over the period of record. Where no trend in the discharge value was evident over the period of record, it was assumed that the impact to the overall determination of an annual low flow statistic was minimal and these sites were retained. This process targets gaging stations with the minimum possible influences on stream flow from water use and flow controls, recognizing that most Highlands watersheds will exhibit at least some effects from water use.

The criteria for selecting the 96 low flow, partial record sites used in the analysis were the same as the continuously gaged sites, with the exception that sites were included only if they have a minimum of eight low flow measurements taken over a four year period. The overall average of all LFPR stations used included 22 measurements over 30 years.

The locations of the 25 stream flow gaging stations and 96 low flow partial record stations used in this assessment are shown in the figure titled *Location of Stream Flow Gaging Stations in the Highlands Study Area*. Note that these station drainage areas do not necessarily correspond to an individual HUC14 subwatershed, but rather multiple subwatersheds. The seven digit station site number, station name, drainage area size, latitude and longitude, period of record and station type for all stations are listed in the table *Site Information for Continuous Record Stream Flow Gaging Stations and Gaging Stations Analyzed as a Partial Record Station in the New Jersey Highlands.*

STATISTICS COMPUTED FROM STREAM FLOW GAGING STATIONS

The computer program PART (Rutledge, 1998) was used to determine mean annual base flow from the 25 continuous record stream flow gaging stations in and near the Highlands Region and included in this study. Estimates of annual base flow derived for each of these stations using the PART program were then analyzed for their frequency of occurrence providing statistics on base flow recurrence intervals.

PART automates hydrograph separation procedures to estimate mean daily base flow from stream flow records. PART uses stream flow partitioning to estimate a daily record of ground water discharge under the stream flow record. Mean annual base flow values were determined by hydrograph separation through use of the PART program. This method separates the hydrograph into its base flow and runoff components by equating stream flow to base flow on days after a storm that meet a requirement of antecedent-recession length greater than the duration of the surface runoff, and with a rate of recession of less than 0.1 log cycle per day. Where this test fails, base flow discharges are linearly interpolated and the points are connected to form the separation line under the hydrograph.

The probability of occurrence (p) for annual mean base flow values was estimated using the Weibull plotting position,

$$p = m / (n + 1)$$

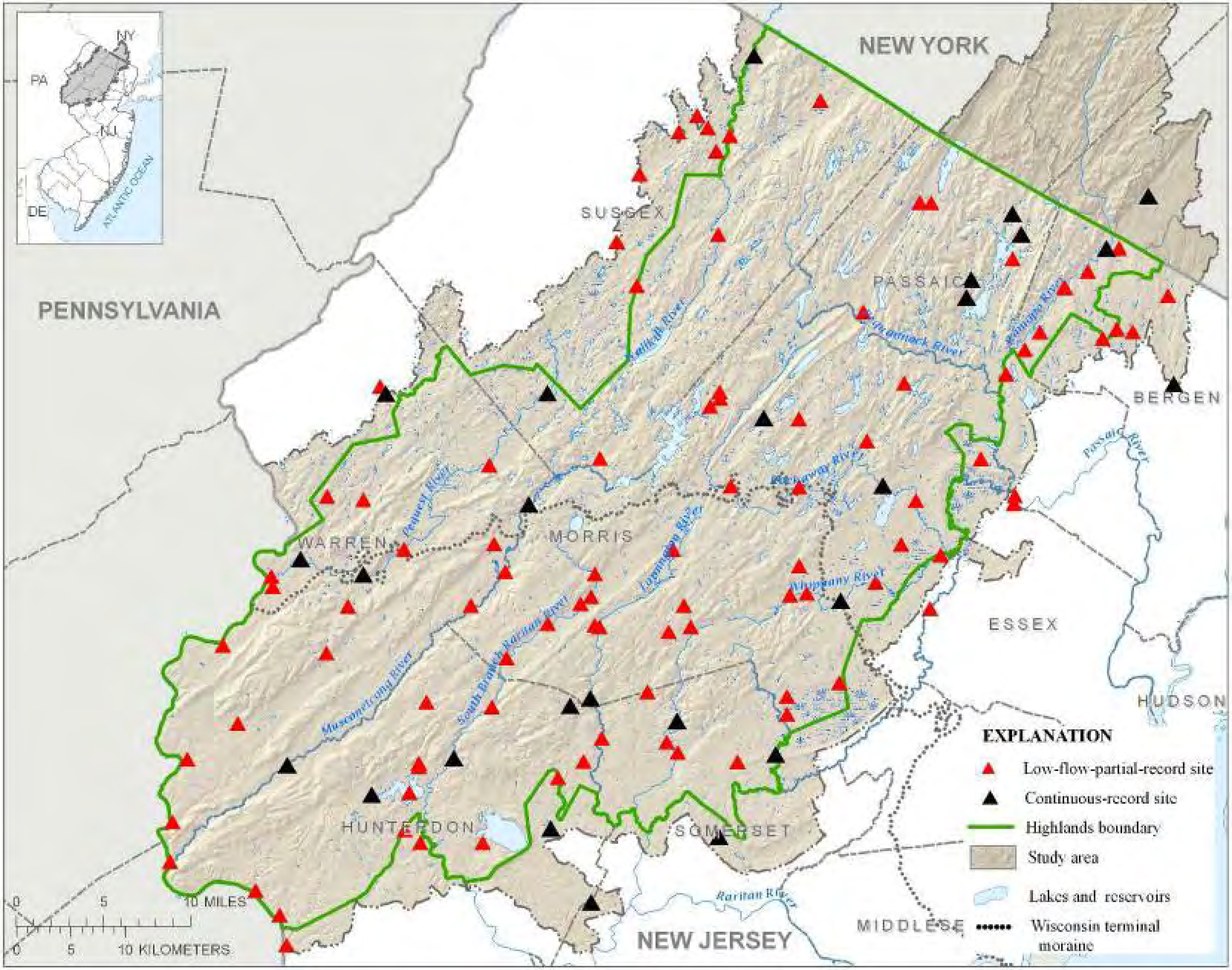
where m is the rank of the mean annual base flow value (from largest discharge to smallest) and n is the number of years of record. The recurrence interval (T), which is defined as the average interval, in years, between two discharges of a particular magnitude, can be calculated as the reciprocal of this probability.

$$T = 1 / p$$

Base flow discharges are then linearly interpolated in order to determine the 2, 5, 10, 25 and 50-year intervals. Ten or more years of data are normally required to perform a frequency analysis for the determination of recurrence intervals. The term "25-year base flow recurrence interval" is an alternative definition describing a discharge of this magnitude that statistically has a four percent chance of occurring in any given year. Therefore it is possible that the 25-year base flow can occur in consecutive years. Rutledge (1998) shows that estimated stream base flow using the PART computer program compares reasonably well with published results of the manual execution of base flow record estimation in the eastern United States.

The 7Q10 (7-day, 10-year low flow) low flow frequency statistics were determined for the stream gaging stations from a series of annual mean flows for a given number of days. These statistics can be computed for any combination of days of minimum mean flow and years of recurrence. For example, the 7Q10 is determined from the annual series of minimum seven day mean flows at a station. The mean flow for each consecutive seven day period is computed from the daily records, and the lowest mean value for each year represents that year in the annual series. The seven day minimum mean flows are then fit to a log-Pearson Type III distribution to determine the recurrence interval for an individual seven day minimum mean flow (Riggs, 1972). The value that recurs, on average, once in 10 years is the 7-day, 10-year low flow or 7Q10.

The USGS has automated the process of determining low flow frequency statistics for stream gaging stations. The computer program SWSTAT (Lumb and others, 1990) was used to determine 7Q10 low



Location of Stream Flow Gaging in The Highlands Study Area

Site Information for Selected Continuous-Record Stream-Flow Gaging Stations, Low-Flow Partial-Record Stations, and Gaging Stations Analyzed as a Partial-Record Station in the New Jersey Highlands

Site number	Station Name	Drainage Area (mi^2)	Beginning period of record	Ending period of record	StationType
01367700	Wallkill River at Franklin, NJ	29.4	1959	2005	Low Flow
01367750	Beaver Run near Hamburg, NJ	5.59	1967	2002	Low Flow
01367770	Wallkill River near Sussex, NJ	60.8	1959	2005	Low Flow
01367800	Papakating Creek at Pellettown, NJ	15.8	1959	2004	Low Flow
01367850	West Branch Papakating Creek at McCoys Corner, NJ	11	1967	2004	Low Flow
01367890	Clove Brook above Clove Acres Lake, at Sussex, NJ	19.2	1967	2002	Low Flow
01367900	Clove Brook at Sussex, NJ	19.7	1959	1963	Low Flow
01367910	Papakating Creek at Sussex, NJ	59.4	1977	2004	Low Flow
01368000	Wallkill River near Unionville, NY	140	1938	1980	Gage
01368950	Black Creek near Vernon, NJ	17.3	1977	2004	Low Flow
01378750	Great Brook at Green Village, NJ	7.92	1961	2002	Low Flow
01378800	Primrose Brook near New Vernon, NJ	4.68	1961	2002	Low Flow
01378850	Great Brook near Basking Ridge, NJ	23.1	1961	2002	Low Flow
01379000	Passaic River near Millington, NJ	55.4	1980	2003	Gage
01379150	Harrisons Brook at Liberty Corner, NJ	3.74	1964	2002	Low Flow
01379570	Passaic River at Hanover, NJ	128	1963	1988	Low Flow
01379630	Russia Brook tributary at Milton NJ	1.64	1968	1971	Gage as Low Flow
01379750	Rockaway River at Dover, NJ	30.8	1963	1997	Low Flow
01379773	Green Pond Brook at Picatinny Arsenal, NJ	7.65	1983	2003	Gage
01380050	Hibernia Brook at outlet of Lake Telemark, NJ	2.53	1966	2002	Low Flow
01380100	Beaver Brook at Rockaway, NJ	22.2	1963	2004	Low Flow
01380300	Stony Brook near Rockaway Valley, NJ	8.43	1963	2003	Low Flow
01380500	Rockaway River above Reservoir at Boonton, NJ	116	1938	2003	Gage
01381150	Crooked Brook near Boonton, NJ	7.86	1963	2002	Low Flow
01381400	Whippany River near Morristown, NJ	14	1964	2002	Gage as Low Flow
01381470	Jaquis Brook at Greystone Park State Hospital, NJ	1.39	1967	1973	Low Flow
01381490	Watnong Brook at Morris Plains, NJ	7.77	1966	2002	Low Flow
01381550	Malapardis Brook at Whippany, NJ	5.07	1961	2001	Low Flow
01381700	Troy Brook at Troy Hills, NJ	10.1	1961	1973	Low Flow
01382360	Kanouse Brook at Newfoundland, NJ	3.87	1963	2003	Low Flow
01382700	Stone House Brook at Kinnelon, NJ	3.45	1992	2001	Low Flow
01382890	Belcher Creek at West Milford, NJ	7.27	1973	1995	Low Flow
01382910	Morsetown Brook at West Milford, NJ	1.31	1973	1980	Low Flow
01384500	Ringwood Creek near Wanaque, NJ	19.1	1935	2003	Gage
01385000	Cupsaw Brook near Wanaque, NJ	4.37	1935	1957	Gage
01385500	Erskine Brook near Wanaque, NJ	1.02	1935	1940	Low Flow
01386000	West Brook near Wanaque, NJ	11.8	1935	1978	Gage
01386500	Blue Mine Brook near Wanaque, NJ	1.01	1935	1957	Gage
01387450	Mahwah River near Suffern, NY	12.3	1959	1994	Gage
01387490	Masonicus Brook at West Mahwah, NJ	3.84	1992	2001	Low Flow
01387500	Ramapo River near Mahwah, NJ	120	1904	2003	Gage
01387600	Darlington Brook near Darlington, NJ	3.38	1963	2002	Low Flow

Site Information for Selected Continuous-Record Stream-Flow Gaging Stations, Low-Flow Partial-Record Stations, and Gaging Stations Analyzed as a Partial-Record Station in the New Jersey Highlands

Site number	Station Name	Drainage Area (mi^2)	Beginning period of record	Ending period of record	StationType
01387670	Ramapo River near Darlington, NJ	131	1963	1998	Low Flow
01387700	Bear Swamp Brook near Oakland, NJ	3.25	1963	2002	Low Flow
01387884	Pond Brook at US Route 202 at Oakland, NJ	7.53	1964	1972	Low Flow
01387930	Ramapo River tributary No. 5 at Oakland, NJ	0.86	1963	2002	Low Flow
01388700	Beaver Dam Brook at Lincoln Park, NJ	12.3	1992	2002	Low Flow
01388720	Beaver Dam Brook at Ryerson Road, at Lincoln Park, NJ	13.1	2000	2003	Low Flow
01389100	Singac Brook at Singac, NJ	11.1	1983	2005	Low Flow
01389140	Deepavaal Brook at Two Bridges, NJ	7.59	1983	1999	Low Flow
01390450	Saddle River at Upper Saddle River, NJ	10.9	1964	2005	Low Flow
01390500	Saddle River at Ridgewood, NJ	21.6	1955	2003	Gage
01390700	Hohokus Brook at Wyckoff, NJ	5.31	1963	2002	Low Flow
01390800	Valentine Brook at Allendale, NJ	2.48	1963	2002	Low Flow
01390900	Ramsey Brook at Allendale, NJ	2.55	1982	2003	Low Flow
01396120	South Branch Raritan River at Bartley, NJ	12.5	1963	1990	Low Flow
01396180	Drakes Brook at Bartley, NJ	16.6	1963	2003	Low Flow
01396190	South Branch Raritan River at Four Bridges, NJ	31	1998	2001	Gage as Low Flow
01396240	Electric Brook at Long Valley, NJ	3.17	1990	2001	Low Flow
01396280	South Branch Raritan River at Middle Valley, NJ	47.7	1964	1999	Low Flow
01396350	South Branch Raritan River at Califon, NJ	58.5	1975	2002	Low Flow
01396500	South Branch Raritan River near High Bridge, NJ	65.3	1919	2003	Gage
01396550	Spruce Run at Newport, NJ	5.67	1998	2003	Low Flow
01396590	Spruce Run near High Bridge, NJ	15.5	1973	1980	Low Flow
01396600	Spruce Run near Clinton, NJ	18.1	1959	1987	Low Flow
01396660	Mulhockaway Creek at Van Syckel, NJ	11.8	1977	2003	Gage
01396670	Mulhockaway Creek tributary at Van Syckel, NJ	2.76	1973	1980	Low Flow
01396700	Mulhockaway Creek near Clinton, NJ	20.5	1959	1963	Low Flow
01396865	Sidney Brook at Grandin, NJ	4.71	1996	2004	Low Flow
01396900	Capoolong Creek at Lansdowne, NJ	14.1	1959	2003	Low Flow
01397100	Prescott Brook at Round Valley, NJ	4.61	1957	1963	Low Flow
01398107	Holland Brook at Readington, NJ	9	1978	1996	Gage as Low Flow
01398220	India Brook near Mendham, NJ	4.36	1963	1967	Low Flow
01398300	Dawsons Brook near Ironia, NJ	1.04	1963	1967	Low Flow
01398360	Burnett Brook near Chester, NJ	6.64	1963	1967	Low Flow
01398500	Nb Raritan River near Far Hills, NJ	26.2	1922	2003	Gage
01398700	Peapack Brook at Gladstone, NJ	4.23	1963	1967	Low Flow
01398850	Peapack Brook at Far Hills, NJ	11.7	1963	1975	Low Flow
01399194	Succasunna Brook near Succasunna, NJ	1.72	1977	1982	Low Flow
01399295	Tanners Brook near Milltown, NJ	2.78	1990	2001	Low Flow
01399300	Lamington River at Milltown, NJ	23.2	1988	2001	Low Flow
01399500	Lamington (Black) River near Pottersville, NJ	32.8	1922	2003	Gage
01399510	Upper Cold Brook near Pottersville, NJ	2.18	1973	1995	Gage
01399525	Axle Brook near Pottersville, NJ	1.22	1977	2002	Gage as Low Flow

Site Information for Selected Continuous-Record Stream-Flow Gaging Stations, Low-Flow Partial-Record Stations, and Gaging Stations Analyzed as a Partial-Record Station in the New Jersey Highlands

Site number	Station Name	Drainage Area (mi^2)	Beginning period of record	Ending period of record	StationType
01399540	Cold Brook at Oldwick, NJ	5.32	1963	1967	Low Flow
01399570	Rockaway Creek at McCrea Mills, NJ	17	1961	2003	Low Flow
01399670	South Branch Rockaway Creek at Whitehouse Station, NJ	12.3	1978	2003	Gage
01403150	West Branch Middle Brook near Martinsville, NJ	1.99	1979	2003	Gage
01443275	East Branch Paulins Kill tributary 1 near Lafayette, NJ	1.81	1992	1997	Low Flow
01443300	Paulins Kill at Lafayette, NJ	33	1959	1966	Low Flow
01443500	Paulins Kill at Blairstown, NJ	126	1922	2003	Gage
01443510	Blair Creek at Blairstown, NJ	13.1	1989	2001	Low Flow
01445000	Pequest River at Huntsville, NJ	31	1940	1961	Gage
01445100	Pequest River at Long Bridge, NJ	48.4	1940	2004	Low Flow
01445430	Pequest River at Townsbury, NJ	92.5	1977	2004	Low Flow
01445490	Furnace Brook at Oxford, NJ	4.29	1965	2001	Low Flow
01445500	Pequest River at Pequest, NJ	106	1922	2003	Gage
01445800	Honey Run near Ramseyburg, NJ	2.21	1982	1990	Low Flow
01445900	Honey Run near Hope, NJ	10.2	1966	2002	Low Flow
01446000	Beaver Brook near Belvidere, NJ	36.7	1923	2003	Gage
01446400	Pequest River at Belvidere, NJ	157	1974	2003	Low Flow
01446520	Pophandusing Brook at Belvidere, NJ	5.36	1990	2001	Low Flow
01446568	Buckhorn Creek at Hutchinson Road, at Hutchinson, NJ	8.38	1990	2001	Low Flow
01455100	Lopatcong Creek at Phillipsburg, NJ	14.5	1958	2001	Low Flow
01455160	Brass Castle Creek near Washington, NJ	2.34	1963	2000	Low Flow
01455230	Merrill Creek at Coopersville, NJ	3.85	1981	1993	Low Flow
01455300	Pohatcong Creek at Carpentersville, NJ	57	1932	2002	Low Flow
01455350	Weldon Brook near Woodport, NJ	3.63	1965	1972	Low Flow
01455360	Beaver Brook near Woodport, NJ	2.79	1966	1972	Low Flow
01455370	Weldon Brook at Hurdtown, NJ	8.09	1973	2003	Low Flow
01455780	Lubbers Run at Lockwood, NJ	16.3	1981	2002	Low Flow
01456000	Musconetcong River near Hackettstown, NJ	68.9	1922	1973	Gage
01456080	Mine Brook near Hackettstown, NJ	4.96	1990	2001	Low Flow
01456100	Hatchery Brook at Hackettstown, NJ	1.82	1966	1972	Low Flow
01456210	Hances Brook near Beattystown, NJ	4.13	1990	2001	Low Flow
01457000	Musconetcong River near Bloomsbury, NJ	141	1904	2003	Gage
01457400	Musconetcong River at Riegelsville, NJ	156	1973	2004	Low Flow
01458100	Hakihokake Creek at Milford, NJ	17.2	1944	2003	Low Flow
01458400	Harihokake Creek near Frenchtown, NJ	9.75	1959	2003	Low Flow
01458700	Little Nishisakawick Creek at Frenchtown, NJ	3.5	1959	1965	Low Flow

flow statistics for this assessment. SWSTAT determines the annual series of minimum mean flows, ranks them, fits them to a log-Pearson type III distribution, and plots the resulting line of fit through the annual values. September median stream-flows (used in conjunction with the 7Q10 statistics to determine the Low Flow Margin) are the median of daily mean flows for all complete Septembers during the period of record at a stream gaging station.

STATISTICS COMPUTED FROM LOW FLOW PARTIAL RECORD STATIONS

The low flow statistics listed in the table entitled Base and Low Flow Statistics at Selected Continuous Record Stream Flow Gaging Stations, Low Flow Partial Record Stations, and Gaging Stations Analyzed as a Partial Record Station in the New Jersey Highlands for 96 partial record stations were estimated by relating the low stream flow measurements made at the stations to daily mean discharges on the same days at nearby, hydrologically similar stream gaging stations (Appendix B). The low flow statistics were estimated by using the Maintenance of Variance Extension Type 1 (MOVE1) method of correlation analysis (Hirsch, 1982). The MOVE1 method fits a straight line to a data set. The stream flow data are transformed to logarithms to make the distribution of data more symmetrical and the relation more linear. A correlation coefficient and standard error of estimate are used as measures of accuracy. Daily mean flows from at least three gaging stations, referred to as index sites in the MOVE1 program, are correlated with measurements at each partial record station. A weighted mean of all estimates is computed on the basis of the standard error of estimate. Only measurements made at base flow are used in the MOVE 1 analysis.

LOW FLOW STATISTICS FOR UNGAGED BASINS

Estimates of stream flow statistics often are needed for sites on streams where no data are available. For both methods, low flow statistics computed for the 121 gaged basins (which vary in size from less than one square mile to about 157 square miles) were required to be computed for stream segments within the 183 HUC14 subwatersheds. The two methods used most commonly to estimate statistics for ungaged sites are the drainage area ratio method and regression equations. The drainage area ratio method is most appropriate for use when the ungaged site is near a stream gaging station on the same stream (i.e., nested). Regression analysis can be used to obtain estimates for most ungaged sites, and requires an analysis of basin characteristics. Additional detail on application of these methods is provided below.

DRAINAGE AREA RATIO METHOD

The drainage area ratio (DAR) method assumes that the stream flow at an ungaged site is the same per unit area as that at a nearby, hydrologically similar stream gaging station within the same overall watershed that is used as an index station. If the site is upstream or downstream of an index station, then a drainage area ratio relation may be used to determine the statistic of interest. The accuracy of the drainage area ratio method is dependent on how close the two sites (gaged and ungaged) are to one another, similarities in drainage area, and on other physical and climatic characteristics of their drainage basins.

Ries and Friesz (2000) determined that in Massachusetts, the recommended ratio of the drainage area at the point of interest on a stream, to the drainage area of the station for use of the DAR method is between 0.3 and 1.5. They also indicate that within these limits the DAR method provides equal or better accuracy than the use of regression analysis. Other researchers have recommended similar drainage area ratio limits. (Choquette, 1988; Koltun and Roberts, 1990; Lumia, 1991; Bisese, 1995) Outside these ratios, regression equations are recommended. The drainage area ratio method is used to estimate low flow statistics at an ungaged site on the basis of low flow values from stream gaging stations on the same stream. Low flow statistics for an ungaged basin are calculated by multiplying the ratio, i.e., ungaged basin area divided by the gaged basin area, by the low flow statistic (i.e., base flow, 7Q10, September median) of the gaged basin.

For example;

$$DAR = (A_{ungaged}/A_{gaged})\ (7Q10_{gaged})$$

DAR	Drainage Area Ratio
$A_{ungaged}$	Area of ungaged basin
A_{gaged}	Area of gaged basin
$7Q10_{gaged}$	7-day, 10-year low flow

The DAR method was used to provide low flow statistics for 53 of the 183 HUC14 subwatersheds.

DEVELOPMENT OF REGRESSION EQUATIONS

Multiple regression techniques have been widely used in the development of regional relationships between peak or low flows and climatic, morphometric, topographic and geologic basin characteristics. Recent research utilizing regression analysis to regionalize low flow statistics includes several studies focused on the northeastern United States. Vogel and Kroll (1990) used a generalized least squares regression model to relate drainage basin area and relief to n-day low flow statistics for various return periods in Massachusetts. Ehlke and Reed (1999) produced regionalized 7-day 10-year low flow (7Q10) discharge values for streams in Pennsylvania using modified equations that were originally developed by Flippo (1982). Drainage area, channel slope, basin geology and annual precipitation were identified as the primary basin characteristics relating to low flow.

Ries and Friesz, 2000 used a weighted least squares regression to estimate flow duration, as well as seven-day, two-year (7Q2), seven-day, 10-year (7Q10) and August median flows for ungaged sites in Massachusetts. They identified drainage area, mean basin slope and area of stratified drift per unit stream length as the most statistically significant predictors of low flow discharges. Flynn (2003) applied generalized least squares regression methods in order to develop 7Q10 frequency equations from stations in New Hampshire and neighboring states. The explanatory variables that were found to correlate with the discharge included the drainage area, mean annual basin wide temperature and average summer precipitation.

For this study, 42 measurable basin characteristics were candidates for initial inclusion in the regression analysis (see table entitled *Basin and Associated Characteristics Examined in the Low Flow Regionalization Regression Models*). A principal components analysis (PCA) (SAS Institute Inc., 1989) was performed on the basin characteristics data set in order to assess the relative importance of the parameters with respect to discharge as well as to identify redundant explanatory variables. The individual explanatory or independent variables are represented by loadings; highest loadings are attributed to the characteristic that accounts for the most variance within each principal component (Kennen and Ayers, 2002). The advantage of a PCA is that it can reduce the dimensionality of the data set without sacrificing much information. The first principal component identified accounts for as much variation in the data set as possible. Each successive component attempts to account for the data variance not explained by the precedent components.

Basin and Associated Characteristics Examined in the USGS Low Flow Regionalization Regression Models

Characteristic Name	Characteristic Label	Units	Definition
Area_of_Carbonate_Rock	ACARBON	mi2,	Area underlain by carbonate rock
Percent_Carbonate	CARBON	Percent	Percentage of area of carbonate rock
Area_of_Glacial_Aquifer_Material	AGLAC	mi2	Area underlain by glacial aquifer material
Percent_Glacial_Aquifer Material	GLAC	Percent	Percentage of area of glacial aquifer material
Area_of_Crystalline_Rock	ACRYST	mi2	Area underlain by crystalline rock
Percent_Crystalline	CRYST	Percent	Percentage of area of crystalline rock
Area_of_Clastic_Rock	ACLAST	mi2	Area underlain by clastic rock
Percent_Clast	CLAST	Percent	Percentage of area of clastic rock
Area_of_Newark_Basin_Rocks	ANEWK	mi2	Area underlain by Newark Basin rock
Percent_Newark_Basin_Rocks	NEWK	Percent	Percentage of area of Newark Basin rock
Area_of_Forest_Cover	AFOREST	mi2	Area covered by forest
Percent_Forest	FOREST	Percent	Percentage of basin covered by forest
Area_of_Impervious_Surfaces	AIMPERV	mi2	Impervious area
Percent_Impervious	IMPERV	Percent	Percentage of impervious area in basin
Area_of_Lakes_and_Ponds	ALAKE	mi2	Area of Lakes and Ponds
Percent_Lakes_and_Ponds	LAKE	Percent	Percentage of Lakes and Ponds in basin
Area_of_Storage	ASTORAGE	mi2	Area of Storage (lakes - ponds - reservoirs, and wetlands)
Percent_Storage	STORAGE	Percent	Percentage of area of storage (lakes ponds reservoirs wetlands)
Area_of_Urban_Cover	AURBAN	mi2	Area covered by urban land use
Percent_Urban	URBAN	Percent	Percentage of basin with urban development
Area_of_Wetlands	AWETLAND	mi2	Area of Wetlands
Percent_Wetlands	WETLAND	Percent	Percentage of Wetlands
Area_of_Agricultural_Land	AAGR	mi2	Area of Agricultural land use
Percent_Agricultural_Land	AGR	Percent	Percentage of basin with Agricultural land use
Area_of_Barrenl_Land	ABAR	mi2	Area of Barren land
Percent_Barren_Land	BAR	Percent	Percentage of basin with barren land
Main_Channel_Length	LENGTH	mi, kilometers	Length along the main channel from the measuring location extended to the basin divide
Total_Stream_Length	STRMTOT	mi, kilometers	Total length of mapped streams in basin
Stream_Density	STRMDEN		Total length of mapped streams in basin divided by basin area
Maximum_Basin_Elevation	ELEVMAX	Feet	Maximum basin elevation
Mean_Basin_Elevation	ELEV	feet, meter	Mean Basin Elevation
Mean_Basin_Slope_from_10m_DEM	BSLDEM10M	percent; degree	Mean basin slope computed from 10 m DEM; where 10 m not available use 30 m
Minimum_Basin_Elevation	MINBELEV	feet, meter	Minimum basin elevation
Relief	RELIEF	feet, meter	Maximum - minimum elevation
Shape	SHAPE	dimensionless	Shape Factor for Area---basin area divided by (main channel length)2
Glacial Aq_per_Stream_Length	GLACPERSTR		Area of glacial material per unit of stream length
Stream_Slope_10-85_Method	CSL10_85	feet, meter	Change in elevation between points 10 and 85 percent of length along main channel to bas divide divided by length between points
Mean_annual_precipitation	PPT	Inches	Average annual precipitation 1971 -2000. PRISM
Maximum_temperature	TEMP_MAX	degC	Maximum annual temperature 1971 -2000. PRISM
Minimum_temperature	TEMP_MIN	degC	Minimum annual temperature 1971 -2000. PRISM
Mean_Climf_GSR32	CLIMF	dimensionless	Ratio of average annual precipitation to average annual (simulated) potential evapotranspirat from NJGS report GSR-32
Mean_Recharge_GSR32	RCHG	mgal/day	Average recharge per basin normalized to drainage area, from GSR-3

Results of the PCA indicated that five components account for approximately 80 percent of the variation in the basin characteristics data set. Beyond the fifth component, additional explanation of the variance increases by only a few percent, therefore little value was added beyond this threshold. Therefore, it was likely that the final regression models will adequately convey discharge using five or fewer explanatory variables. The first component identified was primarily a measure of area; characteristics identified included drainage basin area, area of storage, total stream length within the basin, main stem stream length and main channel or hydrologic length. Loadings were approximately equal among these characteristics. However, drainage basin area was chosen because its relationship to the individual discharge values was strongest, it is an attribute that is readily available or easily determined, and it has been identified in numerous studies as a key predictor of low flow discharge statistics. The second component identified was a measure of basin morphometry, i.e., mean basin slope. Mean basin slope is defined as the maximum rate of change for individual slope value in percent, calculated on a cell-by-cell basis using the DEM. Subsequent components included combinations of precipitation, recharge, storage and glacial aquifer area.

A backward elimination approach was used for the initial development of the regression equations. This technique, similar to a step-wise regression, begins by including all variables in the model and calculating t-statistics for each explanatory variable. As the regression model progresses, each variable having the largest p-value (the probability of observing a t-statistic equal to or larger in magnitude given the null hypothesis that the true coefficient value is zero) above the specified cutoff is removed. In this initial step a conservative p-value of alpha = 0.10 was used in order to preserve variables that might prove significant in the final regression. The process continues until all explanatory variables retained in the model have p-values at or below the above specified number. Independent variables and combinations of variables identified by the PCA were used in this initial regression. Potential explanatory variables for inclusion in the final regression analysis were further reduced by this step.

A common problem associated with flow regionalization via regression is the high degree of correlation among explanatory variables (basin characteristics). Multi-collinearity among explanatory variables can cause inflated errors in the regression parameter estimates and in the variances of the predicted values. The initial PCA served to limit many of the codependent variables; however, to further account for this concern in the regression models, a variance inflation factor (VIF) was used. The VIF is a function of the coefficient of determination and is calculated as 1/(1-R2), where the coefficient of determination (R^2) is determined as each independent or explanatory variable is regressed against all other explanatory variables (Helsel and Hirsch, 2002). R^2 is a measure of how well the regression equation performs in predicting the dependent variable, or discharge value. While there is no formal cutoff value a threshold of 10 is commonly used. For this study the VIF was also set at 10; variables identified as collinear (for example, basin area and channel length) were removed and then entered individually into ensuing models. Final explanatory variables were chosen on the basis of their performance in the individual regression models as well as on the ranking of each model.

The adjusted R-square method was used for the final weighted regression analysis. Various combinations of independent variables identified in the preceding steps were entered into the regression models manually. Models were ranked based on maximizing the adjusted R-square while minimizing the predicted residual sum of squares (PRESS) and the Akaike Information Criterion (AIC). The adjusted R-square (R^2adj) is the R^2 that has been adjusted for the number of explanatory variables used in the model. This allows comparisons between models with differing numbers of explanatory variables as well as imposes a penalty on models with too many variables (Helsel and Hirsch, 2002). Higher values of R^2 are generally interpreted as indicating the better statistical model. However, a weakness of evaluating models based on R^2 alone is that a high R^2 may be attained even when the individual predictors themselves are not significant. The PRESS statistic is the sum of the squares of the residuals using models obtained by estimating the equation with all other observations (Freund and Littell, 1995). By minimizing the PRESS statistic, the model with the least error in the prediction of future observations is the one selected (Helsel and Hirsch, 2002).

AIC includes both a measure of model error as well as a penalty for excessive explanatory variables. Among competing models, those that exhibit a smaller AIC are preferable. In addition to the above criteria for selecting the best model, each independent variable was required to attain a p-value of alpha=0.05 or below, as well as be explainable through some hydrological process. Variables proven to be statistically reliable in predicting low flow included drainage basin area, average annual recharge, mean basin slope and glacial aquifer area.

Because discharge values determined at both continuous record as well as partial record stations were used in the development of the models, a weighting term was needed in order to account for differences in the accuracies of the input data. Plots of the residuals from the initial unweighted regression models showed significant scatter where discharge values were low (typically less than 1 MGD). Much, but not all of this variance was due to measurements made at partial record stations.

Because variance of a stream flow statistic is inversely related to the record length at the station, a weighting term that accounts for variance due to both record length and discharge magnitude was needed. The weight used in the regression analysis was calculated using the equation:

$$W = N / \overline{N} \;/\; (V_c / \overline{V_c})$$

Where:

N = the number of years of record (POR) at a gaged site

Vc = the variance of the stream flow statistic for each station computed from regressing variance to the magnitude of the stream flow

Record length at LFPR stations was calculated as a percentage of the overall period of record. This term is similar to that used by Ries and Friesz (2000) in weighted regression models, for the prediction of flow duration statistics and August median discharges. Use of this weighting term attributed greater influence in the development of the regression equations to the continuously gaged stations, i.e., those exhibiting the least variance. As a result, the associated error of the model decreased.

The number of stations used in the final regression analysis ranged from 98 to 109. Numbers differed from those used in the initial determination of statistics at the gaged stations because the complete set of basin characteristics used in final equations were not available for all gaged basins. In addition, outliers were occasionally excluded from the analysis. For example, several watersheds did not contain glacial aquifer materials. In those cases, nominal values (.0001 mi2) were inserted in order to maintain this variable in the regression equation. Exclusion of this variable resulted in discharge values that were considered artificially low. Where a mean annual recharge value was not available for the output watershed, the resulting flow statistics were determined by relating discharge to drainage area only.

The final regression equations are presented in the table titled Summary of Regression Equations Developed for Estimating Low Flow Statistics for Ungaged Watersheds in the New Jersey Highlands, along with several measures of model adequacy. Because flow statistics and basin characteristics used in hydrologic regression are non-normally distributed, values were log transformed. The distribution of many hydrologic variables is typically non-normal, i.e. skewed to the right. Data are transformed in order to obtain linearity between dependent and explanatory variables as well as to attain equal variance about the regression line. Linearity is a requirement for a least squares solution from which regression constants can be calculated and equal variance satisfies a basic assumption of the regression method that the distribution of residual errors are normal and constant about the regression line. Log or $\log_{10}$

transformations are the most commonly used in hydrology.

Summary Of Regression Equations Developed For Estimating Low-Flow Statistics For Ungaged Watersheds in the New Jersey Highlands

Statistic	Equation	Number of stations	R^2_{adj}	SE	MAD
QBF	$0.163(DA)^{0.987}(GA)^{0.040}(RCH)^{0.640}$	109	0.978	15.9	14.7
QBF_{10}	$0.090(DA)^{0.979}(GA)^{0.046}(RCH)^{0.716}$	108	0.968	19.8	20
QBF_{25}	$0.075(DA)^{0.985}(GA)^{0.050}(RCH)^{0.708}$	106	0.961	20.8	19.5
$QSep_{50}$	$0.025(DA)^{1.192}(BSLP)^{-0.549}(RCH)^{1.208}$	103	0.933	32.3	29.3
Q_{710}	$0.002(DA)^{1.267}(BSLP)^{-0.706}(RCH)^{1.832}$	98	0.856	44.4	45.3

Note:

QBFxx, base flow at the xx-yr recurrence interval; QSep50, September median flow; Q710, 7-day, 10-year low flow; all in million gallons per day; DA, drainage area in square miles; GA, area of glacial aquifer sediments in square miles; RCH, average annual recharge in inches per year (adapted from GSR-32); BSLP, mean basin slope in percent; R2adj, Coefficient of determination; SE, average standard error of estimate, in percent; MAD, median absolute deviation, in percent]

The resulting regression equation takes the form:

$$Y_i = 10^{b0}(X_1^{b1})(X_2^{b2}).....(X_n^{bn})$$

where *Yi* is the estimate of the dependent variable at site *i*, where *i* =(l…n), *Xi* to *Xn* are the explanatory variables, and *b0* to *bn* are the parameter estimates.

The measures of model adequacy include the adjusted coefficient of determination (R^2adj), the average standard error of estimate (SE), in percent, and the median absolute deviation (MAD), in percent. The R^2adj is a measure of the proportion of variance in the flow statistic (dependent variable) that can be predicted by the basin characteristics (explanatory variables) that has been adjusted for the number of explanatory variables used in the model. SE is a measure of the reliability of the regression equation. The standard error indicates the average precision with which the equations will predict discharge at those stations used in the analysis. The probability that an observed discharge value is within the range of this standard error is approximately 68 percent. The MAD as an estimate of model error was calculated as the median of the model residuals. Half of the regression estimates from stations used in the analysis had absolute errors, in percent, above the MAD, and approximately half had absolute errors below the MAD. As the MAD increases, so does the variability in the predicted data.

The figure entitled *Comparison of a) Mean Annual Base Flow and b) the 7 Day, 10 Year Low Flow Statistic to Those Computed from Regression Equations* shows a graphical comparison between the calculated and regressed values of mean annual base flow and 7Q10. The graph (a) depicting mean annual base flow shows good agreement between the calculated and predicted data, with slight scatter in the data at the lower magnitude base flow discharges. The graph (b) depicting 7Q10 shows significantly more scatter between the calculated and predicted discharge, as this was the model with the largest standard error. However results of a t-test on signed ranks indicate that the differences in base flow or 7Q10 discharge values by either method are not significantly different from zero, with p-values of 0.786 and 0.353, respectively.

As noted above, of the 183 subwatersheds examined, 53 satisfied the criteria for the transfer of discharge values by the DAR method. Discharge values were also computed of the same 53 subwatersheds using the appropriate regression equation as a means of comparing the two methods. Discharge values determined by the DAR method were typically greater than those determined by the regression analysis (see figure *Comparison of a) Mean Annual Base Flow and b) the September Median Discharge Computed by the Drainage Area Ratio and by Regional Regression Equations*). However, results of a t-test on signed (positive or negative) ranks indicate that the mean annual base flow discharge values calculated by either method do not statistically differ (p-value, 0.053) at the 95-percent confidence level.

This relatively small p-value indicates a result at the margins of the confidence level; if a less stringent confidence level is applied (90-percent), results of the two methods could be viewed as differing. September median discharge values calculated from the regional regression equation were determined to be statistically smaller than those transferred through DAR (p-value, 0.041). Although somewhat larger in magnitude, the values calculated by the DAR method were preferred as they are derived directly from stream flow data. Values calculated from the regional regression equations, particularly lesser magnitude discharge values such as the September median, may be slightly underestimated. The median percent difference between September median discharges calculated by the DAR and regression is plus 11.8 percent, with the DAR values being higher on average. Subsequent calculations such as the low flow margin may also be underestimated because the computation of the low flow margin is dependent upon the September median value. Values derived via regression analysis are therefore likely more conservative than those computed by the DAR method.

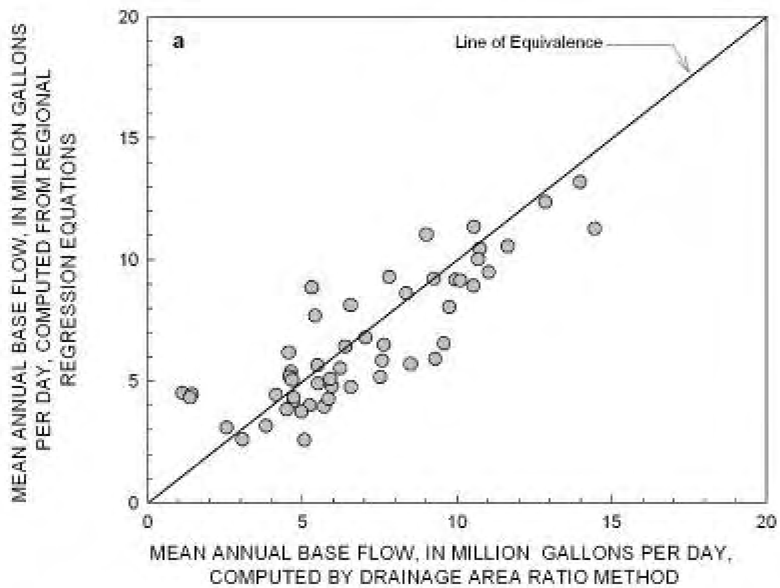
Limitations for the Use of the Equations

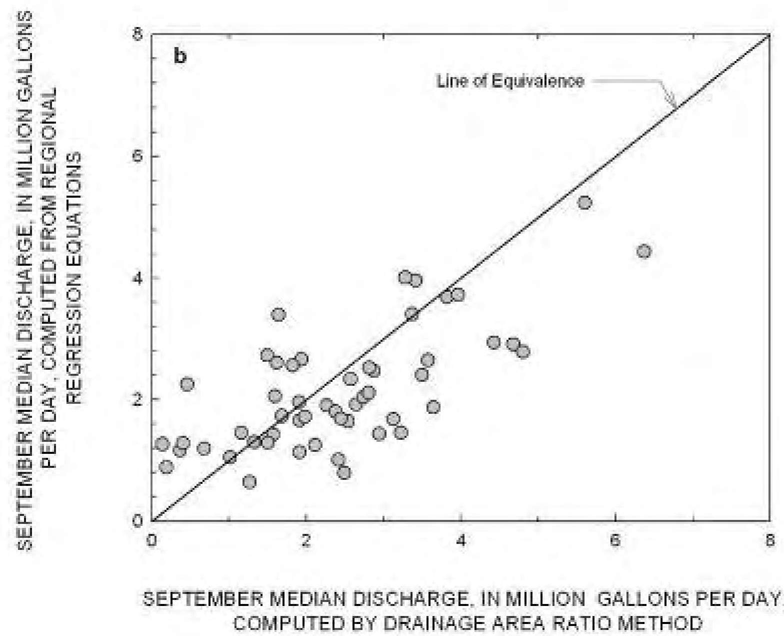
The regression equations for predicting base and low flows for ungaged HUC14 subwatersheds should be applied only to basins in the region for which they were developed. Use of these equations required that the physical and hydrologic basin characteristics used for input be determined from the same datasets as those used in the development of the regression equations. It also required that these characteristics were within the same ranges as those used in the development of the equations. The use of explanatory variables in the regression equations outside of the established ranges may decrease the accuracy of the resultant flow statistic. Additionally, it is recommended that a GIS be used in the determination of all basin characteristics in order to minimize potential error or bias. By using standardized GIS procedures, characteristics are determined in a consistent manner, minimizing any bias that might have been introduced by the analyst if done manually.

The basin characteristics used in the regression analysis were chosen on the basis of their theoretical relationship to differing magnitudes of base and low flow discharges as well as on results of previous studies completed in similar hydrogeologic terrains in the northeastern United States. General categories of basin attributes included basin morphometry, climate, land use/land cover, and geology. Basin characteristics examined include the area of impervious surface, forest cover, barren land and extent of agricultural land, among others. These characteristics are as accurate as the GIS data layers from which they were determined.

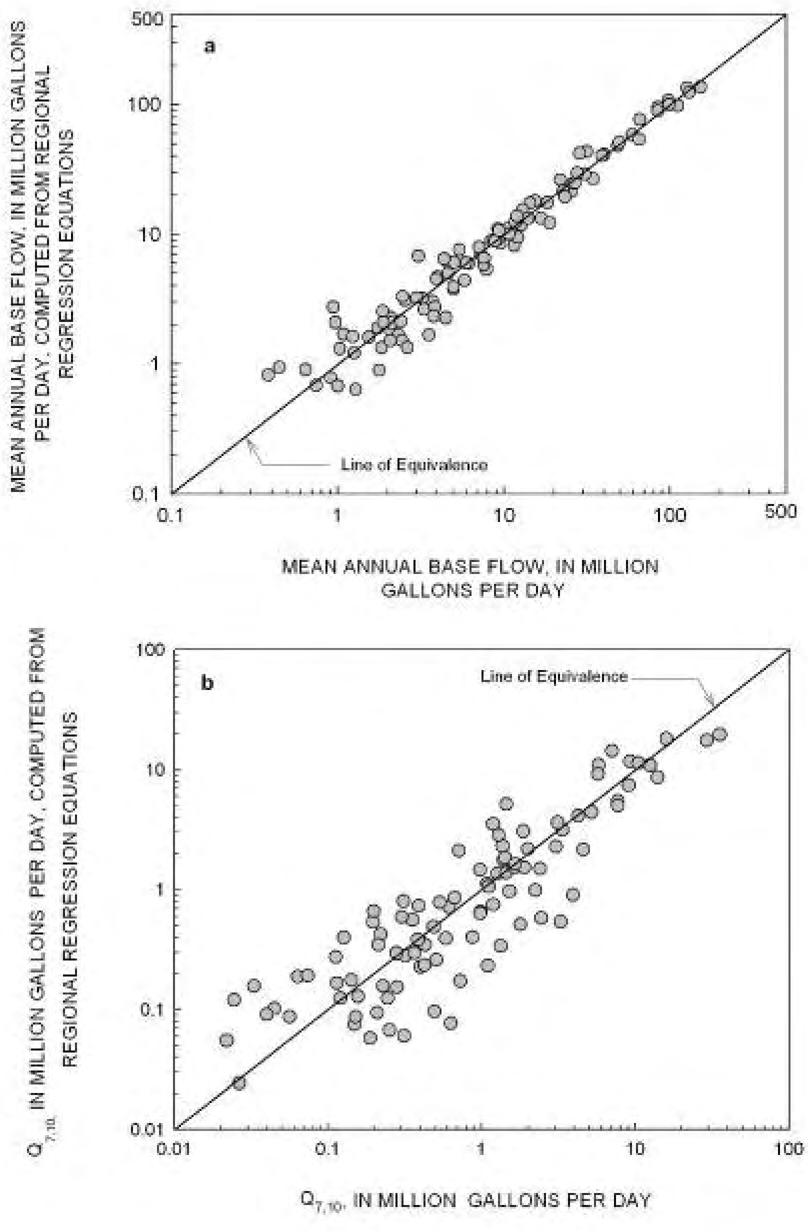
The 2002 land use data sets have more accurate land use determinations than the 1995 data set, which was more accurate than the 1986 data set. The extent of bedrock and glacial aquifers are often inferred from available data, and may have local inaccuracies. Elevation data are determined from remotely sensed data and may also have local inaccuracies. Regional climate data are interpreted from data where the density of data points may be insufficient for high accuracy.

Generally, it is believed that the GIS-determined basin characteristics were appropriate for use in the regression analysis. It must be recognized that local inaccuracies in the development of the regression equations and prediction of low and base flows may have resulted from the use of these data sets. Some sites used in the development of the regression equations may have had altered flows for at least a portion of the period of record. The period of record of these sites spans up to 100 years, and it is





Comparison of a) Mean Annual Base Flow and b) The September Median Discharge Computed by the Drainage Area Ratio Method and by Regional Regression Equations.



Comparison of a) Mean Annual Base Flow and b) 7Day, 10 Year Low Flow Statistic to Those Computed From Regression Equations possible that over a long period of record the flows in their basins may have been altered by withdrawals or other activities. A statistical trends analysis was conducted to determine if the alteration of flows was significant, and care was taken to exclude sites with substantially altered flows. However, it is possible that increased precipitation over the period of record could mask decreasing flow trends.

However, because no part of the Highlands is totally without development or water uses, the flow data can reasonably be expected to include at least some impact from these factors. Subtraction of the full consumptive use (based on one of the methods below) from water availability will, to some extent, double-count those impacts. Because consumptive water use data were only available for HUC14 subwatersheds and not for gaged basins, USGS identified the six gaged basins that nearly or fully correspond to HUC14 subwatersheds, and the consumptive use data for them. The USGS analysis used annual average consumptive use coefficients and data. The table *Consumptive Water Use Within HUC14 Basins that are also a Gaged Basin or a Basin for a Low Flow Partial Record Station* shows the six drainage basins and the results using this annual average data. The maximum month consumptive uses in these basins correspond to roughly 2 percent of the Low Flow Margin. Therefore, it is appropriate for the USGS Low Flow Margin results to be multiplied by 1.02 to correct for the inherent consumptive uses.

Consumptive Water Use within HUC14 Basins that are Also a Gaged Basin or a Basin for a Low Flow Partial Record Station

Site number	Station name	HUC14	Basin	Area	Total use	LFM	Maximum monthly consumptive GW use	MaxMonth Consumptive SW use	MaxMonth Consumptive GW and SW use/LFM
			Gage Type	Square miles	MGD	MGD	MGD	MGD	Percent
1381490	Watnong Brook at Morris Plains	2030103020030	Low-flow partial record	7.77	0.01	1.850	0.003	0.0000	0.16%
1379773	Green Pond Brook at Picatinny Arsenal	2030103030050	Continuous gage	7.65	0.1	1.757	0.012	0.0030	0.85%
1386000	West Brook near Wanaque	2030103070040	Continuous gage	11.8	0.27	1.552	0.034	0.0000	2.19%
1390700	Hohokus Brook at Wyckoff	2030103140010	Low-flow partial record	5.31	0.41	1.315	0.058	0.0000	4.41%
1445900	Honey Run near Hope	2040105100020	Low-flow partial record	10.3	0.11	0.418	0.014	0.0005	3.47%
1396580	Spruce Run at Glen Gardner*	2030105020010	Continuous gage	15.5	0.3	2.118	0.045	0.0000	2.12%
Averages				**9.72**	**0.20**	**1.502**	**0.0277**	**0.0006**	**2.20%**

**Spruce Run gage is somewhat upstream of the HUC14 boundary (~1000 ft), but the difference in area between the gage basin and the HUC14 is minor. (Donald Rice, 31July06, Personal communication)*

ECOLOGICAL FLOW GOALS PILOT STUDY

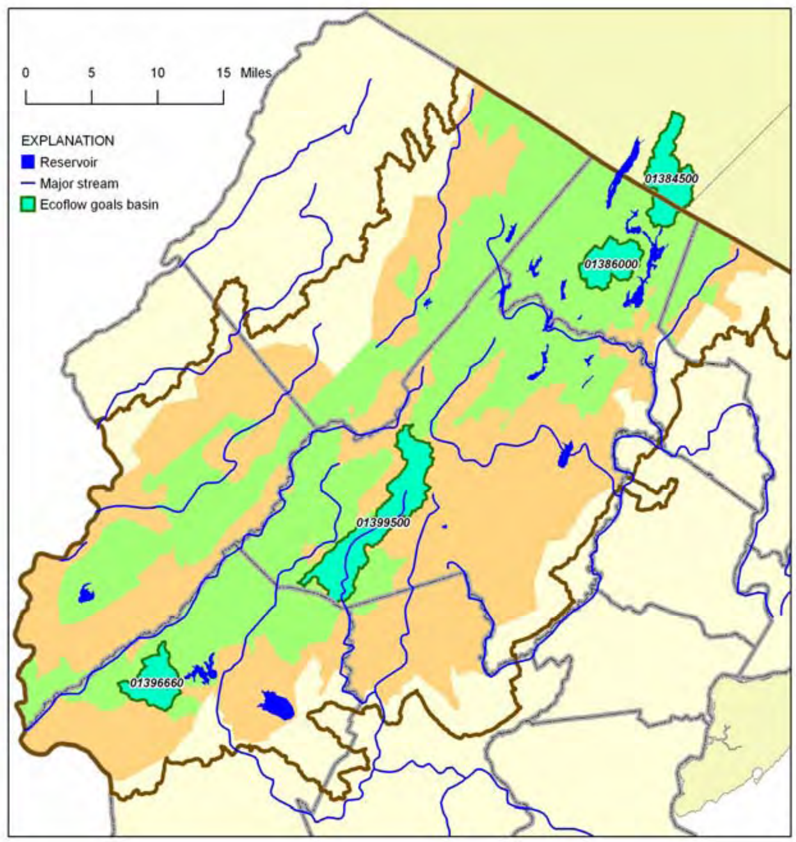
For this study, four gaged stream basins were selected from the Highlands Region that have continuous discharge data collected by the USGS and that meet the following criteria:

1) Stream gages are located in "small" (defined as less than 35 square miles) headwater basins (i.e., they receive no flows from upstream watersheds).

2) Gages are located in unregulated stream reaches (defined as having flow that is not controlled by human activities - e.g., dams or impoundments).

3) Records include at least 20 years of continuous daily discharge data, and reflect a minimum of 10 years where the biotic integrity of the stream has been evaluated by the NJDEP as unimpaired (i.e., AMNET assessments of macroinvertebrate monitoring data).

4) Current conditions should reflect minimal change in basin land use, and basins should have relatively low levels of development.



Map of Selected Basins for Ecological Flow Goals Pilot

The four gaged basins selected are located illustrated in the figure titled Map of Selected Basins for Ecological Flow Goals Pilot. From north to south they are Ringwood Creek near Wanaque (01384500), West Brook near Wanaque (01386000), Lamington River near Pottersville (01399500), and the Mulhockaway Creek at Van Syckel (01396660). Background information for the selected gaging stations is listed in the table *Stream Gages Selected For Pilot Implementation of the Hydroecological Integrity Assessment Process*, and in the table *Land Use and Land Cover Characteristics of Study Basins*. Ringwood Creek and West Brook basins have had relatively low development over the period of record. These sites are considered to be index sites for New Jersey. The only major change in basin land use over the course of the period may result from reforestation from former agricultural lands. The Mulhockaway Creek and Lamington River basins currently have more moderate urban development but this development is mostly agricultural and low to medium density urban. Urban land use has increased by 5-10% in these sites over the past 30 years. These two sites were still included in the study because they reach the first three criteria for site selection, and would increase the available results for the study. All four streams are considered Stream Type C based on the statewide method described above.

Stream Gages Selected For Pilot Implementation of the Hydroecological Integrity Assessment Process

USGS Station Number	Station Name	Drainage Area	Period of Record Used	Total Years of Record Used	Stream Type
01384500	Ringwood Creek near Wanaque, NJ	19.1	1934 -1978, 1986 - 2004	62	C
01386000	West Brook near Wanaque, NJ	11.8	1935 - 1978	43	C
01396660	Mulhockaway Creek at Van Syckel, NJ	11.8	1976 - 2004	28	C
01399500	Lamington (Black) River near Pottersville, NJ	32.8	1921 - 2004	83	C

As shown in the land use/land cover characteristics table below, the four gaged basins are not entirely undeveloped watersheds, but were selected because they met the criteria discussed above. The significant data requirements and methodological limitations of the EcoFlow Goals approach make clear the difficulties of applying this approach regionally, rather than for site-specific project analysis.

To quantify the effects of increased water withdrawal on these selected basins for calculated stream flow indices, the 10 primary or surrogate indices were evaluated for a series of withdrawal scenarios for four sites to determine how much withdrawal is needed for the index statistic to reach the selected critical value (that is, the 25th and 75th or 25/75 percentile range). It should be noted that the 25/75 percentile range used for determining critical values for indices is based on a well established literature value (Richter et al. 1996) and is used as the default setting in HIP. Calculations were also performed for the 40th and 60th (40/60) percentile range to demonstrate the impacts of an alternative critical value, in order to better understand the potential implications of policy decisions still to be made. This approach implies that when the index reaches or exceeds this critical value, the withdrawal amount may significantly alter the ecological integrity of the stream.

Land Use and Land Cover Characteristics of Study Basins

Percentage Land Use (%) in Study Basin									
Station Number	2002 Land Use/Land Cover (LULC)			1995 LULC		1986 LULC		1973 LULC	
	Impervious Cover	Urban	Agricultural	Urban	Agricultural	Urban	Agricultural	Urban	Agricultural
01384500	2.2	10.9	0.0	10.9	0.0	10.8	0.0	4.6	0.3
01386000	3.7	17.2	0.5	17.1	0.5	15.7	0.5	16.6	0.0
01396660	5.2	25.6	16.8	22.8	19.8	18.2	25.0	3.6	35.9
01399500	7.4	29.7	9.9	28.8	11.1	28.2	13.0	17.1	20.8

For Ringwood Creek near Wanaque, the period of record was discontinuous and no hydrological data were available for the period of 1979-1986. For this site, all index and threshold values were recalculated by using an average of the index values for the two time periods, weighted by the number of years in each period.

Critical thresholds were established for each index (see earlier Primary and Surrogate Indices table for definitions of each index) and each stream for stream data sets without withdrawal alteration. Daily flow data for each site over the course of the period of record were entered into the NJHAT program to calculate all significant indices and index thresholds at the 25/75 and 40/60 percentile ranges. All daily flow data used for the calculations were retrieved from the USGS National Water Information System

(NWIS). This data can be accessed on the web at http://waterdata.usgs.gov/nwis).

For temporal indices, the upper and lower thresholds were determined to be the 25/75 and 40/60 percentile ranges. For spatial indices, the threshold limits are the index value plus and minus the inter-quartile or inter-percentile range (based on the 25/75 or 40/60 percentile index values) of that index for all sites in Stream Type C. These thresholds were calculated for each index for the stream data sets without withdrawal alteration. The table *Upper and Lower Thresholds Representing Critical Values for Indices Based on 25/75 Percentile Default Values* provides the results for the 25/75 threshold values for each index and each stream, below.

Upper and Lower Thresholds Representing Critical Values for Indices Based on 25/75 Percentile Default Values

Site Number	Lower Index Threshold Limits									
	DH11	**DL16**	**FH3**	**FL1**	**MA24**	**MH14**	**ML3**	**RA6**	**TH3**	**TL1**
01384500	10.72	7.91	34.29	5.00	37.29	11.69	18.00	0.08	0.04	249.04
01386000	18.00	7.89	36.50	6.00	49.79	18.19	12.00	0.12	0.00	238.98
01396660	13.83	4.43	21.00	8.00	57.24	15.75	12.00	0.08	0.03	247.10
01399500	5.33	7.50	12.00	5.00	29.35	5.36	31.00	0.06	0.00	248.55
Site Number	**Upper Index Threshold Limits**									
	DH11	**DL16**	**FH3**	**FL1**	**MA24**	**MH14**	**ML3**	**RA6**	**TH3**	**TL1**
01384500	24.33	19.43	73.25	8.00	61.88	26.06	34.75	0.54	0.36	259.17
01386000	29.93	17.14	72.50	10.00	89.29	33.66	21.75	0.66	0.30	249.10
01396660	38.83	9.50	57.00	18.00	127.58	32.77	17.00	0.76	0.35	257.23
01399500	9.43	14.68	40.00	10.00	58.41	9.39	61.00	0.35	0.00	258.68

Other possible critical threshold values, such as the 40/60 percentile range, could be used if the study objectives were based on a need to be more conservative in response to projected water source development or other needs in a given basin. For example, choice of a narrower range would restrict the variability in the threshold interval for specific index values and result in decreased maximum allowable withdrawals being calculated using this model. The table *Upper and Lower Thresholds Representing Critical Values for Indices Based on 40/60 Percentile Values*, below provides the results for the 40/60 threshold values for each index and each stream.

Upper and Lower Thresholds Representing Critical Values for Indices Based on 40/60 Percentile Values

Site Number	Lower Index Threshold Limits									
	DH11	**DL16**	**FH3**	**FL1**	**MA24**	**MH14**	**ML3**	**RA6**	**TH3**	**TL1**
01384500	13.94	10.93	43.29	5.29	44.58	14.57	22.16	0.15	0.13	252.53
01386000	21.21	9.15	46.00	7.00	62.21	22.00	14.00	0.19	0.14	242.46
01396660	20.70	5.85	32.20	10.20	66.39	20.86	13.00	0.16	0.19	250.59
01399500	6.56	9.00	17.60	6.00	33.06	6.02	43.60	0.10	0.00	252.04
Site Number	**Upper Index Threshold Limits**									
	DH11	**DL16**	**FH3**	**FL1**	**MA24**	**MH14**	**ML3**	**RA6**	**TH3**	**TL1**
01384500	17.407	16.355	54.00	7.00	54.767	17.639	28.161	0.3064	0.2651	255.68
01386000	24.429	13.818	57.00	9.00	79.964	26.222	17.00	0.396	0.142	245.62
01396660	30.867	6.489	42.00	14.00	94.499	29.44	15.00	0.37	.0192	253.74
01399500	7.767	11.171	25.8	8.00	45.114	7.154	51.8	0.201	0.00	255.19

In order to model the affects of water withdrawal from the selected stream gages on ERHI values, and to predict what amount of withdrawal will result in exceedance of either the 25/75 or 40/60 percentile threshold range, daily flow values were modified to reflect simulated withdrawal scenarios.

For each gaging station dataset for its entire period of record, withdrawal scenarios were calculated as percents of the 50th percent exceedance value, or median, of all daily flows removed from each daily flow with respect to minimum passing flow.

The minimum passing flow for each gaging station is defined as the seven day, 10 year (7Q10) low flow for the entire period of record. Exceedance flows, passing flows, and the percent of the record below passing flow are listed in the table titled *Exceedance and Passing Flow Statistics for Period of Record at Study Sites*, below.

Exceedance and Passing Flow Statistics for Period of Record at Study Sites

Station Number	50% Exceedance Flow (Median Flow)		Passing Flow (7Q10), cubic feet/second		Percent of Record Below Passing Flow
	CFS**	**MGD***	**CFS****	**MGD***	
01384500	20	13	0.37	0.24	0.5
01386000	14	9	0.59	0.38	0.5
01396660	12	8	1.88	1.21	0.7
01399500	42	27	4.96	3.21	0.7

** million gallons/day   ** cubic feet/second*

Modified hydrographs of daily stream flow values were calculated to reflect various withdrawal scenarios. Each daily flow was recalculated assuming that a percentage of flow was removed from the stream each day over the period of record.

For all initial daily flows that were greater than the passing flow, each recalculated daily flow for each withdrawal scenario was determined by the following formula:

$$DQf = DQi - (n^*M) \qquad (1)$$

Where,

DQf = Calculated daily flow for withdrawal scenario

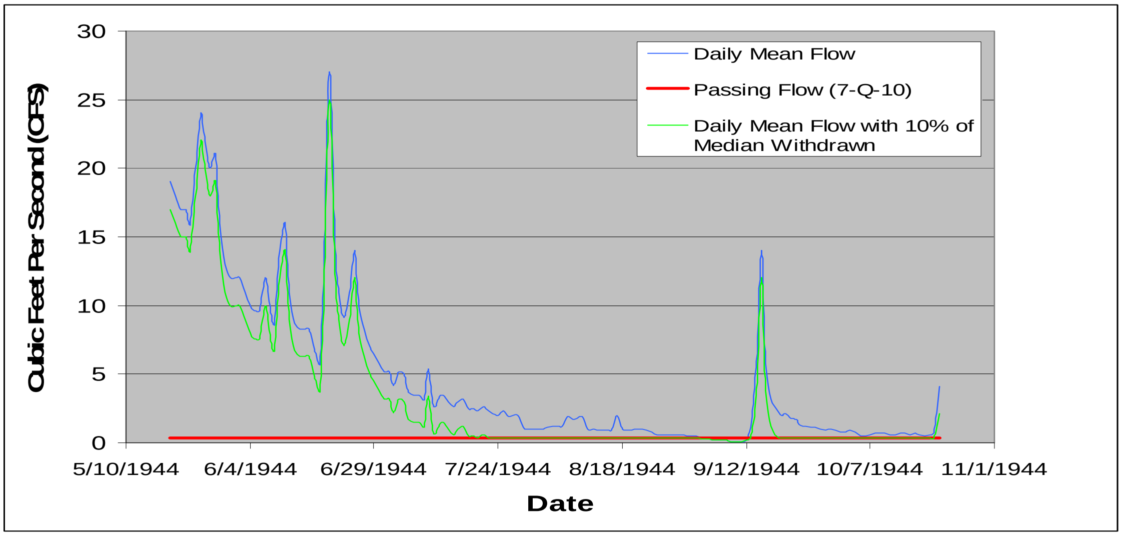
DQi = Initial daily flow (Daily flow values are available at http://waterdata.usgs.gov/nwis)

n = the fraction of flow removed which is specific to the withdrawal scenario defined

M = the 50-percent exceedance flow for the entire period of record (M values for each site are listed in the previous table, Exceedance and Passing Flow Statistics for Period of Record at Study Sites)

An example of one daily flow calculation that represents a time period where the stream level was naturally below the passing flow volume (and therefore, the recalculated withdrawal values were set for passing flow - assuming regulatory compliance) is presented below. The figure *Example of 10% Withdrawal Scenario of Median Flow for Ringwood Creek near Wanaque Compared to Original Daily Flow Values and Minimum Passing Flow* illustrates an example of this procedure applied for Ringwood Creek near Wanaque (01384500) with a 10% median withdrawal. In this example, for the 10% withdrawal scenario for Ringwood Creek near Wanaque (01384500) with a daily flow on July 2, 1944 of 5.2 cubic feet/second (taken from NWIS), the recalculated daily flow for the scenario would be determined by the following equation:

DQf = 5.2 cubic feet/second – (0.10*20 cubic feet/second)



Example of 10% Withdrawal Scenario of Median Flow for Ringwood Creek near Wanaque Compared to Original Daily Flow Values and Minimum Passing Flow

If DQf is less than passing flow as calculated from equation (1), the passing flow is substituted for DQf for that day in the recalculated dataset. If DQi is less than passing flow, DQi is used as DQf for that day in the recalculated dataset.

Ten datasets for each withdrawal scenario were recalculated, where each dataset incorporated "n" values of 0.01, 0.02, 0.03…… to 0.10, respectively. For each dataset, DQf was determined for each day for the entire period of record for daily flows only. Instantaneous peak flows were not recalculated. Each withdrawal scenario dataset was used to recalculate each of the 10 selected indices listed in the previous primary and surrogate indices table.

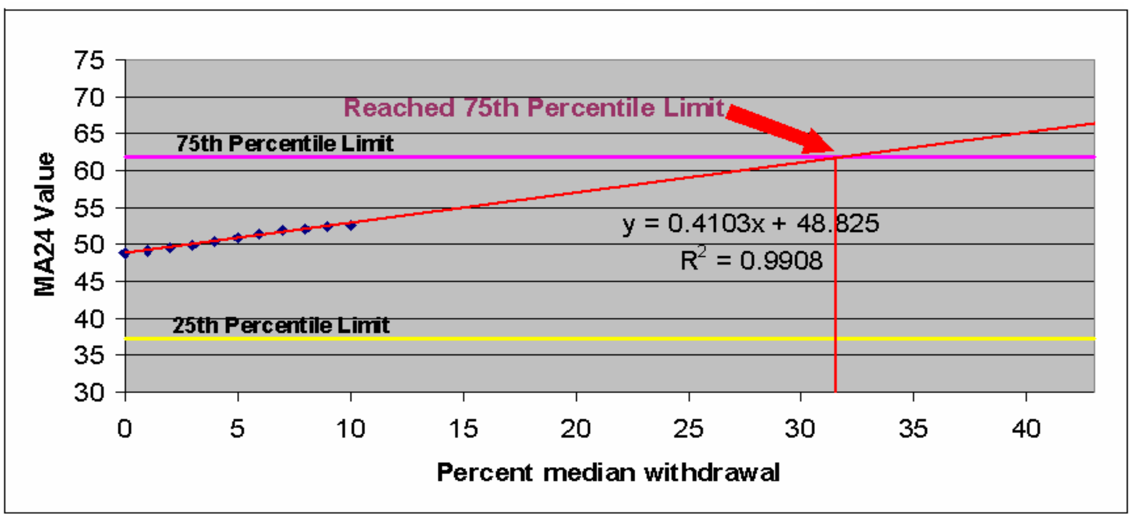
From each data set and each site, a correlation was determined for the percentage of the 50 percent exceedance value for the entire flow record, which was removed from each daily value using the above formula and each calculated index value. This correlation was determined by least squares regression, and the regression was used to predict the withdrawal value in millions of gallons per day (MGD) that would cause the index to reach the pre-established critical value, as defined by the default thresholds listed in Upper and Lower Thresholds Representing Critical Values for Indices Based on 25/75 Percentile Default Values table. An example of this procedure is shown in the figure *Example of Regression Line Extrapolation for MA24 and Percent Median Withdrawal Using the 25/75 Threshold at Ringwood Creek near Wanaque*, which illustrates the effects of withdrawal on MA24 (variability of January median flow values) at Ringwood Creek near Wanaque (01384500), where a withdrawal at roughly 31 percent of median flow would exceed the 75 percentile threshold.

RESULTS

The results from the analysis of 10 withdrawal scenarios for 10 indices at four sites using the 25/75 thresholds are shown in the table *Predicted Withdrawal Required for Indices to Reach Critical Value for 25/75 Thresholds*, and the results using the 40/60 thresholds are shown in the table *Predicted Withdrawal Required for Indices to Reach Critical Value for 40/60 Thresholds*. A summary of the results is depicted in the four figures entitled *Withdrawal (MGD) by Site Required to Surpass the 25/75 (and in a separate figure depicting 40/60 values) Index Threshold Based on Regression Analysis and Withdrawal (MGD) by Site Required for Index to Reach Critical Value for 25/75 (and 40/60) Thresholds in Percent of Median Flow.*

For several indices, a correlation could not be established between withdrawal quantity and index value. Correlations were evaluated by calculating the square of the Pearson product moment correlation coefficient, or R-squared, value. If the R-squared value was less than 0.75, the correlation is considered poor. If the R-squared value was less than 0.55, the regression was discarded and the predicted withdrawal value for that regression was not reported therefore “no trend” is indicated.

For Ringwood Creek near Wanaque (01384500), the maximum amount that could be withdrawn using the 25/75 threshold before the index reached a critical value for at least one of the indices is 3.81 MGD, or 0.199 MGD per square mile (index FH3).



Example of Regression Line Extrapolation for MA24 and Percent Median Withdrawal Using the 25/75 Threshold at Ringwood Creek near Wanaque

Predicted Withdrawal Required for Indices to Reach Critical Value for 25/75 Thresholds

Station Number	Withdrawal in Millions of Gallons/Day (MGD) Required for Index Values to Reach Critical Value									
	DH11	DL16	FH3	FL1	MA24	MH14	ML3	RA6	TH3	TL1
01384500	5.58		3.81*		4.08	6.75	4.26	6.56		
01386000	1.90		1.76*		2.94	2.82	2.91	5.25		0.89
01396660	2.44		2.98		7.71	2.14	1.29*	9.94		1.80
01399500	5.52**		8.33		22.09	12.43	11.63	23.79		3.68*

Indicates a poor R-squared value for the regression

Indicates that there was no trend in the effect of withdrawal on the index value

* Minimum value that can be withdrawn to surpass the critical threshold

** This value is the minimum value predicted to cause the index to reach critical value using a significant regression.

Predicted Withdrawal Required For Indices to Reach Critical Value for 40/60 Thresholds

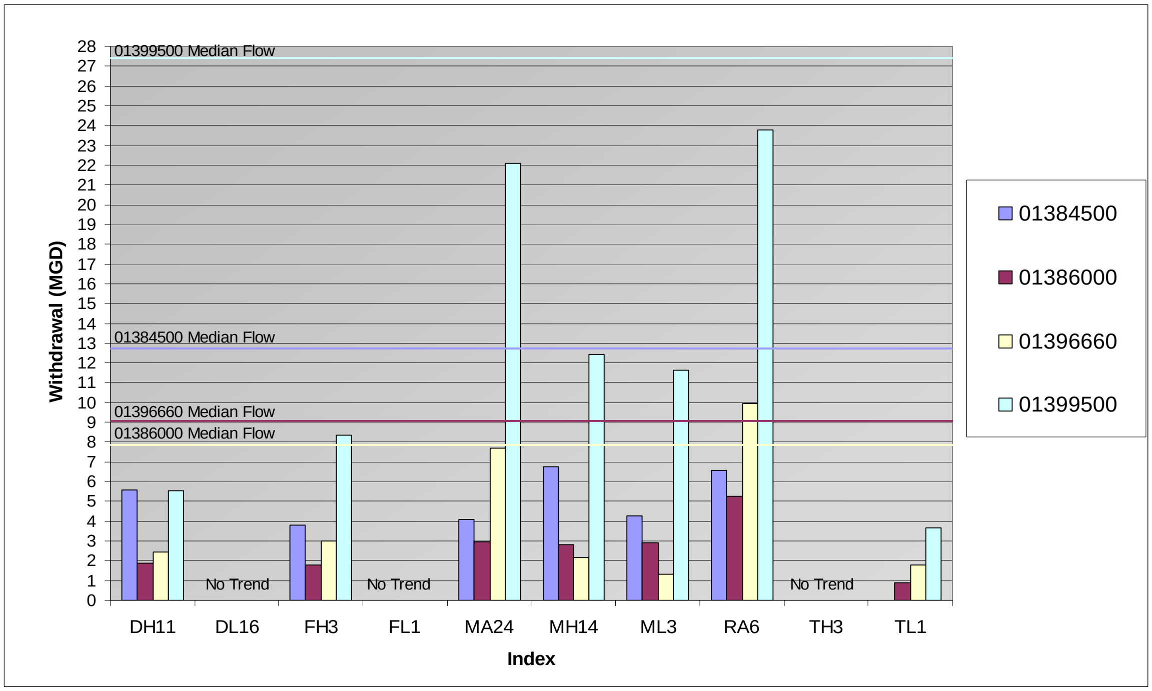
Station Number	Withdrawal in Millions of Gallons/Day (MGD) Required for Index Values to Reach Critical Value for 40/60 Threshold									
	DH11	DL16	FH3	FL1	MA24	MH14	ML3	RA6	TH3	TL1
01384500	.029*		0.82		1.86	1.17	1.57	1.84		
01386000	0.01*		0.99		1.38	0.79	1.62	1.69		0.25
01396660	0.46*		1.01		2.40	1.11	0.65	2.51		0.64
01399500	0.03*		1.92		6.39	2.54	3.49	6.76		2.36

Indicates a poor R-squared value for the regression

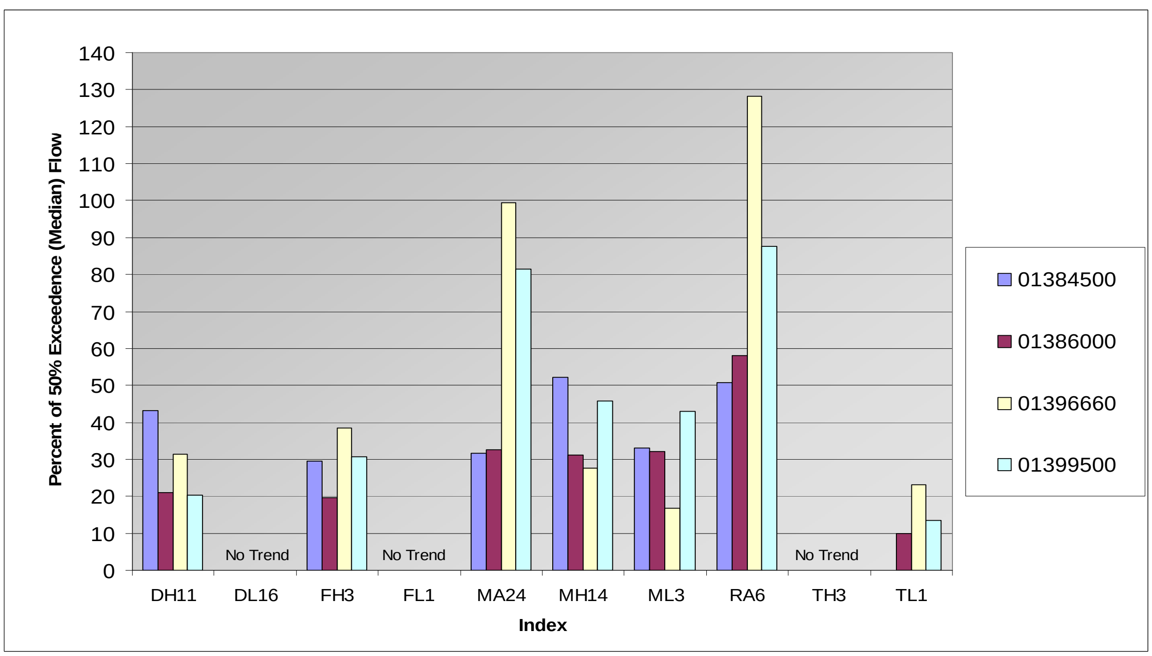
Indicates that there was no trend in the effect of withdrawal on the index value

* Minimum value that can be withdrawn to surpass the critical threshold

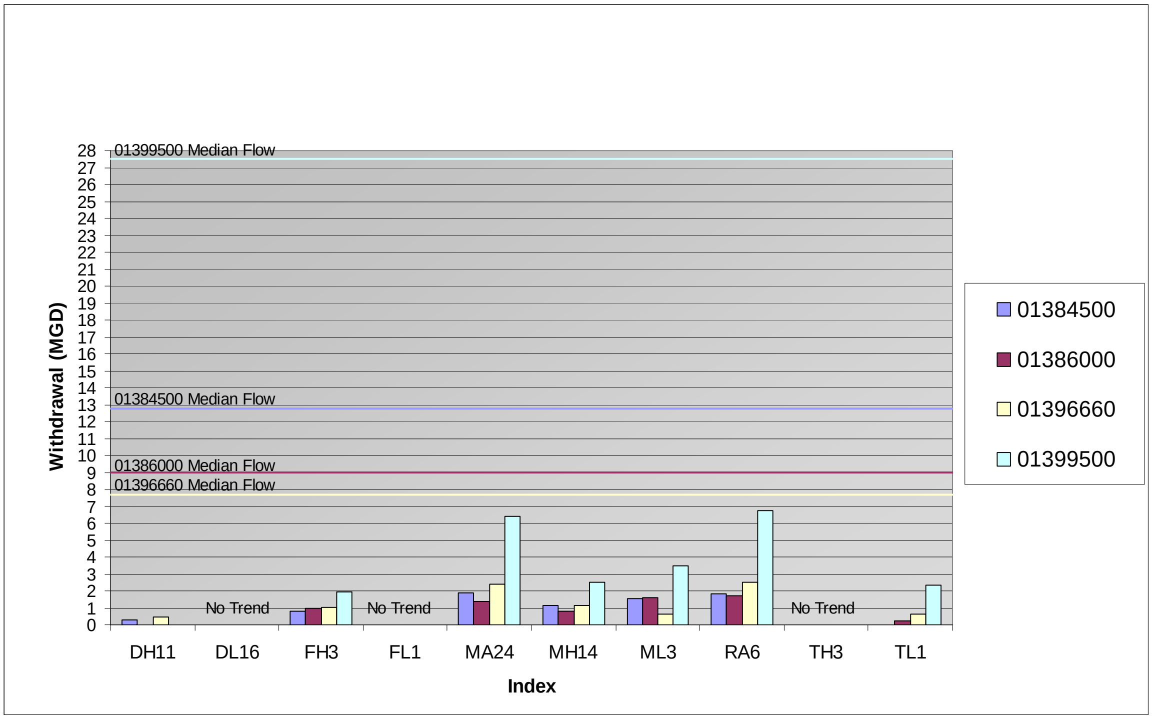
** This value is the minimum value predicted to cause the index to reach critical value using a significant regression.



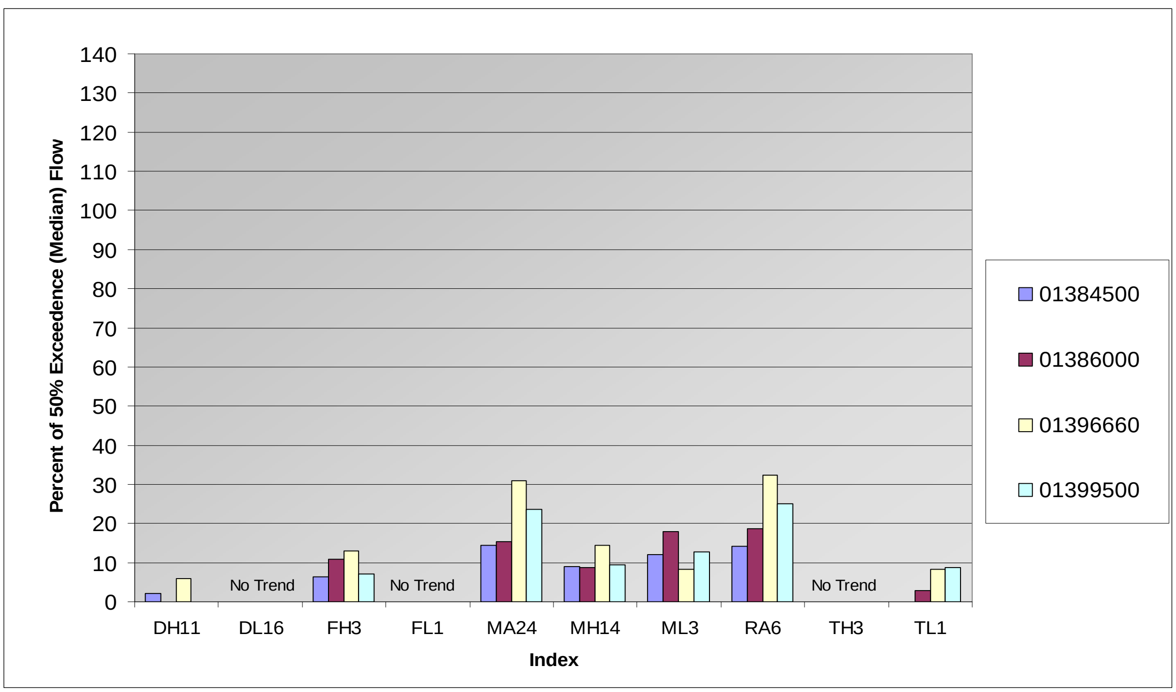
Withdrawal (MGD) by Site Required to Surpass the 25/75 Index Threshold Based on Regression Analysis



Withdrawal (MGD) by Site Required for Index to Reach Critical Value for 25/75 Thresholds in Percent of Median Flow



Withdrawal (MGD) by Site Required to Surpass the 40/60 Index Threshold Based on Regression Analysis



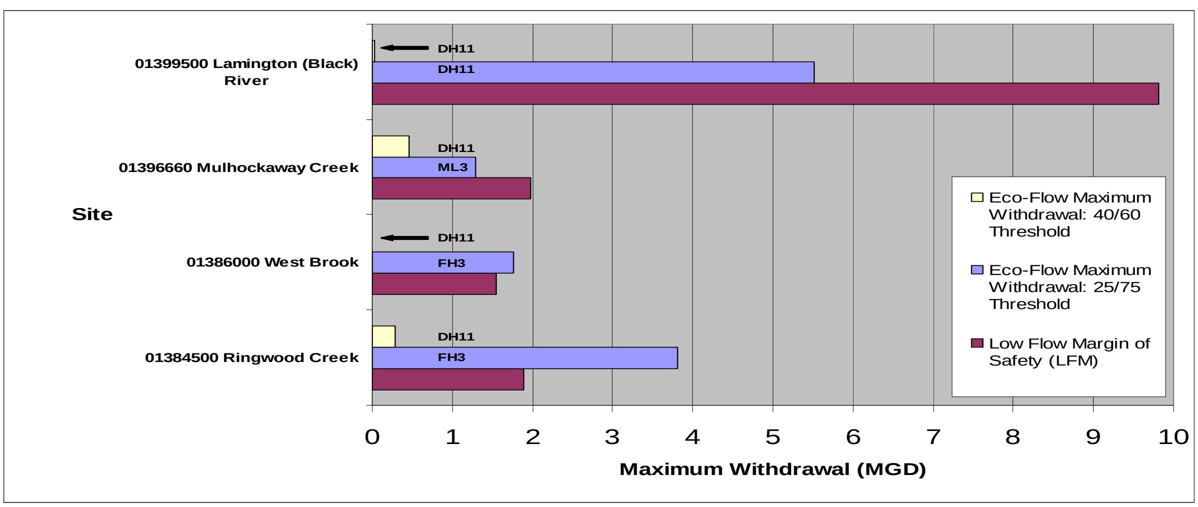
Withdrawal (MGD) by Site Required for Index to Reach Critical Value for 40/60 Thresholds in Percent of Median Flow

For West Brook near Wanaque (01386000), the maximum withdrawal is 1.76 MGD or 0.149 MGD per square mile (index FH3); for Mulhockaway Creek at Van Syckel (01396660), the maximum withdrawal is 1.29 MGD or 0.109 MGD per square mile (index ML3); for the Lamington River near Pottersville (01399500), the maximum withdrawal value is 3.68 MGD or 0.112 MGD per square mile (index TL1). However, for a predicted withdrawal with a more significant regression, 5.52 MGD, or 0.168 MGD per square mile, can be withdrawn (index DH11) before reaching a critical value at Pottersville.

As a comparison to the 25/75 threshold results, the withdrawals required to reach the 40/60 threshold were much lower for all four sites and clearly demonstrated that using this narrower criteria which limits hydrograph alteration is a much more conservative approach. For Ringwood Creek near Wanaque (01384500), the maximum amount that could be withdrawn using the 40/60 threshold before the index reached critical value for at least one of the indices is 0.29 MGD.

For West Brook near Wanaque (01386000) and Lamington River near Pottersville (01399500), no water could be withdrawn to avoid crossing the critical value (0.01 and 0.03 MGD, respectively, can both be considered a negligible withdrawal quantity); and for Mulhockaway Creek at Van Syckel (01396660), the maximum withdrawal is 0.46 MGD. For all four sites, DH11 (high flow duration) was the index in which threshold values were first surpassed (see Predicted Withdrawal Required For Indices to Reach Critical Value for 40/60 Thresholds table. These results of the extrapolated regression line analysis above can be compared to the "Low-Flow Margin of Safety" (LFM) approach for calculating the maximum allowable withdrawal. LFM assumes that some portion of stream flow can be removed without affecting stream ecology. This quantity is based on a percentage of the difference between the typical volume of water that flows from the watershed during the most stressed month (using the September median flow, a typical dry month), and the 7Q10 flow. For this analysis, the percentage shown is 100 percent; but in practice the Highlands Council will establish the percentage for each watershed.

A comparison of the results from the 25/75 threshold analysis, 40/60 threshold analysis, and the LFM method are illustrated in the figure Comparison *of Ecological Flow Maximum Withdrawal vs. Low Flow Margin of Safety (LFM)* and demonstrate the potential utility of the ecological flow method to inform water capacity determinations.



Comparison of Ecological Flow Maximum Withdrawal vs. Low Flow Margin of Safety (LFM)

Discussion

Several indices for several sites were not affected by the action of withdrawal in the drainage basin. These indices include DL16 and FL1, which are both temporal indices, and TH3 and TL1, which are spatial indices. DL16 and FL1 are both pulse counts for low flow. The DL16 is a pulse duration, mostly affected by duration of low flow events. Withdrawing a constant amount of flow from the basin would not be expected to change the duration of the low flow event, since both the 25th percentile flow and all low flows are lowered by roughly the same amount (barring flows that are below passing flow, which remain at less than one percent of total flow values for all sites). Similarly for FL1, which is a count of the number of days that flow is below the 25th percentile flow, withdrawing constant quantities is not expected to have an effect on this index value.

A similar situation is noted for FH3, which is a count of high flow events above three times the median flow. This index may be more affected by withdrawal because the threshold for the count is the median flow, which is multiplied threefold as opposed to only taking the 25th percentile flow. This is demonstrated in the data, in which significant correlations were not observed for DL16 and FL1, but were identified for TH3. TH3 is a measure of the proportion of days in which the flow exceeded the 1.67-year flood events, which can be considered a "count" index. For all four original datasets, this index was zero or close to zero events and withdrawals would only decrease this count of days, which means that subsequent index values calculated were also zero. TL1 is a measure of the Julian date at which minimum flows occur. This date is not changed with constant withdrawals. Therefore, the index is not expected to change using this model.

Although significant correlations between withdrawal and index value changes were not observed for every index, this does not imply that those indices are not significant for other types of hydrograph alteration that would result from anthropogenic changes in the drainage basin. The effects of other activities that can occur in the drainage basin should be taken into consideration, such as regulation, diversion and urban development. The ecological integrity of these streams is dependent upon the stability of multiple facets of the flow regime, which can be quantified by the significant index values identified for each stream type. Any correlation of these index values with other anthropogenic alterations in the basin can compromise this integrity, so affects of these activities on all index values will need to be examined before this method can be implemented throughout the Highlands.

PRELIMINARY COMPARISON OF RESULTS

This section summarizes the results regarding Ground Water Capacity estimates for the Base Flow Recurrence Interval, Low Flow Margin and Ecological Flow Goals methods. The results of the three methods are compared to determine the extent to which they provide useful information for deriving ground water availability. The comparison focuses on both similarities and differences among the methods, and on how the Ecological Flow Goals method (which was only applied to four subwatersheds) was used to inform a choice between the Base Flow Recurrence Interval and Low Flow Margin of Safety methods as the preferred method for use by the Highlands Council.

The Preliminary Results Summarizing Selected Flow Statistics table in (see Appendix B) provides the following low flow statistics and water capacity data for each HUC14 subwatershed:

- Indicator identifying method used: drainage area ratio or regression analysis
- Mean annual base flow in MGD and MGD/mi2
- 10 year recurrence interval base flow in MGD and MGD/mi2
- 25 year recurrence interval base flow in MGD and MGD/mi2

- September median flow in MGD and MGD/mi2
- 7Q10 flow in MGD and MGD/mi2
- Low flow margin in MGD and MGD/mi2
- Ground water capacity for the 10 and 25-year base flow and low flow margin minus total consumptive ground water use in MGD and MGD/mi2
- Ground water capacity for the 10 and 25-year base flow and low flow margin minus maximum monthly consumptive ground water use in MGD and MGD/mi2
- Ground water capacity for the 10 and 25-year base flow and low flow margin minus consumptive ground water use at full allocation in MGD and MGD/mi2
- Ground water capacity for the 10 and 25-year base flow and low flow margin minus total ground water use in MGD and MGD/mi2

Because both the Base Flow Recurrence Interval and Low Flow Margin rely on base flow estimates, the results are presented together. A summary of results for the Ecological Flow Goals methods is given later. The USGS results were provided for several potential estimates of Ground Water Capacity, including the 10 and 25-year base flow recurrence intervals and the Low Flow Margin. In any case, the results would not be used directly as estimates of ground water availability but rather would serve as the baseline information for such estimates. A critical question is whether these methods provide truly different answers. To test this, the Highlands Council compared HUC14 estimates to determine whether they are consistent; that is, do the results of these methods change in a similar manner from one HUC14 to another? This analysis provided the Council with a degree of assurance that these statistics are suitable as the basis for defining Ground Water Availability.

The distribution of these statistics for each HUC14 in relation to discharge in MGD/mi2 is shown graphically in the figures provided in Appendix B. Water capacity calculations at the 10 and 25-year base flow recurrence interval average about 65% and 54% of mean annual base flow, respectively. Water capacity determined using the low flow margin method provides significantly more conservative estimates of ground water capacity than base flow recurrence, averaging about 22% of mean annual base flow.

As noted previously, statistical analyses were performed for stations that represent stream basins with limited water uses and no upstream water flow controls (e.g., reservoirs). Those results are summarized here, with additional analysis of some key issues. The table *Base Flow Analytical Method Results for Gaged Stream Basins* provides average results for the 120 gaged stream basins (not subwatersheds), and compares these values. They are reported here in million gallons per day per square mile (MGD/mi2) to improve the comparability among drainage basins of varying size.

In general, the results for the gaged stream basins show a very similar pattern of relationships between the various base flow analyses, with a clear transition from highest flows to lowest as the base flow methods become more typical of drought conditions (see Appendix B). Differences between the base flows of stream basins can be very large, indicating the importance of basin size, geology, soils, ground water storage, development status and water use status on base flow. The last two items are of some importance even though USGS deliberately selected stream basins with the lowest possible human impacts as the basis for these analyses. As would be expected, the mean annual base flow and 2-year base flow recurrence interval methods yield almost equivalent results. Of the various base flow analyses, the lowest variability (high to low value) is found in the 7Q10 base flow, with a range from 0.0 to 0.69 MGD/mi2, and in the Low Flow Margin, with a range from 0.02 to 0.38 MGD/mi2.

Base Flow Analytical Method Results for Gaged Stream Basins

	Mean of Results MGD/mi2	Percent of Mean Annual BF	Lowest Results MGD/mi2	Highest Results MGD/mi2
Mean Annual Base Flow	0.74	100	0.18	1.49
2-year Base Flow Return Interval	0.72	96	0.17	1.48
5-year Base Flow Return Interval	0.56	74	0.11	1.39
10-year Base Flow Return Interval	0.49	65	0.08	1.35
Drought of Record Base Flow	0.48 [4]	64	0.08	1.36
25-year Base Flow Return Interval	0.41 [5]	55	0.06	1.29
50-year Base Flow Return Interval	0.35 [6]	45	0.04	1.24
September Median Flow	0.25	33	0.03	1.02
7Q10 Base Flow	0.08	10	0.00	0.69
Low Flow Margin (100 percent)	0.17	22	0.02	0.38

Appendix B also includes a comparison of low flow values for selected basins that indicates that one gaged stream basin in particular, Ramapo Tributary No. 5 at Oakland (01387930), has by far the highest base flow values but its Low Flow Margin value is much more closely grouped with the other stream basins. Both the September median flow and 7Q10 are high, resulting in a Low Flow Margin that is not unusual. Other stream basins with notably higher base flow results (though more in line with the others), including Singac Brook (01389100, a tributary of the Passaic River) and Jaquis Brook at Greystone Park State Hospital (01381470, a tributary of the Whippany River). All of these streams are small tributaries; it may be that some small streams include more unusual geologic or landscape settings, and therefore define both the highest and lowest extremes in base flow. Certainly, a small stream basin may receive ground water flows from a larger, interconnected aquifer (leading to higher than average base flows) or may have very limited aquifer storage (leading to lower than average base flows). All of the streams with the lowest base flows are also smaller tributaries.

Another finding worth noting is the comparison between the Low Flow Margin and Mean Annual Base Flow results, where Low Flow Margin is 22 percent of Mean Annual Base Flow, on average. In an undisturbed watershed, the mean annual base flow would be equal to the mean annual ground water recharge. Base flow is created by the movement of ground water into surface waters; recharge and base flow will balance over time. The 1996 NJ Statewide Water Supply Plan (NJDEP, 1996a) recommended a planning threshold for consumptive ground water uses of 20 percent of recharge. This value was based on empirical evidence of aquifer declines above that threshold, and was meant to apply only to regional aquifer systems. However, the 20 percent threshold from the 1996 NJSWSP compares well with the 22 percent value for Low Flow Margin as a percent of Mean Annual Base Flow. What the 1996 NJSWSP did not account for were potential impacts of withdrawals approaching the 20 percent threshold on more sensitive stream systems, of withdrawals from watersheds with more localized aquifers or poor storage, or of concentrated withdrawals within a watershed or aquifer. These factors can be important in

[4] 10 stations with no available statistics for Drought of Record Base Flow
[5] 4 stations with no available statistics for 25-year Base Flow Recurrence Interval
[6] 14 stations with no available statistics for 50-year Base Flow Recurrence Interval

the Highlands, given the wide range of base flow and Low Flow Margin values among gaged stream basins.

The USGS results from the gaged stream basins were used to estimate base flows for each of the 183 HUC14 subwatershed. The results were statistically derived, and therefore all subwatersheds are represented for each analysis. This contrasts with the gaged stream data, where some base flow values were unavailable for some basins. The Base Flow Analytical Method Results for HUC14 Subwatersheds table, below provides the mean, lowest value and highest value for a number of flow statistics, and also for key comparisons of the statistics. Appendix B also includes a Comparison of Low Flow Values for Highlands HUC14s figure showing the same results graphically. The results are provided in million gallons per day per square mile (MGD/mi2) to normalize the results from HUC14s of widely differing size.

The relationships between average base flow results are consistent with those for Low Flow Margin, 22 percent of the Mean Annual Base Flow. The similarity in results is appropriate, given that the analyses from gaged stream basins were used to derive the HUC14 subwatershed results. Mean annual base flow per unit area for the 183 subwatersheds within the Highlands ranged from 0.20 to 1.16 MGD/mi2, with a median value of 0.73 MGD/mi2. The base flow ranges (comparing high to low values) are generally smaller for the HUC14 results, with the lowest values being similar but the highest values being lower (and sometimes markedly lower) than the gaged stream basin results. This reduction in range may result from the smaller size of the largest HUC14s relative to the largest stream basins (157 square miles).

The pattern of base flow estimates between the figures provided in Appendix B showing comparisons of low flow volumes is also quite similar (note that some of the base flow analyses performed for the gaged stream basins were not performed for HUC14s and therefore are not reflected in the second figure illustrating data from basins lacking base flow statistics). HUC14 subwatersheds with higher capacities are generally those with a combination of factors, including larger basin area, greater amounts of precipitation and higher ground water recharge. Basins with lower capacities are generally smaller in size, with a significant percentage of area containing steep slopes that promotes greater surface runoff and lower base flows.

Base Flow Analytical Method Results for HUC14 Subwatersheds

	Mean of Results MGD/mi2	Percent of Mean Annual BF	Lowest Results MGD/mi2	Highest Results MGD/mi2
Mean Annual Base Flow	0.73	100	0.20	1.16
10-year Base Flow Return Interval	0.48	66	0.12	0.75
25-year Base Flow Return Interval	0.40	55	0.08	0.69
September Median Flow	0.23	32	0.03	0.47
7Q10 Base Flow	0.06	8	0.00	0.28
Low Flow Margin	0.16	22	0.02	0.30

ECOLOGICAL FLOW GOALS METHOD

Detailed findings for this method are discussed including analysis of the four sites using the default 25/75 percentile thresholds.

Using the 25/75 threshold, for Ringwood Creek near Wanaque (01384500), the maximum amount that could be used consumptively before the index reached a critical value for at least one of the indices is 3.81 MGD, or 0.199 MGD per square mile (index FH3, frequency of high flow events); for West Brook near Wanaque, the maximum withdrawal is 1.76 MGD, or 0.149 MGD per square mile (index FH3); for Mulhockaway Creek at Van Syckel, the maximum withdrawal is 1.29 MGD, or 0.109 MGD per square mile (index ML3, magnitude of low flow events); for Lamington River near Pottersville, the maximum withdrawal value is 3.68 MGD (index TL1, timing of low flow events), but for a predicted withdrawal with a more significant regression, 5.52 MGD, or 0.168 MGD per square mile, can be withdrawn (index DH11, or high flow duration) before reaching a critical value.

For the Ringwood Creek and West Brook cases, the parameter first exceeded is the frequency of high flow events, not a low flow measure. If the more significant regression result is used for the Lamington River case, then high flow duration is the trigger. Only the threshold indicator for Mulhockaway Creek is unambiguously linked to low flow impacts. However, the NJHAT method defines "high flow" as being three times the median flow, which can be affected by flow reductions linked to continuous withdrawals.

As a comparison to the 25/75 threshold results, the withdrawals required to reach the 40/60 threshold were much lower for all four sites and demonstrated that using this narrower criterion for maximum hydrograph alteration is a much more conservative approach. For Ringwood Creek near Wanaque (01384500), the maximum amount that could be withdrawn before the index reached critical value for at least one of the indices is 0.29 MGD, or 0.015 MGD per square mile; for West Brook near Wanaque and Lamington River near Pottersville, essentially no water should be withdrawn to avoid crossing the critical value (0.01 and 0.03 MGD, or 0.0008 and 0.0009 MGD per square mile, respectively, can be considered a negligible withdrawal quantity equivalent to zero); and for Mulhockaway Creek at Van Syckel, the maximum withdrawal is 0.46 MGD, or 0.039 MGD per square mile. For all four sites, DH11 (high flow duration) was the index in which the threshold was first surpassed, but DH11 can be affected by continuous withdrawals.

RECOMMENDED TECHNICAL METHOD FOR ESTIMATING GROUND WATER CAPACITY

The statistical results from the Base Flow Recurrence Interval and Low Flow Margin methods show extensive variation within each method. As expected, the 7Q10 value is routinely the lowest, as it measures a low flow condition based on a shorter duration than the other statistics. Of greater importance is the relationship of low flow conditions (the last five rows in the Base Flow Analytical Method Results table shown previously). The ratio of 25 year to 10 year base flows is relatively narrow, compared to the next two ratios. Given the nature of these statistics, it is reasonable to expect that they would vary from HUC14 to HUC14 in a consistent manner. However, all of the remaining ratios show a great deal of variation from the mean values. Based on this fairly simple comparison of statistics, the Base Flow Recurrence Interval and Low Flow Margin methods are not co-linear and cannot be used to substitute for one another.

The range of values (from highest to lowest) is lowest for two measures – the 7Q10 and the Low Flow Margin; their highest and lowest values are almost exactly the same, though the mean values are significantly different. Based on previous recommendations of the Highlands Council's Natural

Resources Committee, the choice for estimation of Ground Water Capacity was between a selected Base Flow Recurrence Interval and the Low Flow Margin. Of the recurrence interval statistics, it seems appropriate to consider the 7Q10 value to reduce the potential for wide variations in Ground Water Capacity among the HUC14s.

However, the 7Q10 values include instances where the natural flow regime of various HUC14s involves zero flows during very dry periods, which in turn would mean that the aquatic ecosystems are adapted to periodic dewatering of the stream as a natural condition.[7] Additional ground water uses in such stream basins may increase the zero flow periods, which the ecosystem may or may not be able to tolerate if limited in duration. The question then is whether it makes more sense to use 7Q10 (which would assign zero values for some HUC14s) or the Low Flow Margin (which would assign positive values, albeit sometimes close to zero, to all HUC14s) to estimate Ground Water Capacity, recognizing that these values would then be further limited by thresholds selected for resource protection plus the subtraction of existing flow losses.

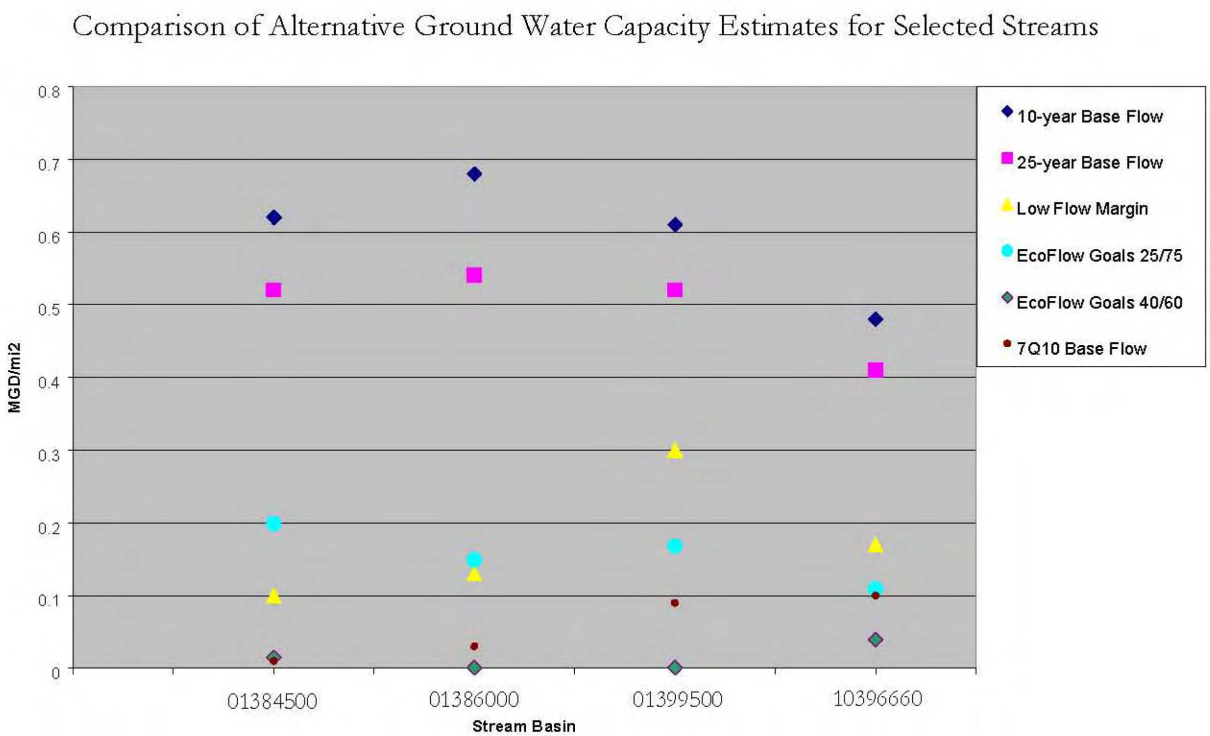
As one potential way of addressing this question, the table *Comparison of Alternative Ground Water Capacity Results for Selected Stream Basins* provides a comparison of the EcoFlow Goals results to both Base Flow Recurrence Interval and Low Flow Margin estimates for the four stream basins for which EcoFlow Goals estimates were available. The figure titled *Comparison of Alternative Ground Water Capacity Estimates for Selected Streams* illustrates same results as a chart.

While admittedly a small sample of cases, the intent is to assess whether the EcoFlow Goals results address the question of whether 7Q10 or Low Flow Method will better reflect the need for ecological maintenance flows. It should be noted that these results are based on the default assessment approach, where the method is used to determine the amount of consumptive water use needed to exceed only one of the ten EcoFlow statistical measures. If the method were based on having at least two of the ten measures exceeded, or focused on specific measures instead of all ten, the results would be different. NJDEP is currently examining various approaches, but no formal guidance is available at this time so the default approach was used.

Comparison of Alternative Ground Water Capacity Results for Selected Stream Basins

Method	**Stream Basin**			
All methods in MGD/mi2	Ringwood Creek near Wanaque (01384500)	West Brook near Wanaque (01386000)	Lamington (Black) River near Pottersville (01399500)	Mulhockaway Creek at Van Syckel (01396660)
10-year Base Flow Interval	0.62	0.68	0.61	0.48
25-year Base Flow Interval	0.52	0.54	0.52	0.41
7Q10 Base Flow	0.01	0.03	0.09	0.10
Low Flow Margin (100 percent)	0.10	0.13	0.30	0.17
EcoFlow Goals 25/75 Result	0.199	0.149	0.168	0.109
EcoFlow Goals 40/60 Result	0.015	0.0008	0.0009	0.039

[7] Note that a zero flow due to anthropogenic influences would not be evaluated in the same manner, as non-natural disruptions of flow could occur at instances where the ecosystem was not adapted to such stresses.



The values for the 25 and 10-year base flow methods are fairly consistent among the four stream basins. The Low Flow Margin and EcoFlow Goals results are more variable. The 7Q10 flows vary by a factor of ten. The Low Flow Margin and the EcoFlow Goals 25/75 percentile methods most closely match each other in value. Without detailed examination of the four stream basins, it is difficult to know why the Low Flow Margin method yielded a significantly higher result for the Lamington River than for the other three stream basins, though this stream basin is considerably larger in size than the other three and is also underlain by both glacial deposits and a carbonate aquifer. However, those factors did not seem to affect the 10-year and 25-year base flow interval results, where the Lamington was slightly lower than West Brook and similar to Ringwood Creek. Likewise, the Mulhockaway Creek shows lower values than West Brook and Ringwood Creek for the 10-year and 25-year base flow interval results, and yet higher for Low Flow Margin. Finally, the EcoFlow Goals method at the alternative 40/60 percentile threshold yield minimal positive values for available ground water.

Given the results, and acknowledging the limited information base for making comparisons, the Low Flow Margin approach is the most appropriate method available at this time for estimating Ground Water Capacity. It provides a positive value for natural capacity, which is reasonable for the HUC14 subwatershed scale, but the magnitude of Ground Water Capacity is limited to reflect low base flow periods. Where a subwatershed has a higher September median flow than others, the 7Q10 is likewise generally higher and therefore the Low Flow Margin is still in line with other subwatersheds. The EcoFlow Goals method for the alternative 40/60 percentile threshold is helpful in showing that ecologically sensitive areas should have a very high percentage of their Ground Water Capacity reserved to the aquatic ecosystem, with a very low percentage available for human use.

Finally, the information available on reference stream basins indicates that consumptive water uses are approximately 2 percent of the Low Flow Margin, which justifies multiplying the USGS values for Low Flow Margin by 1.02 as a reasonable adjustment factor. Although not done during the initial USGS assessment, this adjustment is used in the Net Water Availability calculations of this report.

CONSUMPTIVE AND DEPLETIVE WATER USES IN THE HIGHLANDS

Highlands water use is an important influence on the amount of ground water availability remaining in each Highlands HUC14 subwatershed. The amount of ground water diverted from each basin through either consumptive or depletive uses directly diminishes the residual capacity to sustain water supply and ecological resource values.

The NJDEP Bureau of Water Allocation (BWA) collects monthly withdrawal data for permitted, registered and certified users in New Jersey. The 1981 Water Supply Management Act authorized the NJDEP to monitor withdrawals of ground water and surface water in New Jersey (Saarela, 1992).

Water users must obtain permission in the form of a permit, registration, or certification. Water allocation permits are issued to non-agricultural users who withdraw 100,000 gallons per day or more on a monthly average basis. Permit holders must submit quarterly reports of metered, monthly withdrawal data (Nawyn, 2006). In 2003, for all of New Jersey there were 662 water allocation permits, including 276 public-supply (5,000-series), 344 industrial and commercial (2,000P-series), and 42 surface water only permits (4,000PS-series); these 662 permits covered withdrawals from 3,683 wells and surface water intakes. Permits in the Highlands Region accounted for 22 percent (144) of the total water allocation permits in 2003, with 78 public supply (5,000-series), 58 industrial and commercial (2,000P-series), and eight surface water only permits (4,000PS-series). These 144 permits covered withdrawals from 581 wells and surface water intakes.

Agricultural/horticultural certifications and registrations are issued through the County Agricultural Agent, who collects information on crop type and amount of irrigated acreage and determines the maximum monthly withdrawals for each applicant.

Water use registrations, a class of water users who use pumping equipment capable of producing 70 gallons per minute, but withdraw less than 100,000 GPD must submit annual reports of monthly withdrawals (Nawyn, 2006). There were 797 registrants (10,000W series) in New Jersey in 2003, covering 1,808 withdrawal sites. In the Highlands in 2003 there were 103 10,000W series registrants, covering 198 withdrawal sites.

Agricultural/horticultural water users who withdraw 100,000 GPD or greater must apply for certification. Agricultural/horticultural registrants use pumping equipment capable of producing 70 gallons per minute, but withdraw less than 100,000 GPD. Withdrawals for agricultural/horticultural purposes are rarely metered; water users submit monthly withdrawal data that are estimated by multiplying the number of hours of use and the pump capacity. Monthly withdrawals are reported annually to the NJDEP (Nawyn, 2006). There were 977 agricultural certifications in New Jersey in 2003 covering 2,835 withdrawal sites, with 22 certifications covering 44 withdrawal sites in the Highlands.

The BWA monthly water use data was collected for all water use withdrawal sites covered by all the permits, registrations and certifications it has issued for the Highlands Region for the year 2003. A brief summary of BWA Highlands water use data for 2003 shows that there were 269 permits, registrations, and certifications for 714 ground water and 109 surface water withdrawal sites. The figure *Bureau of Water Allocation Allocated Withdrawal Sites within Highlands HUC14 Basin Boundary* shows the locations of the Highlands Region withdrawal sites.

The year 2003 was selected as the water use year for BWA data because it is the most recent year for which the USGS has completed its review of the data. When the USGS receives the raw data from BWA, it reviews the data for completeness and correctness. The review identifies and corrects missing data, incorrect data (either from transcription or reporting errors), data duplication, incorrect units (i.e., reporting in thousand gallons instead of million gallons), and incomplete or incorrect water use site information (new sites for old permits, new permits, new owners, permit aggregation). After the review is complete, the data are entered into USGS water use data bases. Additional data are collected on ground water wells with water use data including well depth, location and aquifer, so that ground water use can be characterized by aquifer.

Maximum monthly use was determined for each BWA water use site, as the greatest monthly use for each site during 2003. The full allocation amount was more difficult to determine. Each permit, certification or registration has an annual maximum allocation amount (generally in million gallons per year, which was converted into MGD for this analysis) associated with it, i.e., a maximum amount per year that withdrawals from all sites covered under the permit may not exceed. Additionally, the permits with high annual allocations may also have a monthly allocation that exceeds the annual allocation, i.e., a permit may have a monthly allocation amount that when multiplied by 12 is greater than the annual allocation. The higher monthly allocation allows for higher seasonal pumping, as long as the maximum annual allocation is not exceeded. The allocation amount, whether monthly or annual, is for withdrawals from all wells or intakes covered by the permit, certification or registration.

In instances where the full allocation includes more than one withdrawal site, the full allocation amount for each withdrawal site was determined by dividing the 2003 total annual withdrawal for a site by the sum of all 2003 total annual withdrawals for all sites covered by the permitted maximum allocation, and then multiplying that result by the maximum allocation (monthly or annual, whichever was greater) amount. This was necessary to proportion an allocation where the withdrawal was distributed over multiple subwatersheds. The full allocation data are summarized in the section "Summary of Full Allocation Ground and Surface Water Data", but were not used for the net water availability analysis which focused on examining the baseflow impacts of actual monthly demand.

The Council estimated domestic use by identifying those areas served by a potable water utility and assuming households outside such service areas were reliant on domestic wells. Population estimates within these areas were also refined using 2000 census data and incorporating a value of 100 gallons per person per day to account for ancillary water uses and seasonal variations.

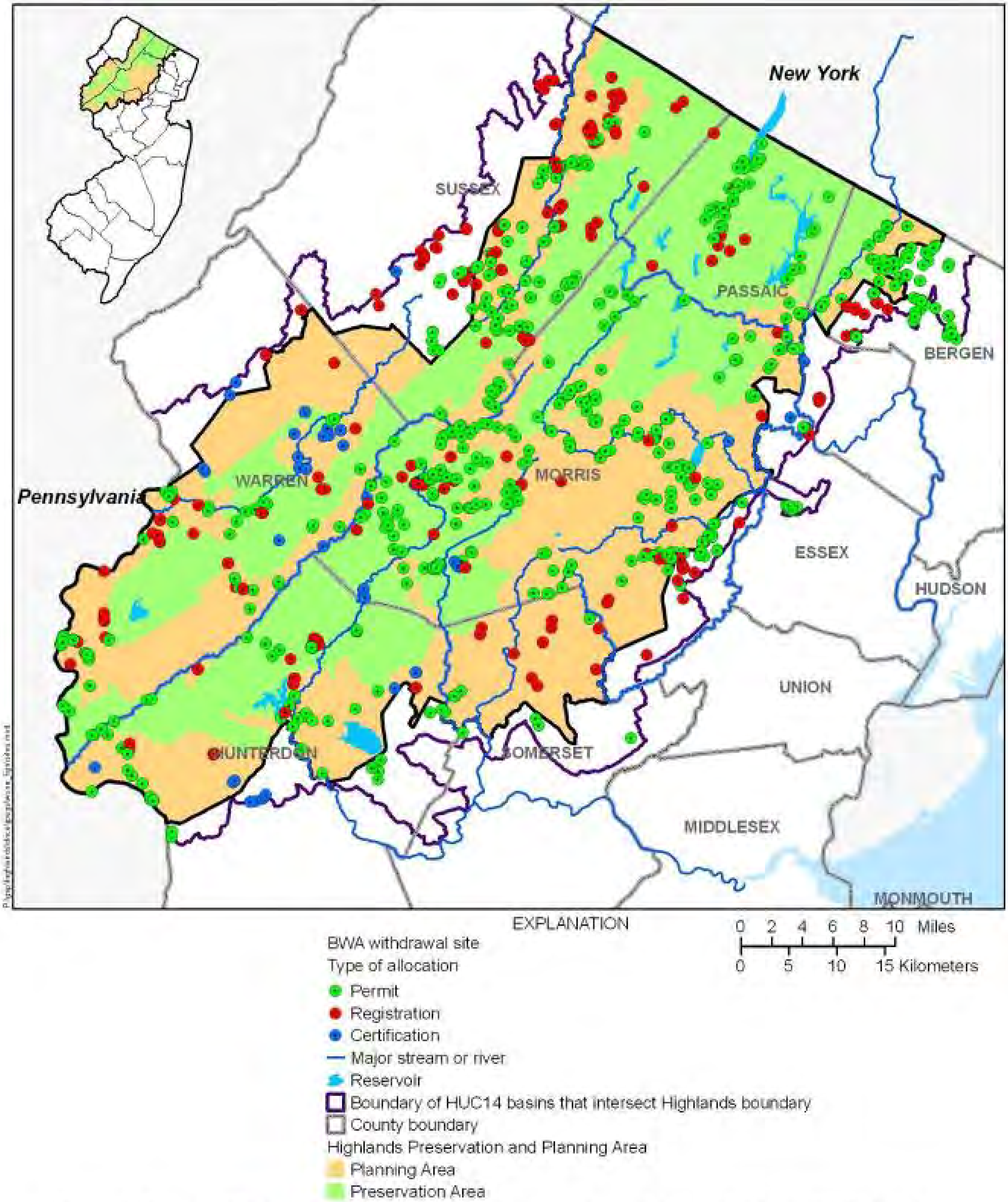
Surface water discharges to Highlands streams from wastewater treatment plants, i.e., sewer returns were also examined. These discharges were reported accordingly to the NJDEP Division of Water Quality under National Pollution Discharge Elimination System (NPDES) regulations. The NJDEP (2006b) has published a 1994 to 2004 annual summary of the State discharges.

A series of estimates for total and consumptive and depletive water uses by HUC14 subwatershed were developed based on 2003 water use statistics available from NJDEP. Water use data is summarized as follows in Appendix C:

- Total Water Use by Use Type- Maximum Month in MGD
- Ground and Surface Water Use by HUC14 – Full Allocation Volumes in MGD

The water use estimates calculated for each HUC14 include:

- Total (surface and ground water) water use by type
- Maximum monthly total consumptive/depletive use (surface and ground water)
- Full allocation use for surface and ground water separately



Bureau of Water Allocation Allocated Withdrawl Sites within The Highlands HUC 14 Basin Boundary

TOTAL WATER USE WITHIN THE HIGHLANDS REGION

The Highlands Region generates in excess of 864 million gallons of water daily (MGD), to meet the needs for potable drinking water, industry and agricultural uses. The Highlands is home to the State's major reservoir systems providing water to urban and suburban areas of northern and central New Jersey. Each day, the Region provides as much as 764 million gallons of potable drinking water to residents both within the Highlands Region and those areas served by Highlands-derived water. The reservoir systems that supply water to major urban areas outside the Highlands account for the vast majority of potable use, approximately 630 MGD of the total volume consumed.

During 2003, the reservoirs in the Highlands Region provided 115 billion gallons of drinking water to meet the public water supply service demand for the greater New Jersey Metropolitan Area, as well as portions of Middlesex, Mercer, Burlington, Camden and Gloucester Counties (see figure *Areas Served by Highlands Water*). The 2003 maximum monthly water use summary data, including volumes and percentage of water use by type is summarized in the table entitled *Highlands Water Uses by Use Type.* The figure titled *Total Water Use by HUC14* illustrates the distribution of water use throughout the Highlands Region.

Potable water supplies used within the Highlands Region are primarily ground water withdrawals, and account for approximately 134 MGD or less than 18% of total potable use. Residents of the Highlands Region get a large amount of their potable water supply, approximately 26 MGD, from private wells. Public non-community systems serving commercial establishments and institutions (e.g., hospitals and schools) withdraw close to 0.7 MGD. Agricultural uses within the Highlands Region accounts for almost 1.6 MGD, only 0.2% of maximum monthly water use.

Highlands Water Uses by Use Type

Use	Use Type	2003 Maximum Monthly Use (Million Gallons Per Day, MGD)			
		MGD	Percent	MGD	Percent
Potable Supply	Domestic	25.78	3.0%	763.97	88.4%
	Reservoirs and Intakes	629.64	72.9%		
	Public Community –GW	107.7	12.5%		
	Public Non-Community	0.68	0.1%		
	Institutional	0.11	0.0%		
Bottling	--	0.04	0.0%	0.04	0.0%
Industrial	Air Conditioning/Cooling	4.70	0.5%	14.69	1.7%
	Industrial	9.52	1.1%		
	Pollution Control	0.47	0.1%		
Commercial	Commercial	0.15	0.0%	0.22	0.0%
	Fire	0.07	0.0%		
Recreation	--	3.14	0.4%	3.14	0.4%
Irrigation	Golf	6.55	0.8%	6.93	0.8%
	Non-Agricultural Irrigation	0.39	0.0%		
Aquaculture	--	12.0	1.4%	12.00	1.4%
Agriculture	--	1.60	0.2%	1.6	0.2%
Power	Geothermal	0.02	0.0%	54.6	6.3%
	Hydroelectric	54.58	6.3%		
Mining	--	6.86	0.8%	6.86	0.8%
	TOTAL	**864**	**100.0%**	**864**	**100.0%**

The significant amounts of this water use is either consumptive, (i.e., transpiration by vegetation, incorporation during manufacturing, evaporation, or other diversion resulting in the water withdrawn not being returned to the basin of origin at the same quantity) or largely depletive, water that is exported from the subwatershed from which it was withdrawn. The most common depletive use is water that is collected in a sewage treatment system and discharged elsewhere, usually downstream. Both consumptive and depletive water uses reduce the amount of water available to sustain human activity and the integrity of water and water-dependent natural resources. This section also provides information on consumptive and depletive water uses, based on information available at the time this report was developed. The figure *Consumptive/Depletive Water Use by HUC14* illustrates the approximate total volumes of consumptive and depletive water use based on maximum month for each HUC14 within the Highlands Region..

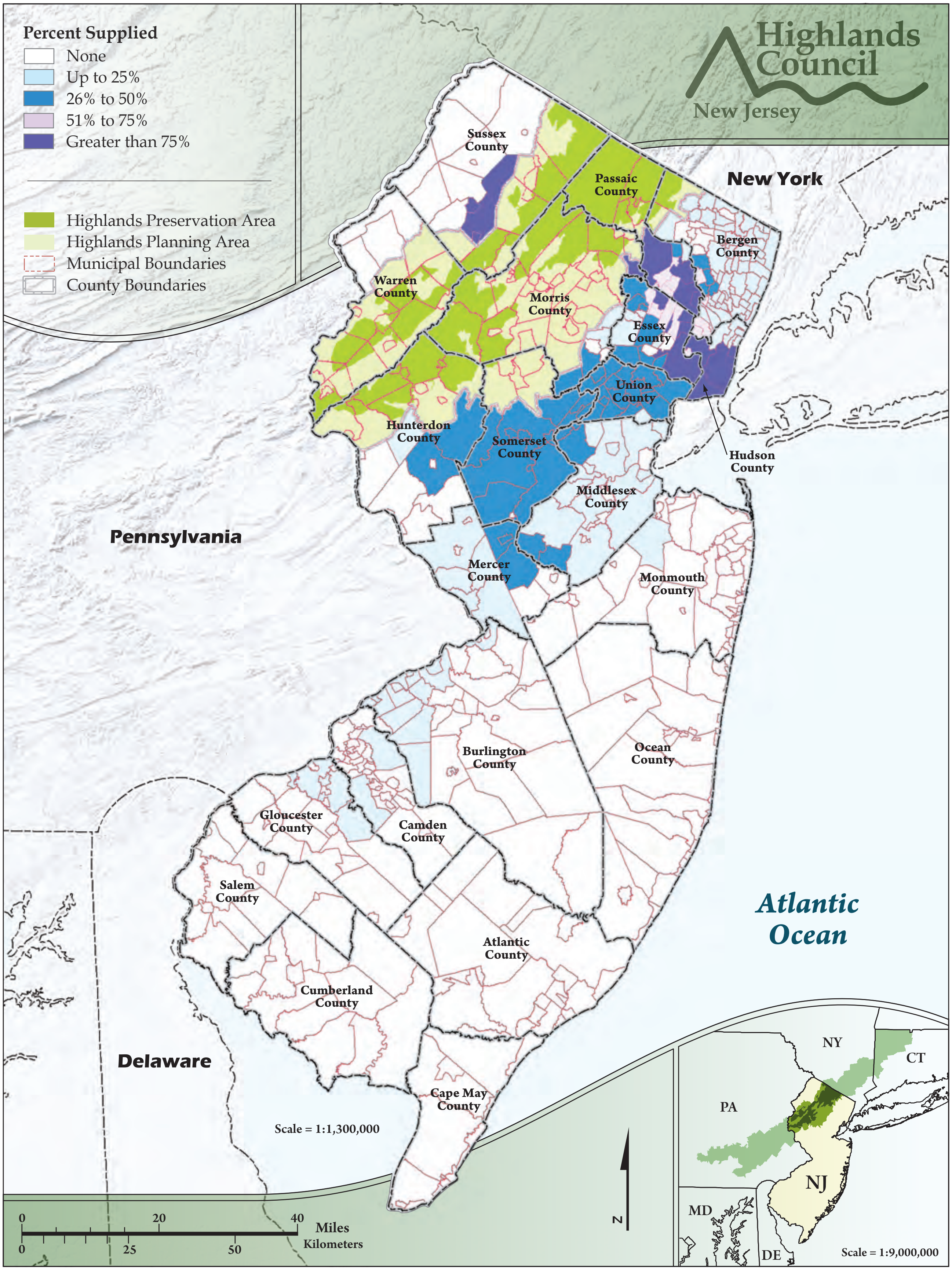
Total water use at maximum monthly volume, based on this 2003 BWA withdrawal data is estimated at 864 MGD being extracted from the water resources of the Highlands The subwatersheds that house major reservoirs and surface water potable supply intakes account for a large amount of this total use, with major withdrawals, constituting almost 630 of the 864 MGD supplying these potable water systems at maximum monthly rates. Maximum month volume data for ground water use was categorized by type, including total and consumptive potable supply, industrial, commercial and fire control, recreation, non-agricultural irrigation, aquaculture, agriculture, power and mining use, as shown in the table Total Water Use by Type and HUC14 - Maximum Monthly Volumes in MGD provided in Appendix C.

Potable supply data indicate a total domestic (self-supplied through private wells) ground water use of almost 26 MGD in the Highlands. With few exceptions (in more urbanized areas), wells are used for potable supply throughout the Highlands. In twenty HUC14 areas throughout Sussex, Passaic, Hunterdon and Morris counties, approximately quarter of a million gallons per day (0.25 MGD) are withdrawn through private wells. Public water supplied by wells totals almost 108 MGD, with 31 HUC14s each supplying more than 1 MGD for this purpose. The Troy Brook subwatershed is the largest public supply withdrawal area, at 8.3 MGD. Public non-community and institutional wells use significantly less ground water, approximately 0.7 and 0.1 MGD total for the Highlands Region, respectively.

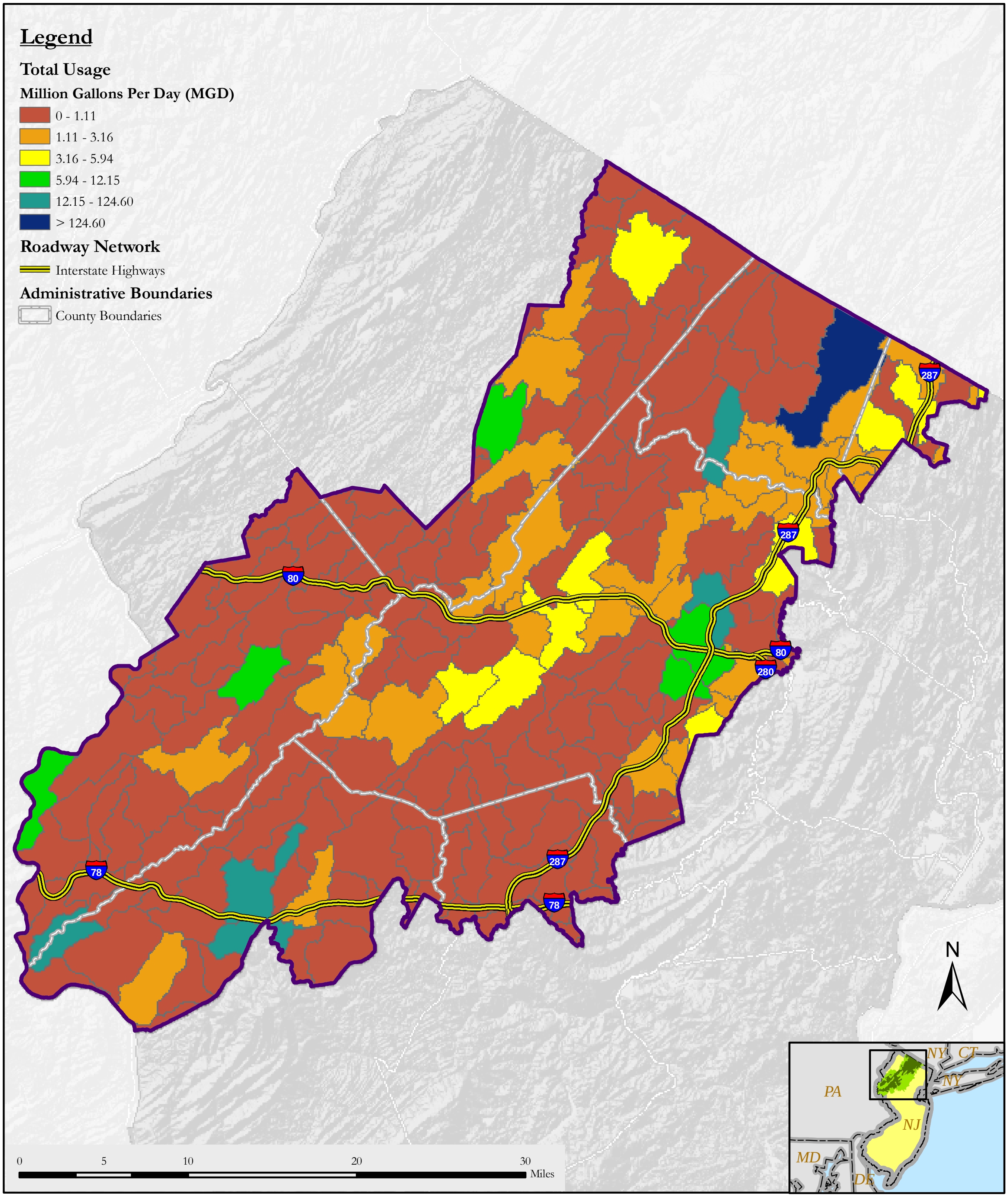
Industrial uses of ground water include actual industrial processing, water used for air conditioning and permitted pollution control withdrawals. Maximum month volumes for these types of use are estimated at 8.6, 3.8 and 0.5 MGD, respectively, totaling 12.8 MGD. Nineteen percent or just more than 2.4 MGD is assumed to be consumptively used. The largest industrial use is in a Musconetcong subwatershed (below Warren Glen) at 3.3 MGD.

Total commercial and fire control water use is estimated at 0.07 MGD across the region, half of that considered consumptive use. Recreational ground water use is almost half a million gallons per day, much of that from Great Gorge Resort. Approximately 0.01 MGD is consumptively used for recreational purposes.

AREAS SERVED BY HIGHLANDS WATER



Total Water Usage by HUC14 (2003)



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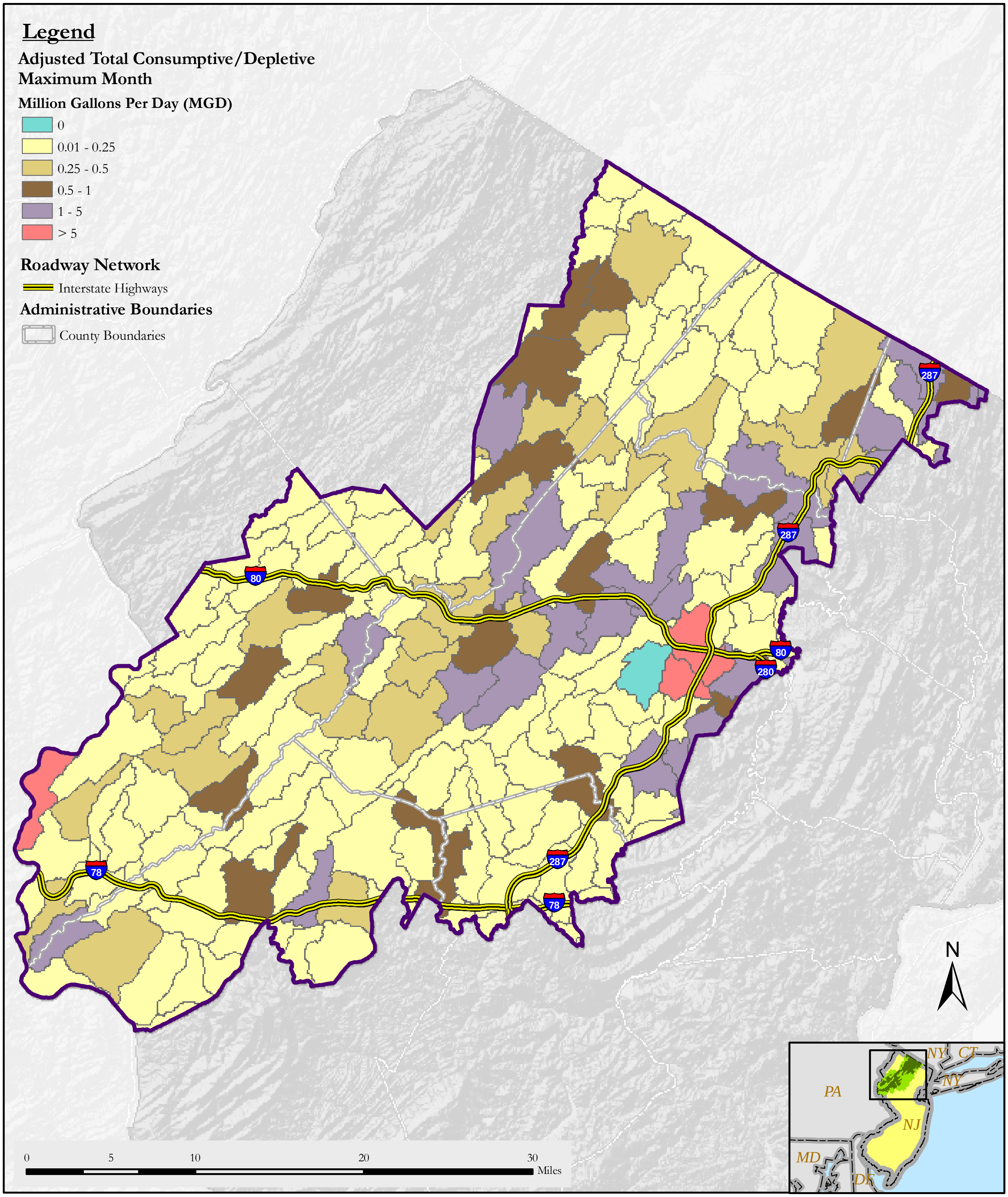
Regional Master Plan, July 2008

Highlands Council
New Jersey

Sources:
New Jersey Highlands Council, 2006

Consumptive/Depletive Water Use by HUC14



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Regional Master Plan, July 2008

Highlands Council
New Jersey

Sources:
New Jersey Highlands Council, 2008

Non-agricultural irrigation accounts for a total of 3.35 MGD, including golf course maintenance. More than half the total can be attributed to golf course irrigation in the Ramapo River (above Fyke Brook) subwatershed in Mahwah and the Wallkill River (Martins Road) subwatershed in Sussex County. Most of this water (2.7 of the approximately 3.4 MGD) is consumptively used. Agricultural ground water maximum month usage totals approximately half a million gallons per day (0.52), of which 0.42 MGD is considered to be consumptive use. The Pequest Hatchery is the only aquaculture user of ground water in the Highlands, totaling 12 MGD. Only 5% of this use is consumptive, as it is returned to the same subwatershed, if not the aquifer from which is it withdrawn.

Power generation uses less than 0.2 MGD ground water, with this use resulting from a geothermal facility located in the Wallkill River (Hamburg surface water body to Ogdensburg) subwatershed. Mining operations use approximately 0.8 MGD, withdrawn from the Green Pond Brook (below Burnt Meadow Brook), Sparta Junction tributaries, Buckhorn Creek and several other subwatersheds.

Total maximum month ground water use is estimated to be 164.4 MGD for all the types identified above. Of that total, 97.5 MGD are consumptive and depletive uses and not returned to the subwatershed from which it is withdrawn.

GROUND WATER USE BY HUC14

Ground water use was aggregated for each HUC14 by use type and is summarized in Appendix C. Overall, total BWA maximum monthly ground water withdrawals were 164.4 MGD for 2003 in the HUC14 subwatersheds that are within or intersect the boundary of the Highlands Region. The greatest total use occurs in a HUC14 subwatershed in the southwest Highlands. Most of the use in this basin comes from the Pequest Trout Hatchery, which pumps over 12 MGD in the maximum month. Additional subwatersheds with high ground water use are also found in the southwestern Highlands with large industrial and public supply use, and several others in Morris County where most of the ground water use is for public supply. Total domestic use for the HUC14 subwatersheds in 2002 was estimated at 25.8 MGD, out of the total potable ground water use for Highlands HUC14s of almost 134 MGD.

As discussed above, consumptive water uses were obtained by multiplying the use amount by a consumptive use coefficient representing the maximum annual consumptive use estimate by use type. When total ground water consumptive use, equal to 2003 BWA consumptive ground water use plus domestic consumptive use in Highlands HUC14 subwatersheds is examined, a difference is apparent when compared to total use.

SURFACE WATER USE BY HUC14

Surface water use was aggregated by HUC14 separately from ground water use data. This detailed water use data is provided Appendix C.

Maximum month surface water use by HUC14 subwatershed is shown in the previous figure Total Water Use by HUC14. Total BWA maximum monthly surface water withdrawals were just less than 700 MGD for 2003 in the HUC14 subwatersheds that are within or intersect the boundary of the Highlands Region, including withdrawals supporting potable supply reservoirs and intakes. Approximately 70 MGD of that total remains if the reservoirs and intake volumes are subtracted and considered separately, as was the case in this analysis and discussed in more detail below.

There were four HUC14 subwatersheds where surface water use exceeded 1 MGD, for other than reservoir and surface water intakes. The withdrawal for the Fibermark Plant is the largest among these, at 54.6 MGD at maximum month volume in the Musconetcong River (below Warren Glen) subwatershed. The three other subwatersheds have much lower, but still significant withdrawal volumes, ranging from 2.6 to 6.0MGD.

Industrial surface water use at maximum month volumes total approximately 2 MGD, with 0.2 MGD being consumptive. These withdrawals are in the Rockaway River (BM 534 to 74d 33m 30s), Furnace Brook, and Lamington River (above Rt 10) subwatersheds. Commercial and fire use is 0.15 MGD, half of that volume being considered consumptive use.

Recreational surface water use at maximum month volume is estimated at 2.64 MGD, withdrawn from the Black Creek subwatershed at the Great Gorge Resort. Golf and other non-agricultural irrigation volumes total 3.6 MGD, spread out over 36subwatersheds and ranging up to 0.48 MGD at the Pottersville gage on the Lamington River.

Agricultural surface water use at maximum month is just over 1 MGD spread over 14 subwatersheds, with 90% of that total (0.97 MGD) considered to be consumptive use. Hydroelectric power use totals 54.6 MGD, mining just over 6 MGD.

Total maximum month consumptive surface water use in the Highlands HUC14 subwatersheds is estimated at just less than 5.84 MGD.

As with public supply ground water, depletive uses would normally be estimated by HUC14, but not include reservoirs and surface water intakes for purposes of this analysis. The Council recognizes that these withdrawals, totaling almost 626 MGD are largely depletive, as most of the water is exported outside the basins of origin. However, they are regulated under passing flow requirements and as such are not considered in the net water availability analysis of this report.

SUMMARY OF FULL ALLOCATION GROUND AND SURFACE WATER DATA

Full allocation volume data for both ground and surface water use was aggregated separately by type and HUC14. (See Appendix C). Total ground and surface water use at full allocation (including reservoirs and surface water intakes) is estimated at greater than 2,814 MGD.

Potable ground water use at full allocation, was estimated at more than 157 MGD. Potable surface water use at full allocation is approximately 3.6 MGD.

Forty one HUC14s have ground water potable use withdrawals at full allocation exceeding 1 MGD, with major permitted withdrawals within the Loantaka Brook, Malapardis Brook, Black Brook, Troy Brook, Rockaway River, Beaver Brook, Pequannock River, Pompton River, Lamington River, Upper Delaware tributaries, Lake Hopatcong and Musconetcong River tributary subwatersheds, among others.

Ground water industrial use at full allocation is estimated at greater than 22 MGD (10 MGD greater than the maximum month use estimate), with 29 subwatersheds having industrial withdrawals ranging up to 3.3 MGD in the Upper Delaware tributaries (Route 22 to Buckhorn Creek) subwatershed. Industrial ground water use approaches 3 MGD in the Musconetcong (below Warren Glen) and Black Brook (Hanover) subwatersheds as well. Ground water commercial and fire surface water full allocation withdrawals total more than 0.4 MGD.

Recreational ground water use at full allocation is estimated at almost half a million gallons per day. Non-agricultural irrigation ground water use at full allocation totals approximately 4.4 MGD. Aquaculture full allocation ground water use is almost 10.3 MGD, as a result of an allocation to the Pequest Hatchery. Ground water total agricultural use at full allocation is 5.4 MGD. Water use for power generation at full allocation totals 0.1 MGD from ground water sources. Mining-related water use at full allocation is 2.8 MGD from ground water.

Surface water industrial use at full allocation is estimated at 1.9 MGD, withdrawn from only two subwatersheds. A total of 0.4 MGD is available at full allocation in the Rockaway River (BM 534 bridge to 74d 33m 30s) and almost 1.5 MGD withdrawn from Furnace Brook.

Surface water commercial and fire withdrawals at full allocation total 0.3 MGD. Surface water recreational use is greater than 10 MGD, resulting from withdrawals from the Black Creek subwatershed below Great Gorge Resort. Non-agricultural surface water use at full allocation for a total of 36 permitted withdrawals is approximately 6.2 MGD. Surface water agricultural use is 9.8 MGD.

Surface water use for power generation is much greater than ground water, at almost 303 MGD from withdrawals in the Musconetcong (below Warren Glen) subwatershed. Mining-related water use at full allocation is 18.6 MGD from surface water sources.

DEPLETIVE WATER USES AND WASTEWATER RETURNS

Ground and surface water exports (also known as depletive uses) reduce base flow beyond the effects of consumptive uses, while imports of water and/or wastewater can add to base flow during critical periods. Therefore, all need to be accounted for to determine Net Water Availability.

Developing an understanding of these impacts requires a detailed knowledge of how withdrawals are linked to water supply service areas, how water supply service areas are linked to wastewater service areas, and how the wastewater service areas are linked to effluent discharges. While each wastewater service area generally has a single discharge point, many water supply service areas have multiple water sources (e.g., well fields, purchases from other water purveyors, combined reservoir/well field operations).

Although both the withdrawal and discharge points are known, the array of connections between systems is complex and not fully understood at this time. Information has been collected to identify where development is served by public wastewater systems and public water system. The discharge site locations and discharge data were obtained from the NJDEP. There were 34 subwatersheds with sewer return sites in the Highlands Region that discharged water to streams in 2003. Water and wastewater transfers can have major impacts on net water availability.

With all water use types except for public water supply, it is assumed that the withdrawal of water, the use, and the return of the non-consumptive portion occur in the same subwatershed. For example, an agricultural user will typically be irrigating fields relatively close to the well. Subsequently, all use types except public water supply only have a consumptive use, and no depletive use. This may not be true in all instances, but since only public water supply is typically conveyed through water mains that may transfer water great distances, it is a reasonable assumption.

Therefore, public water supply use has both a consumptive and depletive amount associated with it; these values however, are reported as a single combined total.

RESERVOIRS AND SURFACE WATER INTAKES

As stated earlier, the Highlands is home to major reservoir systems providing almost 700 million gallons of potable drinking water daily to urban and suburban areas of northern and central New Jersey. Each day, the Highlands Region provides this volume of water to residents both within the Highlands Region and those area served by Highlands water. The extent and importance of these water demands requires action to ensure adequate water supplies, while protecting the Region's ecological resources.

Surface water withdrawals reduce stream flow and affect the ecological integrity of a stream. The greatest surface water withdrawals in the Highlands are taken for potable use from its water supply reservoirs (see figure *Reservoir Watersheds,* and table *Highlands Reservoirs, Storage Capacity, Total Safe Yield, and 2003 Withdrawals*) The Highlands reservoirs are especially important because of their ability to store water for use at critical times, such as a prolonged drought.

The ability of reservoir storage capacity to provide sufficient supplies for such critical times is expressed as a reservoir's "safe yield." Safe yield is defined as the yield maintainable from a reservoir continuously throughout a repetition of the most severe drought of record, after compliance with requirements for minimum passing flows, assuming no significant changes in upstream depletive withdrawals (modified from NJDEPE, 1992).

The impacts of surface water diversions from reservoirs and potable water supply intakes on stream flow are not straightforward. Reservoirs divert and store most of their water for storage during times of high stream flow, so they may reduce high flows in streams downstream of the reservoirs. Reservoir operations may permit normal flow, with no diversions during any stream flow conditions when reservoirs are full, and can constrain stream flow during low stream flow conditions when inflow to the reservoir helps maintain its safe yield.

Another complicating factor in examining a reservoir's and/or intake's impact on stream flow is any passing flow or flow augmentation requirement for the stream. In the case of some reservoirs, flow augmentation may increase stream flows above levels that would otherwise occur without such augmentation during severe dry periods. Flow augmentation is the transfer of water to a stream to meet a passing flow discharge at a specified location or locations. Passing flows represent the minimum volume of water that is required to flow past a specified point in a river or stream at a specified time which may cause a cessation of withdrawal or release of storage to augment flows during low flow periods. Some passing flows for reservoir systems are statutory. Some are implemented through water allocation permits, with differing legal requirements attached to each. These passing flows may be modified (usually by lowering them) during drought emergencies, which are declared by the Governor. This modification is allowed to assure an adequate potable water supply, and can be at the short-term expense of aquatic ecosystem viability.

The Wanaque System includes the Wanaque and Monksville Reservoirs, owned by the North Jersey District Water Supply Commission. These reservoirs receive water from the Wanaque River, whose flow can be supplemented by releases from Greenwood Lake during drought emergencies. The reservoirs have a combined storage capacity of 36 billion gallons and a combined safe yield of 94 MGD. The Wanaque Reservoir, at 29 billion gallons, is the second largest in New Jersey. All flow in excess of the 10 MGD passing flow requirement for the Wanaque River below the Wanaque reservoir can be stored in the reservoirs. The reservoirs are also filled from two pump stations on other rivers. The first is on the Ramapo River near Pompton Lake, which can deliver up to 150 MGD with a passing flow requirement of 40 MGD on the river below the pump station. The second is on the Pompton River at Two Bridges, which can provide 250 MGD to Wanaque Reservoir with a passing flow requirement of 93.5 MGD on the Passaic River downstream of the pump station. In both cases, the passing flows require that pumping be stopped at any river flow below that level; augmentation of flow is not required. The additional water that can be diverted to Wanaque Reservoir from the Ramapo and Pompton Rivers adds 79 MGD to the Wanaque system's safe yield. Total safe yield for the Wanaque system is 173 MGD (NJDEPE, 1992). Total water withdrawals from the Wanaque system reservoirs in 2003 (which was not a drought year) were 147.4 MGD, which is 25.6 MGD less than the safe yield of the Wanaque system.

The Newark System reservoirs provide the potable supply for the City of Newark and several other municipalities. There are five reservoirs in the Newark System with a combined storage capacity of 14.4 billion gallons and a combined safe yield of 49.1 MGD. The reservoirs are filled by flow from the Pequannock River and its tributaries. Reservoir releases can be directed to the Charlottesburg Reservoir where the water is withdrawn for Newark's potable supply. A passing flow requirement of 12.3 cubic feet per second (CFS) or 7.95 MGD for the Pequannock River below the Charlottesburg Reservoir has recently been added as a BWA permit condition for the Newark System reservoirs (NJDEP, 2004a). In 2003, 42.3 MGD was diverted from the Charlottesburg Reservoir of the Newark System for distribution, approaching the safe yield of the system.

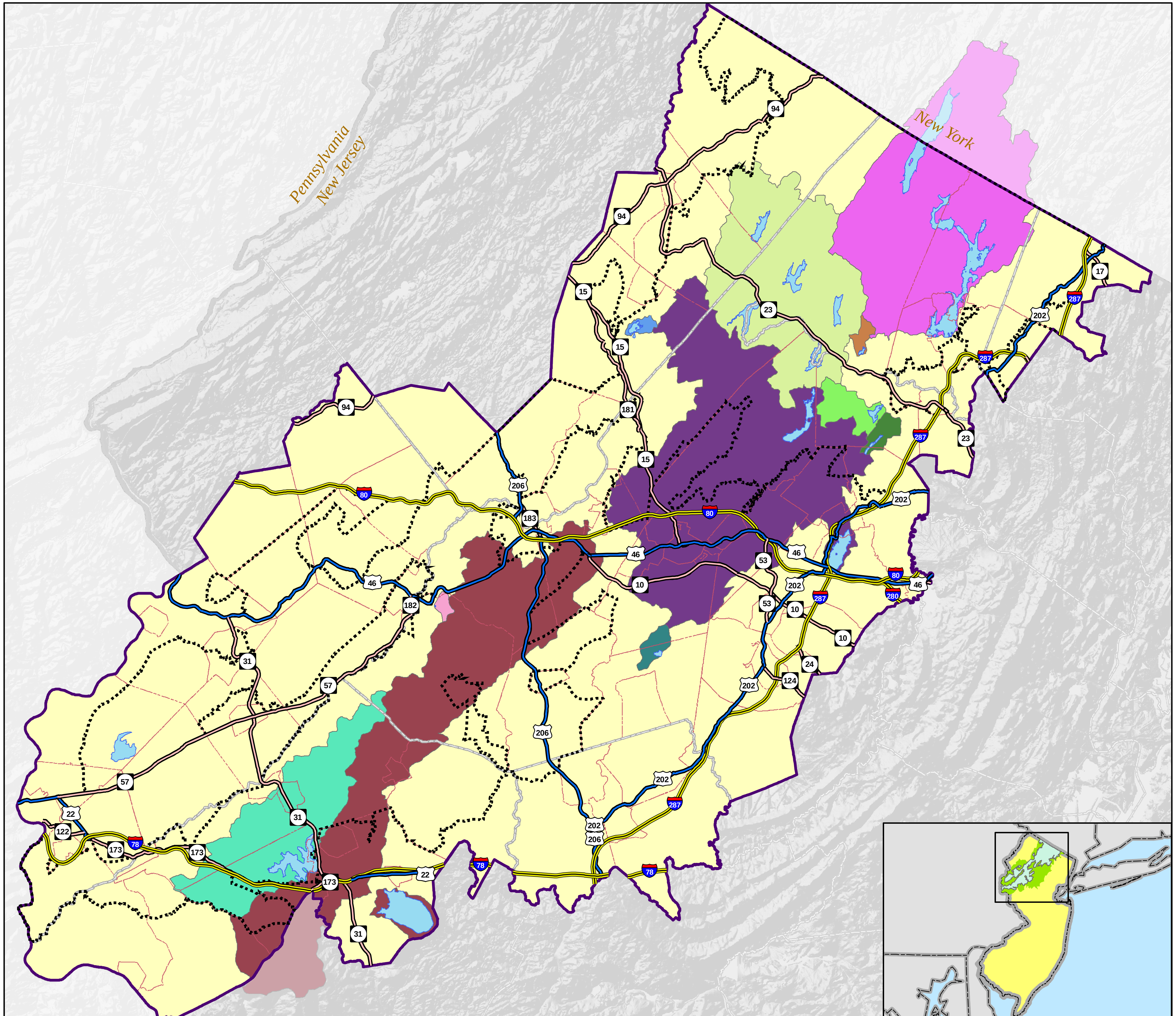
The Jersey City System reservoirs are Splitrock and Boonton. Splitrock Reservoir is upstream of the Boonton Reservoir and serves as an emergency supply reservoir, storing reserve water that can be released to the Boonton Reservoir during times of low stream flow. Boonton Reservoir is the primary reservoir in the system, and is the direct source of Jersey City's potable water supply. The combined storage capacity of both reservoirs is 11.5 billion gallons, while the combined safe yield is 56.8 MGD. There are passing

flow requirements for both Splitrock and Boonton Reservoirs. Passing flows of 5 MGD in Beaver Creek below Splitrock and 7 MGD in the Rockaway River below Boonton are required (NJDEPE, 1992). Water withdrawals from Boonton Reservoir in 2003 averaged 49.8 MGD. This amount indicates that like the Newark system, water use in this system is approaching the safe yield.

The Raritan Basin System reservoirs, Spruce Run and Round Valley are used to augment the flow of the Raritan River for downstream users. Flow augmentation is the transfer of water to a stream or river to meet a required passing flow discharge at a specified location or locations on that stream or river. Releases from Spruce Run and Round Valley Reservoirs are used to augment flow in the Raritan River to meet the passing flow requirements at two locations (Stanton Station and Manville – both outside of the Highlands Region) upstream of New Jersey American's intake on the Raritan River, and at Bound Brook, downstream of the intake, plus any necessary flows to meet customer demands. A total distance of about 28 miles of the Raritan River has its flow augmented with water from these reservoirs. Flow augmentation of the Raritan River is necessary because New Jersey American Water Company withdraws a large amount of water from the river for public supply, above naturally available levels. In 2003 they withdrew 112 MGD. Total system safe yield for these two reservoirs was previously calculated at 160 MGD, as part of a total Raritan Basin System safe yield, with the Delaware & Raritan Canal, of 225 MGD (NJDEPE, 2002). Recent modeling (Shallcross, 2005) now calculates the total Raritan Basin System safe yield as 241 MGD.

Spruce Run Reservoir is filled naturally by impounding the flow of Spruce Run Creek. It has a passing flow requirement of 5 MGD to Spruce Run. Round Valley Reservoir was created by damming a small valley on a hilltop above the South Branch Raritan River, has a small natural basin, and is filled mainly by water pumped up to it from the South Branch Raritan River (New Jersey Water Supply Authority, 2000; Shallcross, 2005). Round Valley Reservoir's storage capacity is 55 billion gallons, the largest of any Highlands (or New Jersey) reservoir. The storage capacity of Spruce Run is 11 billion gallons, third largest in New Jersey. The operation of the Raritan Basin System reservoirs requires careful consideration when examining water use. The water is diverted during high flows into these reservoirs to fill them, and then water is released from them for flow augmentation.

Spruce Run Reservoir is the preferred reservoir to use for releases since it fills naturally - there is no operational cost for diverting water into the reservoir. The total water released from Spruce Run Reservoir in 2003 was 4.8 billion gallons (13.2 MGD). However, 5.6 billion gallons was retained in the reservoir in 2003 to increase storage (Shallcross, 2006). There was no water released from Round Valley Reservoir in 2003. That year had above average precipitation and the flow augmentation needs for the Raritan Basin System were met with only releases from Spruce Run Reservoir. However, 5.8 billion gallons of water were diverted to Round Valley Reservoir in 2003 from the South Branch Raritan River at Hamden to replenish depletion from the 2001-2002 drought (Shallcross, 2006). The water released



Reservoir Watersheds

Legend

Reservoirs

Reservoirs

Reservoir Watersheds

Boonton
Kakeout
Butler
Clyde Potts
Mine Hill
Morris Lake
Newark Reservoirs
Round Valley
Spruce Run
Taylortown
Wanaque/Monksville

Roadway Network

Interstate Highways
U.S. Routes
State Routes

Administrative Boundaries

County Boundaries
Municipal Boundaries

Highlands Boundary

Highlands Planning Area
HighlandsPreservationArea

Source:
New Jersey Highlands Council, 2008

N

0 2.5 5 10 15 Miles

The information contained on this map is the best available according to the procedures and standards of the New Jersey Highlands Water Protection and Planning Council ("Highlands Council"). The Highlands Council is regularly maintaining the information in its databases and GIS layers in order to maintain the quality and timeliness of the data. However, unintentional inaccuracies may occur, particularly where data or information is derived from sources other than the Highlands Council. The Highlands Council has made every effort to present the information in a clear and understandable way for a variety of users. However, we cannot be responsible for the misuse or misinterpretation of the information presented herein. Therefore, under no circumstances shall the State of New Jersey or specifically, the Highlands Council be liable for any actions taken or omissions made from reliance on any information contained herein from whatever source nor shall the State be liable for any other consequences from any such reliance. Additional sources of information may include NJDOT, NJDEP, and USGS information work products.

Prepared By:
New Jersey Highlands Council
July 2008

Highlands Reservoirs, Storage Capacity, Total Safe Yield, Average, Maximum Monthly and Full Allocation Water Use, and 2003 Withdrawals								
System	**Reservoir**	**BWA Permit Number**	**BWAUID**	**Storage Capacity (billion gallons)**	**Average Withdrawals**	**Maximum Monthly Use**	**Full Allocation Use**	**Total Safe Yield (MGD)**
NJDWSC	Wanaque Monksville	5094X	WARG78626	36	147.4	336.1	1677.4	173
Newark Water Dept.	Charlottesburg Echo Lake Clinton Oak Ridge Canistear	5123	WSIN74436	14.4	42.3	46.3	58.1	49.1
Jersey City Water Dept	Boonton Splitrock	5268	WSIN74194	11.5	49.9	53.8	86.6	56.8
Raritan Basin	Spruce Run Round Valley	4007PS 4008PS	WSYT77792 WSIN73343	66	31.4	185.3 [1]	494.1 [1]	160
SE Morris County MUA	Clyde Potts	5310	WSIN75928	--	--	--	--	--
Hackettstown MUA	Mine Hill Burd	5145	WSIN75405 WSIN75406	-- --	0.67	0.97	0.81	--
Butler Boro Water Dept	Kakeout	5128	WSIN74163	--	1.17	1.65	4.08	6
Newton Town	Morris Lake	5225	WSIN74239	--	1.07	1.21	1.27	--
Boonton Town	Taylortown	5109	WSIN75805	--	0.45	0.56	1.13	1.5

[1] Flow augmentation reservoirs used as necessary with water released from storage, do not reflect end use

MGD, million gallons per day; --, data not available from Spruce Run helped meet the passing flow requirements on the Raritan River and was a part of the 112.1 MGD withdrawn from the Raritan River by Elizabethtown Water Company (now operating as NJ American Water Company) in 2003.

Besides the major reservoir systems, there are six other water supply reservoirs in the Highlands Region, including Clyde Potts, Upper and Lower Mine Hill, Kakeout, Morris Lake, and Taylortown. Withdrawals from these reservoirs totaled 3.5 MGD in 2003.

Only a small portion of the potable water supplied by the major reservoir systems is used within the Highlands Region, as most is exported to other areas of the State. The needs of Highlands residents and municipalities are largely met through withdrawals from ground water wells tapping local aquifers and with some smaller surface water sources.

DATA LIMITATIONS

Water use data would seem to be straightforward volume measurements, with few limitations. However, the data are actually very complicated and their limitations need to be understood when working with the data set. The BWA data are reported by the users. They may have direct information on the quantity of water – as collected from a water meter that can give them a direct reading for the volumes used. Other users may be able to only indirectly estimate the amount of water used by using the time a pump operating at a specific pump volume, or even more remotely measured by the amount of electricity used by a pump to estimate the amount of water pumped in a given time period. The reporting of the data is subject to inaccuracies in the estimation of water use. Sometimes water is used but no amount is reported. USGS carefully reviewed all water use data it received using an established quality assurance process to help eliminate errors related to the use reporting. However it is still possible there are limited reporting errors in the data set.

Another important aspect of water use data is where the use occurs. The site information associated with the water use data is important to the accuracy of the water capacity analysis. The public supply use sites generally have the best location data, as most wells and surface water intakes have global position system (GPS) coordinates. The locations of many other sites have been manually determined, with coordinates taken from topographic maps or state atlas sheets and may have significant error associated with them. All Highlands water use site locations were reviewed for accuracy and adjusted as needed. However, it is possible that some sites still have inexact locations.

The water use data reported here includes BWA permitted water use and estimates of domestic water use. There is a third type of water use data not reported, i.e., the non-permitted, non-domestic use. Examples of this type of use would be water from a well that supplies a day care center or convenience store. These uses would be less than 100,000 GPD, the volume requiring a BWA permit. In the Highlands Region there are hundreds of these types of sites. This 100,000 GPD threshold was reduced to 50,000 gallons per day in the Highlands Preservation Area, but the 2003 data predate the Highlands Act. Many of these uses may be regulated as a public non-community water supply which requires the facilities to meet drinking water standards but not to report water use. The U.S. Environmental Protection Agency Safe Drinking Water Information System (SDWIS) web site for New Jersey can be found at:
http://oaspub.epa.gov/enviro/sdw_form.create_page?state_abbr=NJ.

Limited information on such sites, including site name, county in which it is located, and population served is provided at this site. It is possible to view the SDWIS sites by range of population served. The "Very Small" range of population served is 0-500, and most of the sites in this range would not have an allocation permit. The water use sites in this range for Morris County were examined to assess the ability and level of effort required to address these non-permitted, non-domestic water use volumes in the ground water capacity analysis at this time.

Most of Morris County is located in the Highlands Region. There are 324 SDWIS sites in this range in Morris County, but some of these are also BWA sites. To sort out the permitted from non-permitted sites and their locations would be difficult. More difficult would be to develop water use estimates for these sites, as they are neither monitored nor metered. The SDWIS data set is useful for identification of non-permitted water use sites, but it would be impractical to apply this data set to the water capacity analysis. It should be recognized that there is water use that is not included in the analysis.

The consumptive use estimates are prepared by multiplying a water use amount by a consumptive use coefficient. The limitations of these estimates are threefold. The first limitation is the accuracy of the initial water use amount. The second limitation is the determination of the type of use. For example, a school would normally be considered an institutional use type with a consumptive use coefficient of 29%. However, that same school may use the water for irrigating its athletic fields - which would have a consumptive use coefficient of 90%. The accuracy of the use type for each use site then becomes a limitation. The third limitation is the accuracy of the use of the established consumptive use coefficient itself. The availability and numeric values of these coefficients vary widely in the scientific literature. Even for those water uses for which coefficients are available, they are usually provided with a caveat that they are rough estimates only and additional research is necessary to determine accurate coefficients, much less estimates of consumptive water use. Finally, a distinction can and should be made between consumptive use coefficients that reflect annual average or seasonal maximum levels, depending on the analysis required. As discussed above, the Highlands Council used seasonal maximum values to better reflect the peak demand period that most closely corresponds to the period of lowest stream flow.

WATER CAPACITY WITH APPLICATION OF WATER USE STATISTICS

A series of two ground water capacity maps were developed to highlight the results of the Low Flow Margin method to estimate ground water capacity as it relates to water use, showing the remaining capacity after applying preliminary current ground water use data. (See figures *Ground Water Capacity Defined As The Low Flow Margin Minus Maximum Monthly Consumptive Ground Water Use* and *Ground Water Capacity Defined As The Low Flow Margin Minus Total Ground Water Use.*

These figures do not provide the actual results for water availability, as they only incorporate preliminary estimates of consumptive ground water use and several additional steps are needed to determine water availability as will be discussed in latter sections of this report. They do, however, illustrate how water use data can be used in the overall analysis of water availability for various water statistics including:

- Maximum monthly consumptive ground water use;
- Total ground water use.

In addition, the table *Summary Statistics of Selected Discharge and Capacity Values* provides a summary statistics for the comparison of water capacities under various ground water withdrawal scenarios for several alternative low flow statistical methods. As can be seen from this preliminary analysis, there is limited capacity for the natural and current built infrastructure of the Highlands Region to support additional water withdrawals. Numerous HUC14s are indicated as having current ground water withdrawal, at or near sustainable thresholds, representing a chronic stress on the system.

SELECTION OF WATER USE ESTIMATES FOR CALCULATING WATER AVAILABILITY

A variety of water use estimates were evaluated for use in calculating water availability including total use, full allocation, and consumptive/depletive use at monthly maximum volume. The use of maximum month consumptive/depletive use is considered the best indicator of stress on Highlands water resources for purposes of estimating water availability Ground Water Availability (ground water capacity expressed as low flow margin minus water use) represents the volume of water beyond current use (if any) that can be reasonably available within the HUC14 for future use by either human or ecological needs.

Using total water use is inappropriate because not all water use results in ground water or stream flow stresses. In addition, total consumptive ground water use does not recognize the seasonality of water use and the potential for maximum use periods to place greater stresses than annual average uses on the system during its most critical period. Finally, full allocation consumptive use reflects a speculative future that may not be supported by the Regional Master Plan. However, there is some value to inventorying the potential use if current allocation permits were fully utilized.

Total water use has some potential use if one assumes that all water withdrawals are not returned to the same drainage area, and therefore are drains on the natural system. However, in areas with septic systems and other discharges to ground water, this would not necessarily be the result. In addition, not all withdrawals are entirely consumptive, and some portion of the water withdrawal may return to the water unit as recharge or discharge.

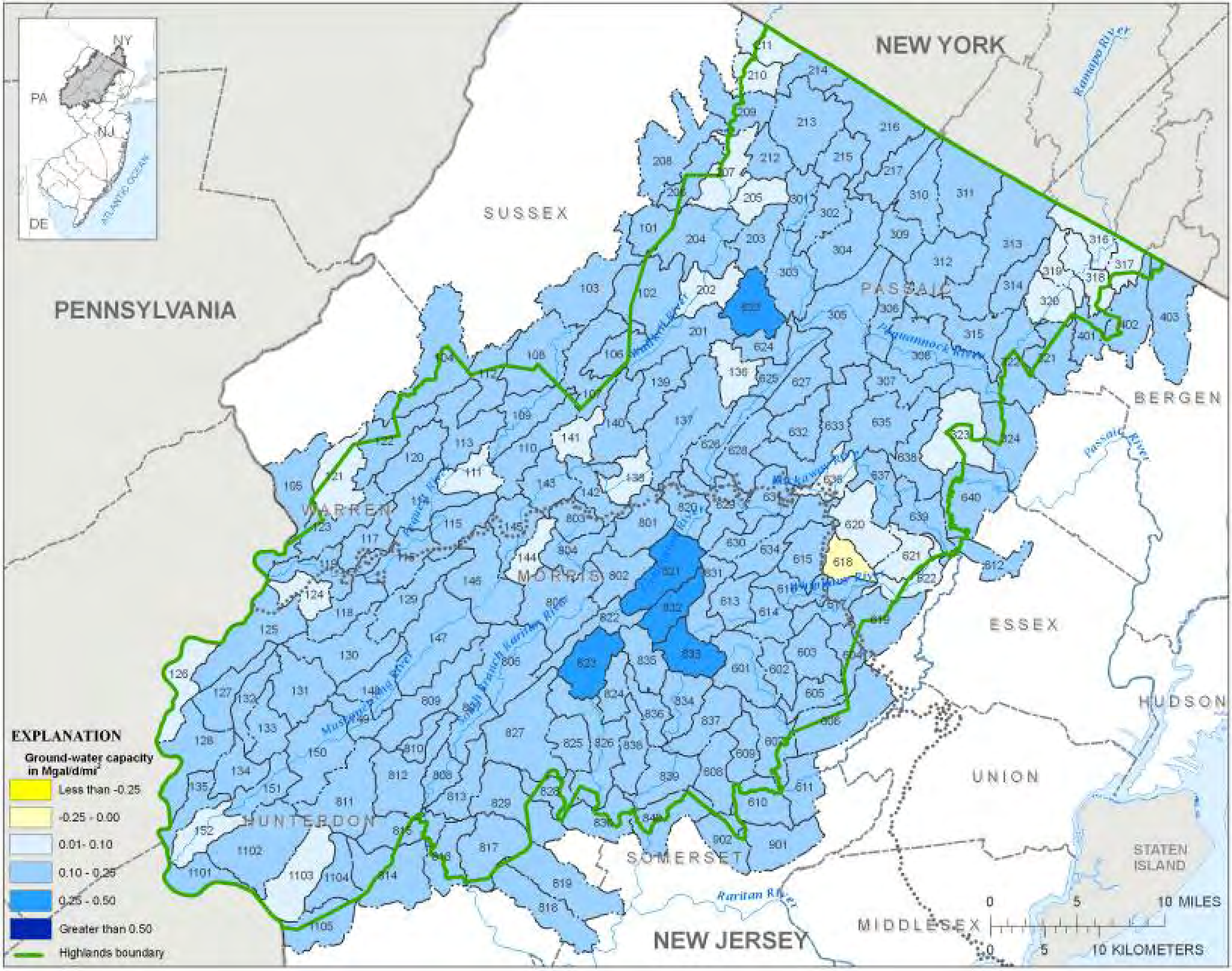
Total consumptive use is a useful indicator of stress on aquatic ecosystems and surface water uses, but has some limitations. It assumes that the impacts of water uses are spread across the year and that water use stresses do not vary from season to season, or that the impacts of water uses are primarily felt during seasons that pose the fewest stresses to other water uses (e.g., during periods when flows are commonly higher and both temperature and flow stresses on aquatic ecosystems are lower, such as the winter).

Water uses clearly vary from season to season, with summer typically being the highest use period for irrigation (both agricultural and lawns) and recreational water uses. Determining the timing of stream flow reductions based on the timing of withdrawals on a regional basis require development of more sophisticated models that are beyond the scope of this assessment. It is reasonable to assume that peak use periods for shallow wells near streams would most quickly affect stream flows, while deep, confined or semi-confined wells would have a longer lag effect between peak use and stream flow impacts. Because many Highlands wells are relatively shallow and close to streams, NJGS has found that the peak summer demands can affect stream flows in September (NJDEP, 2006c), which is already the month with the lowest average flows.

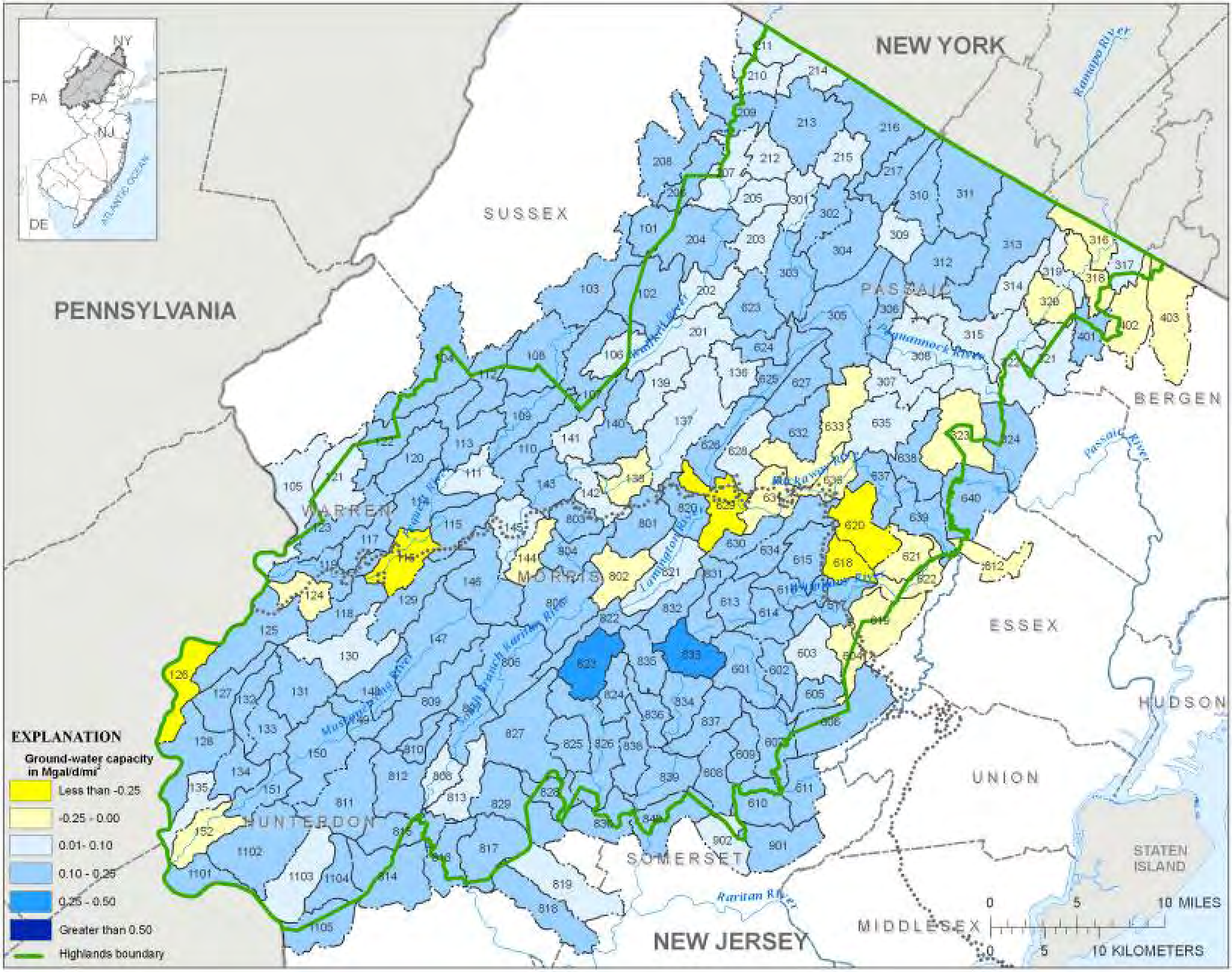
Because the base flow impacts of seasonal withdrawal variations cannot be estimated regionally, and yet are likely to affect stream flow relatively quickly, the use of the maximum month consumptive/depletive water use provides a conservative estimate of net ground water availability and was used by the Highlands Council in these analyses of water capacity and availability.

Use of the maximum month consumptive/depletive water use assumes that the maximum withdrawal will affect base flow almost immediately. The true value for net ground water availability may be somewhat higher but is not likely to be lower. Because maximum uses tend to occur in the summer, the period of maximum flow stress is generally in September, reflecting a lag effect.

There is a need for an adjustment factor for maximum month consumptive/depletive use, as most ecological impacts of ground water use relate to stream base flow reductions exhibited in the months of September and October. Both NJGS and USGS models indicate that flows in those months are related to periods of maximum withdrawal (generally July or August), with a lag effect.



Ground Water Capacity defined as the Low-Flow Margin Minus Maximum Monthly Consumptive Ground Water Use



Ground Water Capacity Defined by Low-Flow Margin Minus Total Ground Water Use

Summary Statistics of Selected Discharge and Capacity Values

Discharge or capacity statistic	N	minimum		25th percentile		median		75th percentile		maximum		mean	
		Mgal/d	Mgal/d/mi2	Mgal/d	Mgal/d/mi2	Mgal/d	Mgal/d/mi2	Mgal/d	Mgal/d/mi2	Mgal/d	Mgal/d/mi2	Mgal/d	Mgal/d/mi2
Base flow	183	1.12	0.2	4.45	0.65	5.87	0.74	7.86	0.83	16.24	1.16	6.6	0.73
BF_{10}	183	0.6	0.12	2.81	0.42	3.95	0.48	5.18	0.55	10.78	0.75	4.3	0.48
BF_{25}	183	0.41	0.08	2.3	0.34	3.29	0.39	4.28	0.45	8.98	0.69	3.55	0.4
Low flow margin	183	0.12	0.02	0.96	0.14	1.31	0.16	1.81	0.19	3.96	0.3	1.48	0.16
$GWC_{10}A$	183	0.58	0.12	2.77	0.41	3.89	0.47	5.07	0.54	10.7	0.74	4.22	0.47
$GWC_{10}B$	183	0.58	0.11	2.74	0.4	3.82	0.47	5.07	0.54	10.7	0.74	4.19	0.46
$GWC_{10}C$	183	0.56	0.1	2.65	0.4	3.75	0.46	5.07	0.53	10.66	0.74	4.13	0.46
$GWC_{10}D$	183	-3.61	-0.67	2.37	0.33	3.49	0.44	4.69	0.51	10.15	0.72	3.66	0.4
$GWC_{25}A$	183	0.39	0.08	2.28	0.33	3.11	0.39	4.17	0.44	8.9	0.69	3.47	0.39
$GWC_{25}B$	183	0.39	0.08	2.23	0.32	3.09	0.38	4.17	0.44	8.89	0.68	3.43	0.38
$GWC_{25}C$	183	0.38	0.08	2.16	0.32	3.07	0.38	4.12	0.44	8.85	0.68	3.38	0.37
$GWC_{25}D$	183	-4.54	-0.7	1.85	0.26	2.83	0.35	3.78	0.42	8.34	0.65	2.91	0.32
$GWC_{LFM}A$	183	-0.03	-0.01	0.89	0.13	1.24	0.15	1.74	0.18	3.92	0.3	1.4	0.15
$GWC_{LFM}B$	183	-0.24	-0.05	0.85	0.12	1.23	0.15	1.74	0.18	3.92	0.3	1.37	0.15
$GWC_{LFM}C$	183	-0.33	-0.05	0.79	0.12	1.23	0.14	1.74	0.18	3.83	0.29	1.31	0.14
$GWC_{LFM}D$	183	-7.52	-0.91	0.46	0.07	0.96	0.12	1.42	0.16	3.71	0.28	0.84	0.09

Note:

All values in Mgal/d/mi2; BF10, base flow at the 10-year recurrence interval; BF25, base flow at the 25-year recurrence interval; LFM, low flow margin calculated as the September median minus the 7-day 10-year low flow discharge; GWC10A, ground-water capacity calculated as BF10 minus consumptive ground-water use; GWC10B, ground-water capacity calculated as BF10 minus maximum monthly consumptive ground-water use; GWC10C, ground-water capacity calculated as the BF10 minus consumptive ground-water use projected at full allocation; GWC10D, ground-water capacity calculated as the BF10 minus total ground-water use.

Although annual base flow reductions are roughly equal to the annual consumptive/depletive use, the available ground water models indicate that the impact of the maximum month use on September flows is not 1:1, but roughly 1:0.9 (NJDEP, 2006c). Therefore, the consumptive use estimates for each subwatershed are adjusted to account for this effect (multiplying the USGS maximum monthly consumptive use estimates by 0.9).

Surface water consumptive/depletive withdrawals (other than from reservoirs) have the same impact on aquatic ecosystems as the consumptive/depletive use of ground waters. Unlike ground water uses, the effects are direct and immediate and so no adjustment factor is needed. The effects of reservoir withdrawals are more complicated because they come from storage during higher flow periods, rather than necessarily from stream flow, and therefore are addressed separately.

CALCULATION OF CONSUMPTIVE AND DEPLETIVE WATER USES

For the calculation of net water availability (further described in the next section), an estimation of the total maximum monthly consumptive and depletive water uses is required.

The fundamental approach in the estimation of consumptive and depletive water uses applies a simple water balance model to each subwatershed. Each reported withdrawal, whether ground or surface water, represents water out of the subwatershed. Each withdrawal has two components associated with it: 1) a consumptive portion, which is always "lost" (typically as evapotranspiration) to the subwatershed; and 2) a non-consumptive portion, which may be returned to the subwatershed, or may be transferred out to another subwatershed. The amount of water that returns represents water into the subwatershed. Water can also be imported in the form of wastewater. If the non-consumptive portion does *not* return to the original subwatershed, it is considered a depletive use (for public water systems only). The arithmetic difference between all ground water and surface water withdrawals minus all ground water and surface water inputs (whether as non-consumptive returns or wastewater returns) is the total consumptive and depletive use for the subwatershed.

Consumptive use is calculated by multiplying total water use by consumptive use coefficient factors for each water use type. The maximum monthly use volume, in combination with maximum annual consumptive use coefficients is then used to evaluate the effect the greatest ground and surface water withdrawals have on stream flow at a time when stream flow is lowest. With all use types except for public water supply, it is assumed that the withdrawal (water out) and the non-consumptive portion of the use (water in) occur in the same subwatershed. For example, an agricultural use will typically be irrigating fields relatively close to the well. Therefore, all use types except public water supply only have a consumptive use associated with it. No depletive uses are generated. This may not be true in all instances, but since only public water supply is typically conveyed through water mains that may transfer water great distances, it is a reasonable assumption.

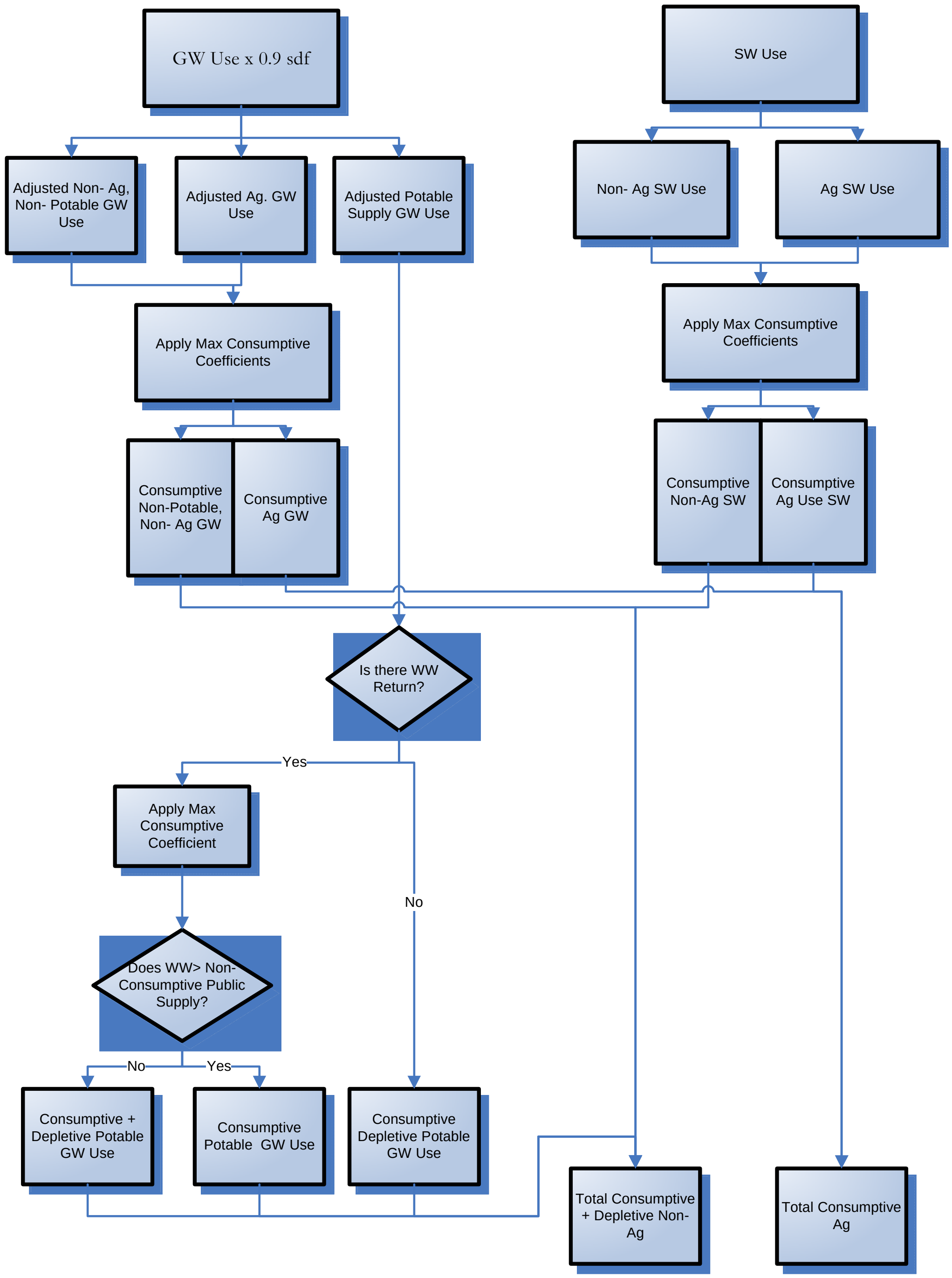
For public water supply uses, there is a potential for consumptive *and* depletive uses. To account for that effect, the wastewater return is compared against the non-consumptive portion of the public supply withdrawal. If there is no wastewater return (as a sewer discharge) within the subwatershed, then no water is returned and the non-consumptive portion is considered entirely depletive. If there is a wastewater return, that volume is assumed to be the non-consumptive portion returning through a public sewer discharge. However, no credit is given for a wastewater return exceeding the non-consumptive portion (i.e., no surplus of wastewater is created). Ultimately, a consumptive/depletive use for the public water supply uses is estimated as a single combined value, as there is no need to differentiate the relative fraction between consumptive/depletive amounts; they both represent a "loss" to the subwatershed.

The consumptive use coefficients (expressed as a percent of total water use) are for specific types of use, within general use group categories. The table *Types of and Percent of Consumptive Use Compared to Total Use Annually and per Month*, which is modified from Domber and Hoffman (2004), includes data from other sources of information regarding maximum consumptive use rates for various water use types, gives the percent of consumptive use for the types of use found within the Highlands. Preliminary analysis performed by USGS used annual average consumptive use coefficients. The Highlands Council, in cooperation with USGS and based on additional research, has derived and incorporated maximum annual consumptive use coefficients in subsequent analyses of consumptive water use volumes and water availability.

The Regional Master Plan also encourages agricultural sustainability, potentially resulting in rising demands for irrigation water. For these reasons, it is beneficial to consider agricultural uses separately. As described in the following section, a separate accounting of agricultural water availability is performed for Conservation Zone subwatersheds. It examines agricultural uses separately.

The calculation of consumptive and depletive is demonstrated in the following flow chart:

Calculation of Consumptive and Depletive Uses



Types of and Percent of Consumptive Use Compared to Total Use Annually and per Month

Use Category	Consumptive Use	Percent consumptive use												
		Maximum Annual	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Power	Geothermal heat pump	**1**	1	1	1	1	1	1	1	1	1	1	1	1
	Hydroelectric	**3**												
Mining	mining	**12**	12	12	12	12	12	12	12	12	12	12	12	12
Industrial	air conditioning	**10**	10	10	10	10	10	10	10	10	10	10	10	10
	dewatering	**0**	0	0	0	0	0	0	0	0	0	0	0	0
	Cooling industrial	**10**	10	10	10	10	10	10	10	10	10	10	10	10
	industrial	**10**	10	10	10	10	10	10	10	10	10	10	10	10
	injection	**0**	0	0	0	0	0	0	0	0	0	0	0	0
	pollution control	**10**	10	10	10	10	10	10	10	10	10	10	10	10
Commercial	commercial	**50**	0	0	0	0	27	41	49	50	32	14	0	0
	fire	**50**	50	50	50	50	50	50	50	50	50	50	50	50
	recreation	**3**	0	0	0	0	0	0	0	0	0	0	0	0
Potable supply	bottling	**80**	80	80	80	80	80	80	80	80	80	80	80	80
	domestic	**29**	0	0	0	3	15	24	29	24	15	8	0	0
	public non-community	**29**	0	0	0	3	15	24	29	24	15	8	0	0
	public supply	**29**	0	0	0	3	15	24	29	24	15	8	0	0
	institutional	**29**	0	0	0	3	15	24	29	24	15	8	0	0
Irrigation	golf	**90**	90	90	90	90	90	90	90	90	90	90	90	90
	nonag irrigation	**90**	90	90	90	90	90	90	90	90	90	90	90	90
Agriculture	aquaculture	**5**	5	5	5	5	5	5	5	5	5	5	5	5
	general agriculture	**90**	90	90	90	90	90	90	90	90	90	90	90	90
	greenhouse	**90**	90	90	90	90	90	90	90	90	90	90	90	90
	sod	**90**	90	90	90	90	90	90	90	90	90	90	90	90
	tree fruit	**90**	90	90	90	90	90	90	90	90	90	90	90	90
	vegetables, leaf crops	**90**	90	90	90	90	90	90	90	90	90	90	90	90

Note:

Modified from Domber and Hoffman, 2004 and other sources

METHOD FOR ESTIMATING GROUND WATER AVAILABILITY

This report has previous sections that described the Low Flow Margin method that was used to estimate Ground Water Capacity for each subwatershed. Ground Water Availability is defined as the portion of that is available for consumptive human use without harm to ecosystems of the Highlands. Net Water Availability is defined as the quantity of Ground Water Availability remaining after subtraction of all consumptive and depletive human uses.

Section 11.a.(1)(a) of the Highlands Act supports the necessity to determine the amount and type of human development and activity that the ecosystem of the Highlands Region can sustain while still maintaining the overall ecological values thereof, with special reference to surface and ground water quality and supply. The Act does not specify a method, and therefore a technically sound method is needed that addresses the intent of the Act using available information. The Highlands method for estimating Net Water Availability must include the following components:

- Definition of Ground Water Capacity that is applicable to each subwatershed within the Highlands Region;
- Determination of Ground Water Availability based upon potential variations in ecological water needs, for each land use capability zone. This determined what portion of Ground Water Capacity can be provided for human use;
- Identification of additional constraints on Ground Water Availability due to subwatersheds that are designated as a water availability deficit area, or as tributary upstream to a water availability deficit area;
- Estimates of maximum consumptive/depletive water uses for subtraction from total Ground Water Availability; and
- Modifications of Net Water Availability based on return of treated wastewater effluent to a stream.

The Low Flow Margin method provides a reasonable scientific approach available at this time for estimating capacity of ground water supplies to maintain both ecological flow needs and estimate sustainable levels of human consumption. Therefore, the computation of Ground Water Capacity was performed at a subwatershed level utilizing the Low Flow Margin method (Median September Flow minus 7Q10).

As discussed previously estimates of Ground Water Capacity for each subwatershed are adjusted by multiplying the Low Flow Margin by 1.02 to adjust for existing consumptive uses within reference drainage basins (2 percent of the Low Flow Margin) and for that portion of the HUC14 that occurs with the Highlands Region. These values are reported by subwatershed in the table *Ground Water Capacity by HUC14* located in Appendix D.

CALCULATION OF GROUND WATER AVAILABILITY

A key issue for water availability estimates is to what extent Ground Water Capacity should be made available for both current and future human uses. Here, it is important to recognize that the Highlands Act emphasizes that human water uses should be constrained by ecological needs. Therefore, only a portion of Ground Water Capacity is considered available for human use, with the majority being reserved for ecosystem integrity. That amount, called Ground Water Availability, is defined as the portion of Ground Water Capacity that is available for consumptive and depletive human use without harm to ecosystems of the Highlands Region.

Utilizing this method, Ground Water Availability is obtained by multiplying Ground Water Capacity by a percentage threshold, of water availability as shown below:

Ground Water Availability = (Ground Water Capacity)*(% Water Availability Threshold)

In the most ecologically sensitive HUC14 subwatersheds, Ground Water Availability should be severely limited to protect aquatic ecosystems and the related terrestrial ecosystems. For other HUC14s, a graduated scale is appropriately based on ecological values. HUC14s with concentrated development or agriculture and limited ecological constraints would be assigned a higher portion of Ground Water Capacity. To avoid having a highly complex system, few water availability thresholds should exist in the entire system.

Implementation of the Regional Master Plan is guided by a Land Use Capability Map that identifies geographic "zones" based on a comprehensive evaluation of resource constraints and development opportunity. The Land Use Capability Map identifies those resource constrained lands where development should be limited, and as such, where it is appropriate to reserve more water for ecosystem function in order to maintain ecological value. Therefore, the thresholds established in the calculation of Ground Water Availability are determined based on the corresponding zone of the Land Use Capability Map.

WATER AVAILABILITY THRESHOLDS

The three zones derived from the Land Use Capability Map – the Protection Zone, Conservation Zone, and Existing Community Zone – are used to reflect the nature of the Highlands' environmental resources and their associated value. Water availability threshold percentages are initially assigned to each zone to relate the conservation objectives of those areas (see table *Ground Water Availability Thresholds as Percentage of Ground Water Capacity*). The thresholds can also be subsequently modified by other constraints as discussed later in this section. The percentages are deliberately conservative to ensure that the Ground Water Availability estimates reflect several types of methodological uncertainty: climate change; gauging station accuracy; watershed changes such as reforestation, deforestation and development; data record limitations such as number of stations, stream types covered (first and second order streams are rarely monitored) and length of record; model limitations regarding direct correlations between stream flows and aquatic ecosystem integrity; the potential variation of impacts within individual watersheds and subwatersheds based on water use and land use patterns; the difficulty of directly relating changes in recharge to changes in base flow by area or time; and the potential for water uses that are not documented.

Ground Water Availability Thresholds as Percentage of Ground Water Capacity

Land Use Capability Zone	Standard Threshold	Existing Constrained Areas
Protection Zone	5% LFM	5% LFM
Conservation Zone	5% LFM Non-Ag 10% LFM Ag	5% LFM (non-ag)
Existing Community Zone	20% LFM	Existing C/D uses + 5% LFM (up to standard threshold)

C/D = monthly consumptive and depletive water uses

The 5 percent threshold for the Protection Zone and Conservation Zone is highly protective of stream flows to maintain the integrity of aquatic ecosystems. The assumption in this zone is that ecosystems will tolerate only extremely limited disturbance, and so water uses (and the associated land uses) are stringently limited. Therefore, the maximum threshold percentage of the Ground Water Capacity that is appropriate for such HUC14s is 5 percent, which primarily would be used to support limited development. While the comparison of Low Flow Margin to EcoFlow Goals 40/60 percentile results is somewhat variable, the use of a 5 percent threshold yields results that are reasonably comparable to the EcoFlow Goals results. However, it should be noted that the selection of a 5 percent threshold is not definitive. Because there is no regional method for directly linking flows to ecological health or change, the selection of a specific percentage is inherently a policy decision, driven by the need to limit the potential for risk of ecosystems. The policy mandate drives the risk perception. A somewhat lower threshold (e.g., 4 percent) could be justified based on a desire to be absolutely certain that the results will not compromise highly sensitive ecosystems. However, an extremely low percentage (e.g., zero or 1 percent) is much harder to justify given the natural variability in stream flows that affect all aquatic ecosystems. Increases in this threshold would necessarily need to rely on a demonstration that ecological health or function would not be impaired due to additional withdrawals.

The Existing Community Zone, or these area deemed more appropriate for development includes a threshold that is based on an empirical examination of known watershed issues regarding stream flows and aquifer capacity; the threshold percentage is accordingly set below the level at which such issues seem to occur. There may be justification for a higher percentage for a particular aquifer where detailed hydro-ecological studies are conducted in the future to prove that such an increase is sustainable, but in the absence of those studies a uniform percentage is recommended. For this purpose, results of Ground Water Capacity from all HUC14 subwatersheds using the Low Flow Method were compared to maximum month consumptive water use from 2003 to determine the percentage of Ground Water Capacity that is already used consumptively (note that depletive water uses and wastewater returns are not included in this value). These estimates of consumptive use stress range from 0.24 to 279 percent of the total Low Flow Margin. These values were then compared empirically to areas that have already been identified through other studies or NJDEP water allocation permit analyses to exhibit aquifer stress or stream flow depletion. The analysis focused initially on thresholds of 5, 10, 20, 30 and 40 percent of LFM. Based on this analysis, it appeared that stresses exist where maximum month consumptive uses exceed 20 percent of the Low Flow Margin. Subwatersheds with values of less than 20 percent did not appear to coincide with stressed areas. Therefore, it appears that a 20 percent threshold would be reasonable for HUC14 subwatersheds within the Existing Community Zone, where there is very limited potential for damage to sensitive aquatic ecosystems. However, to ensure that this estimate is conservative, pending more detailed analyses, the 20 percent threshold should be applied to the aggregate maximum month consumptive/depletive water use. Exports that are supported by reservoir storage would not be included in the estimate of depletive uses, as reservoirs store high flows against need during low flow periods and therefore do not have the same direct relationship to low flows as other depletive uses.

As a further check on the threshold for the Existing Community Zone, the HUC14 subwatersheds with consumptive uses between 10 and 20 percent were subdivided into two groups; from 10 to 15 percent and from 15 to 20 percent. Although the results are less clear-cut, the group from 10 to 15 percent seemed more similar in character and known aquifer stress levels to the group below 10 percent, and the group from 15 to 20 percent seemed more similar in character and known aquifer stress levels to the group above 20 percent. However, it should be noted that many of the Existing Community Zone areas are upstream of surface water supply reservoirs and intakes, subject to additional constraints on water availability (a 10 percent threshold) as discussed below. Therefore, the difference between a 20 percent and 15 percent threshold for the Existing Community Zone would have limited impacts on water availability.

The percentage threshold for the Conservation Zone, which includes a large concentration of agricultural areas and also significant ecological resources, should be very protective of these resources. Given the availability threshold recommended due to highly sensitive resources in the Protection Zone, it is reasonable to assign the same threshold for water availability in the Conservation Zone. However, it is recognized that agricultural uses will occur in these areas, dependent on irrigation wells, irrigation ponds and run-of-the-river intakes. In recognition that sustainable agricultural is supported by the Highlands Act, there is value to reserving significant amounts of water availability to agricultural operations using best management practices. Thus, the water availability threshold in the Conservation Zone is bifurcated: 10 percent for agricultural uses and 5 percent for all other uses. The results of the calculations of Ground Water Availability with the threshold percentages applied are summarized for each subwatershed in the table *Ground Water Availability by HUC14* located in Appendix D.

Because most subwatersheds consist of more than one land use capability zone, a method to assign a threshold is needed. The calculation examines if the subwatershed is dominated in area by greater than 75% of one LUC zone. If so, the subwatershed is assigned that zone determination and applicable threshold. If a subwatershed is not dominated in area by greater than 75% of a single LUC zone, then an alternate method is applied. The Watershed Resource Value indicator, which was developed as an indicator of watershed quality (see section *Assigning Watershed Value Classes* of the *Ecosystem Management Technical Report*), is then employed according to the following criteria:

Watershed Resource Value	Applied Zone Designation
High	Protection
Moderate	Conservation
Low	Existing Community

When multiplied by the Ground Water Capacity, this yields Ground Water Availability.

OTHER FACTORS AFFECTING WATER AVAILABILITY ESTIMATES

The method for water availability should reserve sufficient water capacity for a variety of purposes, including downstream water supplies, ecological integrity, maintenance of water quality, or surface water system safe yields uses. Although the water availability thresholds discussed are appropriately conservative, constraining water use where water resources are threatened, or may be threatened, is warranted.

Where Net Water Availability is already negative (a Current Deficit Area), this is a clear indication that existing water uses are exceeding available water resources and pose a high risk to the surface water supplies or the integrity of Highlands waters and the aquatic ecosystems on which they depend. Management measures will be needed so that the Net Water Availability is no longer negative, and preferably is positive, to the maximum extent practicable. Options include either reducing consumptive and depletive water uses within those subwatersheds, recycling or reusing treated wastewater (with due care to the potential impacts on stream flows) or providing alternative water supplies from other subwatersheds (where Net Water Availability exceeds anticipated needs) or from reservoirs with excess supplies. This analysis must occur on a subwatershed or watershed basis, as appropriate, to avoid solving one problem by creating or exacerbating another.

A second issue occurs regarding consumptive and depletive uses upstream of a HUC14 subwatershed in a deficit situation. Significant reductions in flows from upstream subwatersheds would exacerbate the downstream deficit situation for the main stem stream itself, though it would not have any impact on tributaries within the downstream subwatershed. These upstream subwatersheds are identified as Existing Constrained Areas (assuming they are not already Current Deficit Areas themselves).

Recognizing that the downstream deficit occurs throughout the entire subwatershed, regardless of land capability zone, availability thresholds are to be equitably applied. Therefore for Existing Constrained Area, a 5 percent LFM threshold above the current consumptive and depletive water is applied, with a maximum of the standard threshold in that zone. This method ensures that upstream water availability is constrained to ensure continued downstream stream flows by limiting consumptive and depletive water uses in the contributing watersheds, but does not inequitably restrict the upstream subwatershed due to excessive water uses downstream. In practice, Protection Zone and Conservation Zone subwatersheds are unaffected, because their threshold is already 5%.

CALCULATION OF NET WATER AVAILABILITY

Net Water Availability is estimated by subtracting from the Ground Water Availability for that subwatershed an estimate of the consumptive and depletive ground water use, and the consumptive and depletive surface water uses that are not supported by reservoir storage or safe yields. As discussed above, the consumptive ground water use estimates for each subwatershed are adjusted to account for this effect maximum month ground water withdrawals, multiplied by the maximum annual consumptive use coefficients. Surface water consumptive withdrawals (other than from reservoirs) have the same impact on aquatic ecosystems as the consumptive use of ground water. Unlike ground water uses, the effects are direct and immediate and so no adjustment factor is needed. Depletive effects are calculated for public supply water uses only, based on the following two assumptions: 1) Public water supply users will be connected to public wastewater sewer systems, as most commonly occurs in developed areas, and this infrastructure must account for the import/export of water and wastewater within each subwatershed; and 2) for uses other than public supply (e.g., irrigation, recreation), the withdrawal and the return of that water use occurs within the same subwatershed, so only consumptive effects need to be considered.

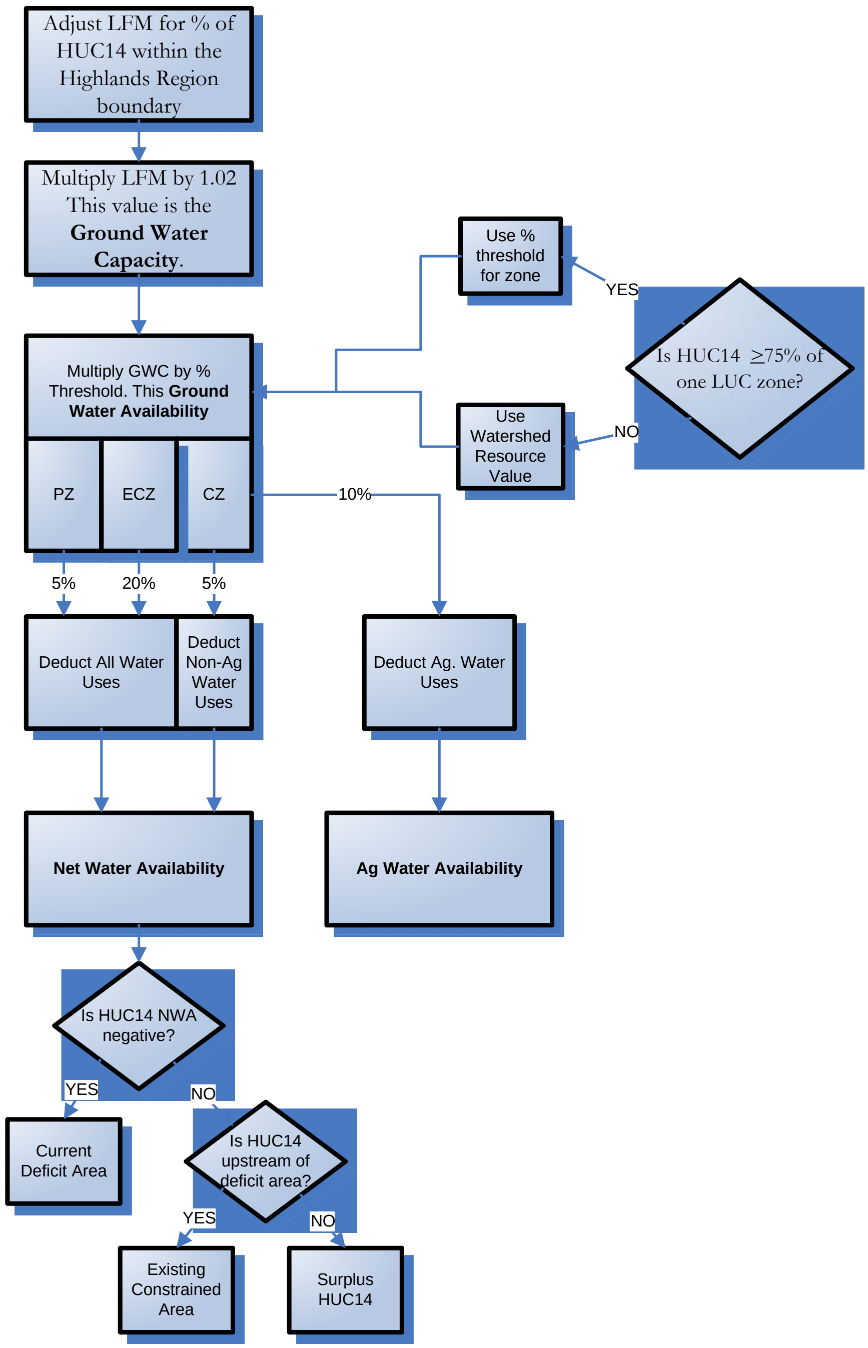
A similar calculation is performed separately for agricultural water availability. However, it differs from the net water availability calculation in several ways:

- The calculation provides results that are reported only for agricultural uses in a Conservation Zone subwatershed;
- The water availability threshold utilized is 10%, not 5%;
- Only agricultural water use are deducted from agricultural ground water availability;
- All agricultural uses are assumed to be consumptive; no depletive uses are assumed;
- No constraints such as Existing Constrained Areas are examined;
- A corresponding calculation is performed for all non-agricultural uses in the Conservation Zone for the net water availability analysis.

For the purposes of this report, the term net water availability is considered distinct from agricultural water availability, although the two parameters and associated calculations are quite similar. This section focuses primarily on the process to derive net water availability, which represents the analysis of the amount of water available for human use in the Highlands Region. The agricultural water availability is a more limited analysis for a specific purpose

The final process used for deriving Net Water Availability is as follows:

Net Water Availability Calculation



RESULTS BY SUBWATERSHED

The table *Net Water Availability by HUC14* located in Appendix D provides values at for each HUC14 deducting net use from Ground Water Availability. The figure *Net Water Availability by HUC14* maps the results of the net availability calculations by subwatershed.

According to the results of the calculation of Net Water Availability, 114 of 183 subwatersheds have maximum monthly consumptive and depletive current water uses that exceed their Ground Water Availability; therefore, these areas are considered Current Deficit Areas.

Of the 183 HUC14 subwatersheds, 22 have consumptive and depletive ground and surface water uses that exceed their full Ground Water Capacity. An additional 44 HUCs have consumptive and depletive ground and surface water uses greater than 20 percent of Ground Water Capacity. Therefore, if the 20 percent threshold discussed above was applied uniformly across the Highlands Region, 66 HUC14 subwatersheds would already have no net available water at this level of analysis. Many of these subwatersheds are within areas where ground water models have been developed in response to known stresses on aquifer systems, such as the Central Passaic River Buried Valley Aquifer system, the Ramapo River and the Rockaway River, all in the Passaic River Basin. In all, 122 of the 183 HUC 14 subwatersheds have consumptive and depletive water uses of five percent or greater.

DEFICIT MITIGATION

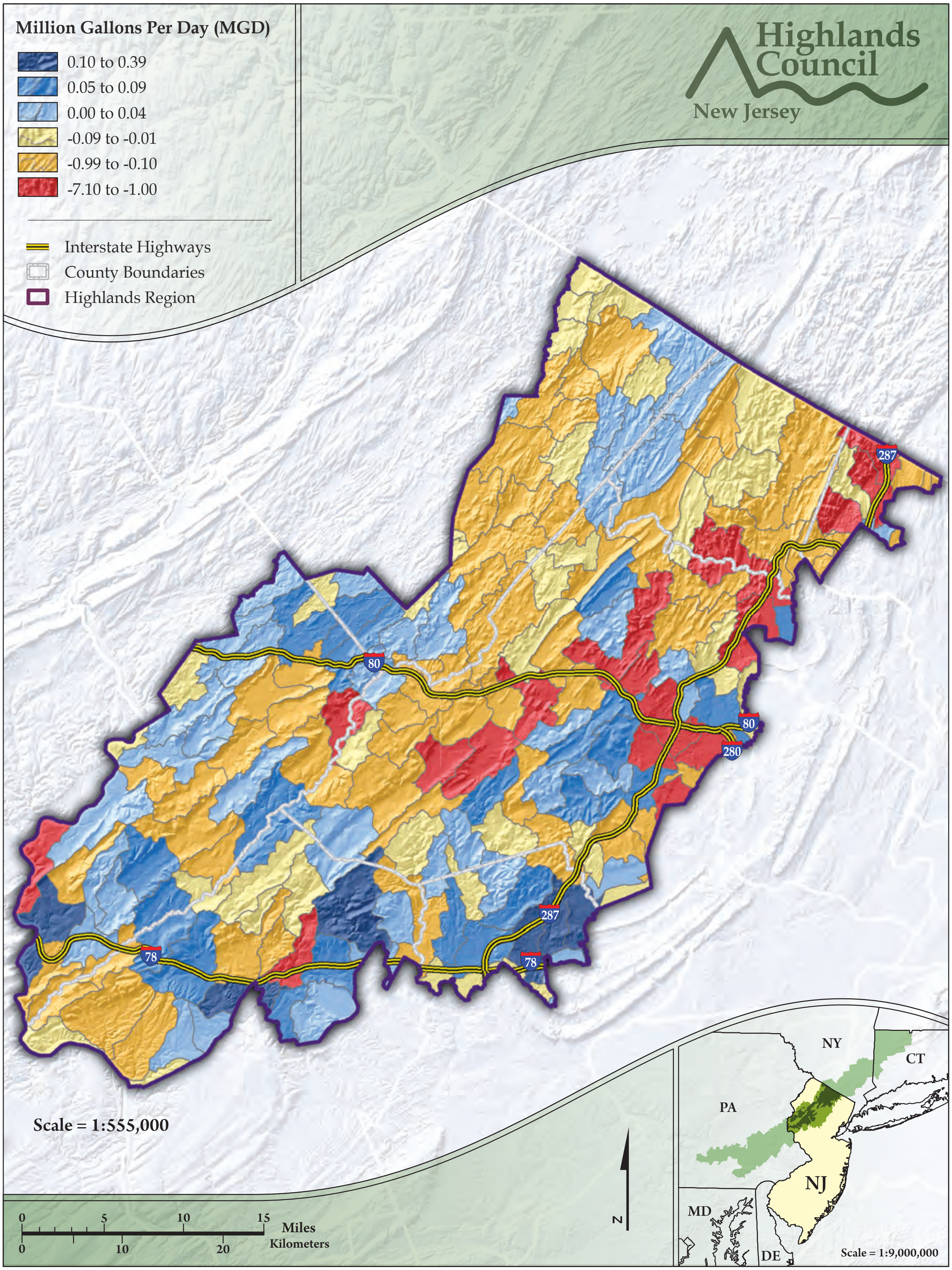
Of the 183 HUC14 subwatersheds, 114 show deficits ranging from less than 100 gallons per day (gpd) to more than 7 million gallons per day (MGD), within the following ranges:

Deficit (MGD)	# of HUC14s
0.0001 – 0.050	22
0.051 – 0.100	7
0.101 – 0.250	25
0.251 – 0.500	17
0.501 – 1.000	16
1.000 – 7.100	17
TOTAL	**114**

The highest deficits are primarily caused by major depletive uses. In some cases, clean water is delivered across subwatershed and watershed lines to users. One example is the Morris County MUA well fields in the Lamington and Drakes Brook watersheds. In other cases, the water is used within the subwatershed but then moved as wastewater to another subwatershed for treatment. The upper Rockaway River watershed is an example. For a few cases, the inter-watershed transfers occur over a very short distance (e.g., just past the subwatershed boundary). Phillipsburg is an example, where the source subwatershed is next to the Delaware River, and the wastewater is to the Delaware River itself. The discharge is calculated as a depletive water use, but may not be an actual problem because the discharge is so close to the area where ground water would normally flow.

Because the largest deficits are primarily caused by inter-watershed transfers, deficit solutions may similarly require infrastructure solutions. Such solutions may have effects outside of the Highlands Region, and therefore NJDEP must be closely involved in the analysis and approval of those deficit reduction approaches.

NET WATER AVAILABILITY BY HUC 14



FEASIBILITY OF MITIGATION

Questions remain regarding how certain the technology and requirements could be used in achieving mitigation. However, the questions have been more about technology and impacts rather than process. Issues include:

- **Recharge Technology** – The recharge technology envisioned in the RMP is the same as relied upon by NJDEP in its Stormwater Management Rules and Best Management Practices Manual. These techniques have been incorporated into BMP manuals and both local and state regulations throughout the northeastern part of the country. USEPA and other agencies around the country have conducted research on their effectiveness. If the methods are appropriate for stormwater management practices, then they are also appropriate for deficit mitigation. As these methods currently have the approval of NJDEP, the Highlands Council should endorse their use. The Council should also continue to track ongoing BMP research, and should implement the science agenda components that will monitor subwatershed changes based on development, redevelopment and deficit reduction.
- **Recharge Impacts** – There are several different issues regarding impacts.
  - First is whether impacts of recharge are felt quickly or slowly by the hydrologic system. Technical studies in areas with relatively high water tables (typical of the Highlands Region) show that infiltration of water to the ground water table (recharge) happens relatively rapidly due to the short travel distances involved.
  - Second, confusion sometimes occurs regarding the difference between time necessary for recharge to occur (days to weeks) and time for that water to reach its natural outlet, which can range from years to millennia. However, the time of travel to a natural outlet is not the key issue. Recharge increases the elevation of the water table and therefore the "head" or pressure gradient of an aquifer, which is transmitted through the aquifer much faster than the actual water travel time. So, increased recharge causes an increase in stream base flows relatively rapidly, much as water being pumped <u>from</u> an aquifer creates a relatively fast decrease in stream base flows.
  - The third issue is whether the location of the recharge benefits the same aquifer system or streams that are affected by the new consumptive or depletive water use. This legitimate issue is the basis for mandating that the mitigation occur within the same subwatershed as the <u>withdrawal</u>, not the use. There can be situations where the use is from an aquifer, but the recharge moves more directly to stream base flow instead of to the aquifer, or where the timing of the benefit to stream flow differs. It is a reason why NJDEP requires under its water allocation permit process that any new well be tested to ensure that it does not damage nearby wells, wetlands and stream flow. Short of extensive (and expensive) ground water modeling for every new development and aquifer, it is not feasible to ensure that recharge benefits the exact source of the water being used. However, by requiring that the mitigating recharge be in the same subwatershed, stream flow in that subwatershed will benefit regardless.
  - A "purest" approach, requiring that ground water uses be allowed only if the mitigation precisely offsets both the quantity and timing of its impact on stream flow, is not feasible and is the equivalent of a declaration that no ground water should be used for water supply. To our knowledge, no regulatory agency uses this approach.
- **Water Conservation Techniques** – Water conservation technology has been proven over time, including major conservation gains in New Jersey based on State and national requirements for improved water using fixtures and appliances. Therefore, the effectiveness of the technology is not

in doubt. A more legitimate issue is one of ensuring that conservation technology and techniques actually occur and in a timely manner.

- Generally, residential appliances and fixtures, once installed, are not removed and retain their effectiveness. The same is true of office building fixtures. In most programs, objectives are established that allow for some loss of effectiveness over time; in essence, the program objectives "overshoots" the actual need to ensure success. Progress can be tracked through billing records of water purveyors.
- Industries and water-using commercial operations have incentives to maintain water conservation once implemented, as it reduces their costs for both water supply and wastewater treatment. Because these entities are either customers of public utilities or have water allocation permits, their progress can be tracked individually over time.
- Lawn irrigation systems tend to remain in place once installed, but they may require more monitoring to ensure that upgraded systems are being used properly, as owners can manually override the systems and may not maintain them properly. Progress can be tracked in the aggregate through peak water use rates of water purveyors.
- Agricultural irrigation practices also tend to remain in place once installed, and NJDEP is strengthening its oversight of agricultural water certifications to ensure proper practices. Where agricultural conservation is implemented as a mitigation project, the contracts should require system maintenance and proper use. Such contracts must consider and address issues of crop changes over time.
- One potential improvement to the proposed RMP would be to require monitoring and compliance evaluations by an outside expert party as a condition of approval. While this provision can readily be included in water management plans, it should be considered for project-specific mitigation as well.
- Water rates, and in particular inclining block rates or summer peak use rates, have potential for reducing water use through pricing signals to the consumer, especially if combined with customer education so that they notice the link between the rate structure and their water supply bills.

- **Aggregate Impacts of Mitigation** – The final issue relates to "proof of concept" for deficit reduction. The history of water deficits in the northeastern United States (and most other locations) is that they are addressed only when a major drought endangers supplies to major developed areas. The solutions are nearly always primarily based on new infrastructure (e.g., reservoirs, interconnection pipelines, well fields), though many include conservation to reduce infrastructure costs. The water availability analysis is fundamentally different in that it focuses on ecological impacts of deficits that are in many cases very small relative to historic norms. The difficulty of deficit reduction is proportional to deficit size.
  - As discussed above, nearly half (54) of the 114 deficit subwatersheds have deficits of less than 250,000 gpd, or 0.25 MGD. 71 deficits are less than 500,000 gpd or 0.5 MGD. 29 are less than 100,000 gpd or 0.1 MGD. These deficits are very small relative to the deficits historically addressed by major infrastructure projects. It should be relatively easy for deficits of this nature to be addressed through a Water Use and Conservation Management Plan and mitigation projects, especially for deficits less than 0.25 MGD.
  - Seventeen subwatersheds have deficits above 1 MGD, primarily driven by depletive water uses. Deficits of this size and cause will be more difficult and perhaps impossible to address without a major infrastructure project. However, in some cases the infrastructure project could involve a concerted recharge enhancement effort, rather than a new reservoir or

importation of water. At any rate, a conditional water availability of less than 0.025 MGD (the norm) represents a <u>very</u> limited use compared to the water availability deficit, and even more limited compared to total water use. In such situations, project-specific mitigation will not affect the deficit much at all in any direction. Within existing water supply service areas for major public systems, the impacts of new development may not even be noticeable relative to total system use. True deficit reduction will require implementation of management strategies and major water resource and conservation projects. In the most severe cases, deficit elimination will require coordinated action with NJDEP. Fortunately, these areas are also identified by NJDEP as being in deficit based on the upcoming Statewide Water Supply Plan methods, and so cooperative efforts should be possible.

- o Sixteen subwatersheds have intermediate deficits, of between 0.5 and 1.0 MGD. These subwatersheds will benefit less from project-specific mitigation, and will have fewer structural options for water resources projects.
- o In some cases, more detailed evaluations of the subwatersheds and their deficits may show that the subwatersheds should be managed as an aggregate unit, modifying the deficits and the feasible solutions. Where subwatersheds with major deficits are close together, creating a combined water resources project may be more appropriate than having separate projects for each subwatershed.

In summary, the smaller deficits can legitimately be resolved through a combination of project-specific mitigation, water conservation and water resource projects emphasizing recharge augmentation. The largest deficits will only be resolved through intensive water conservation and water resource projects, and the inclusion of these subwatersheds as deficit areas in the Statewide Water Supply Plan will help with the identification of those solutions. The middle-sized deficits may be the most difficult to resolve, except where they can be included within a larger sub-regional solution.

MITIGATION STRATEGIES

The approaches the Council may take to reducing water deficits vary, but all are based in part on policy decisions of the Highlands Council and the goals, policies, and objectives of the RMP. However, two mechanisms are likely to be incorporated, 1) a water management plan (titled Water Use and Conservation Plan), which would be developed for water use within each conforming municipality; and 2) a policy of allowing the strictly limited use of water in deficit subwatersheds, called conditional water availability.

The development of a Water Use and Conservation Management Plan would be used as the best option for deficit reduction. These plans could be developed quickly for areas with minor deficits, will require solutions that are entirely within the subwatershed, can be very effective for relatively small deficits, and should incorporate mitigation requirements.

The policy of conditional availability and mitigation for new consumptive and depletive water uses can be implemented to provide an opportunity for private and public sector development activity to help reduce or eliminate existing deficits. It also avoids the possibility of a discriminatory policy, where customers of water purveyors (which are regulated by NJDEP) are treated differently than self-supplied water users (which are not). The wide range of deficits, the wide range of potential solutions, and the fact that Plan Conformance is voluntary in the Planning Area make a policy of preventing new water uses a less useful as a tool than might be true in other situations.

RECOMMENDED APPROACH FOR IMPROVING ESTIMATES

It should be noted that there are always uncertainties in modeling processes, because no model can fully reflect reality and because data and methodology limitations always exist. The Highlands Council focused on providing a sound conceptual approach that can be augmented, as better data become available. Key areas for research and program development revolve around the following known uncertainties in the process:

- Gauging station accuracy – Stream monitoring stations are mechanical devices that are routinely checked for accuracy, but will always have a certain potential for inaccuracy based on the limitations of the technology and the gauging station sites. USGS considers records to be of "excellent" quality if 95% of daily measurements are within 5% of the true value. Models can address the sensitivity of results to the potential for measurement differences from true values.
- Data record limitations such as number of stations, stream types covered and length of record – There is a limited number of stream monitoring stations in the Highlands. Very few of them monitor stream flows from very small drainage basins (e.g., those of first or second order streams) that might be more sensitive to the impacts of development, such as impervious surfaces or stormwater systems, or of localized water withdrawals. Length of record issues can only be solved by time, which makes the establishment of new monitoring stations in critical areas a very time-sensitive issue.
- Conceptual model limitations regarding direct correlations between stream flows and aquatic ecosystem integrity – An approach is needed to allow subwatershed-based (and not just stream reach based) analyses of stream flow needs for aquatic ecosystem integrity. Doing so will require consideration of many types of flow needs, not just low flows, so that many types of ecological needs are addressed including biota viability, spawning, channel structure and sediment movement. A model with this capacity would legitimately be the gold standard for instream flow requirements, and would be invaluable for a densely populated state such as New Jersey. Considerable research is occurring on this issue nationally, including the Index of Hydraulic Alteration (Nature Conservancy 2006), and NJDEP is working with USGS to develop a model that addresses this issue in part, the NJ Hydroecological Assessment Tool. However, this tool is based on assumptions drawn from research regarding the link between flow statistics and ecological impacts. More research is needed to develop a stronger link, and should include field research on actual stream ecosystem flow needs to establish better conceptual models and to "ground truth" what is developed. Methods such as R2Cross, Wetted Perimeter or other field methods may be useful. The extent to which any of these methods can be applied on both headwaters and main stem streams also needs to be addressed.
- The potential variation of impacts within individual watersheds and subwatersheds based on water use and land use patterns – The analyses for water availability relied on the HUC14 subwatershed as the smallest "accounting unit" feasible at this time. However, water uses and water availability are not always uniform across the subwatershed. Further, the movement of water in public water systems and wastewater systems is complex. There are two methods to improve the analysis over time: developing smaller scale drainage areas using the upcoming LiDAR topography data; and better linkages between the source of water and its ultimate discharge. Both should be pursued to ensure that the analysis does not "hide" intensive small scale impacts or lose water in the transfer between subwatersheds.
- Watershed changes such as reforestation, deforestation and development – Reforestation has been noted in several areas of New Jersey (Watson and others, 2005), as previously farmed areas are allowed to regrow forest cover. This process can increase both recharge and evapotranspiration, and

reduce runoff. Deforestation also occurs, related to new development and to new agricultural development, which can reduce recharge and evapotranspiration and increase runoff. The impervious and semi-pervious surfaces associated with development also modify both recharge and runoff patterns and quantities, although new regulations require retention of pre-construction recharge rates. Improved understanding of how each of these factors affects recharge, stream base flows and water availability would be valuable. In addition, understanding the ecological impacts of increasing runoff will be important for reasons not related to water availability.

- The difficulty of directly relating changes in land uses to changes in recharge, and of changes in recharge to changes in base flow by area or time – Recharge to ground water is not uniform across a subwatershed. Movement of that ground water to aquifers also is not uniform. The addition of land uses (including impervious surfaces) within a subwatershed will therefore have different impacts on recharge depending on where the land uses are, the nature of the land uses, the extent to which impervious cover drains to stormwater systems versus to pervious areas that can infiltrate that water, the extent to which recharge is artificially maintained to match pre-construction rates, etc. The flow of recharge water to streams is also variable with location, time, season and climatic event. Streams in some cases recharge ground water (losing stream reaches), and in other cases receive flow from ground water (gaining stream reaches). There is a strong conceptual case that increased land development should result in decreased stream base flow, but two USGS studies of long-term base flow trends in New Jersey did not find many statistically significant trends in low flows (Brandes and other 2005, Watson and others 2005). As the studies note, the reasons for this lack of declining trends are not clear, and require research. It should be noted that these studies did not rule out such a link between increasing development and base flows, but the research methods were focused on trend analysis and were not developed for the purpose of proving or disproving the link. An improved understanding of this issue will allow for a more robust water availability modeling approach in the future.

- Undocumented water uses – NJDEP regulates certain classes of water uses through the water allocation permit and agricultural water use programs, and has information on some smaller potable water uses through the safe drinking water program. However, information on other small water uses is limited, and the U.S. Bureau of the Census last included the source of water (on-site well versus community system) on the 1990 household survey. For this reason, other approaches will be needed to develop updated estimates of non-regulated water uses. The Highlands Council has used GIS tools to determine the location and density of households using domestic water supply wells and residential septic systems, and this tool can be applied to each Land Use/Land Cover database from NJDEP to assess changes over time.

- The need for updated consumptive use assumptions by water use type – Consumptive use estimates by water use type are based on assumptions of consumptive use as a percentage of total use. Improved information on the actual consumptive use percentages will provide a more robust basis for both water availability and water conservation activities. NJDEP provided consumptive use coefficients, and additional research was completed by the Council to determine appropriate consumptive use coefficients for use in this analysis. Continued improvements in consumptive use coefficients are needed and will provide for improved estimates of water availability in the future.

- Climate change – Scientific consensus has been developing in the last decade that the increase in greenhouse gases is and will be causing increases in global temperatures (see the section below on Surface Water Availability.) The climatic impacts of these increases on a regional basis are less clear, and local impacts are even less clear. Models can be developed that assess the sensitivity of hydrologic systems to changes in rainfall patterns and densities, evaporation and transpiration rates, etc. Management approaches can be used to then ensure sustainability based on the most likely impacts.

COMPARISON OF WATER AVAILABILITY TO WATER SUPPLY UTILITY CAPACITY

Ultimately, one use of water availability estimates will be to identify which water supply utilities have:

- Available system capacity based on water from Current Deficit Areas, where increased water withdrawals could harm base flows, aquatic ecosystems and downstream water supplies.
- Available system capacity based on water from areas with sufficient net water availability or reservoir safe yield, where that capacity is needed for development and redevelopment sanctioned by the Regional Master Plan.
- Available system capacity based on water from areas with sufficient net water availability or reservoir safe yield, where that capacity is not needed for development and redevelopment sanctioned by the Regional Master Plan and therefore is surplus capacity.
- No available system capacity, but where capacity is needed for development and redevelopment sanctioned by the Regional Master Plan.

Depending on the specific case, decisions will need to be made regarding water supply utility withdrawals, water use patterns and efficiencies, service area expansion or contraction, etc. Where withdrawals already exceed water availability (a Current Deficit Area), NJDEP is constrained by the Water Supply Management Act from reducing water allocations below current demands unless certain steps are taken, including provision of alternate water supplies.

SURFACE WATER AVAILABILITY

The Highlands Act emphasizes the protection of water resources throughout the Highlands Region. This includes the major reservoir systems that provide water to urban and suburban areas of northern and central New Jersey and smaller reservoirs providing water supply on a local scale. Highlands reservoirs provide over 600 million gallons per day (MGD) to public water supply service areas in these regions, with individual reservoir system supplies ranging from less than one to roughly 175 MGD. These figures do not include self-supplied industrial and agricultural uses, which are not supported by Highlands reservoirs. A better understanding of the affects of this water demand on the quality and integrity of Highlands water supply is needed.

The reservoirs store water during times when stream flows are higher, and then release water from storage both to serve customers and to maintain mandatory "passing flows" to downstream areas during dry periods. The water supply system yields are determined through the use of models that consider incoming stream flows, passing flows, reservoir storage and other factors. As such, changes in either incoming stream flows (e.g., from upstream diversions of ground or surface waters) or in required passing flows can cause significant changes in safe yields. Water quality may also affect yields, especially in the case of pumped storage reservoirs (e.g., Wanaque Reservoir) where the magnitude and timing of pumping from surface water bodies into storage may be constrained by permit conditions regarding water quality. Finally, climate change could potentially increase or decrease yields, due to changes in either the quantity or pattern of precipitation or the pattern or fluctuation of ambient temperatures.

This section provides information on the surface water supplies for potable water systems that are either located in or directly supported by the Highlands Region, including their yields and passing flows. The section also presents several technical and policy issues regarding the impacts of water quality, upstream water uses and climate change on system yields, and therefore, surface water availability.

A major purpose for protection of the Highlands is the Region's role in providing the vast majority of potable surface water supplies used in northern and central New Jersey, where the majority of the State's population resides. These reservoirs rely either directly or indirectly on water flowing in Highlands streams. Most, though not all, were constructed in the 1890s and early 1900s, long before the Highlands began to be used for suburban and exurban development. Only the two Raritan River reservoirs (Round Valley and Spruce Run, constructed in the 1960s) and the Monksville Reservoir (part of the North Jersey District Water Supply Commission, constructed in 1985) are of more recent vintage. Even in these instances, most of the existing development in their contributing watersheds was constructed after the reservoirs.

Surface water availability is determined by several factors, most important of which are storage capacity, incoming stream flow, and requirements for reservoir releases to maintain stream flows below the reservoirs (i.e. passing flows.) Incoming stream flow is comprised of runoff during precipitation events, ground water movement into the reservoirs, and stream baseflow that is derived from ground water moving into the stream. As such, surface water availability is affected by watershed characteristics, including patterns in stream flows. During drought periods, reservoirs will capture nearly all of the upstream runoff that enters the reservoir, but often must release even larger flows from the reservoir. These factors are components of the "safe yield" for a surface water supply system, which is explained below. Safe yield models use various assumptions regarding these factors, generally for the purpose of ensuring that the safe yield is conservative. However, there is no single method either required or used for these models.

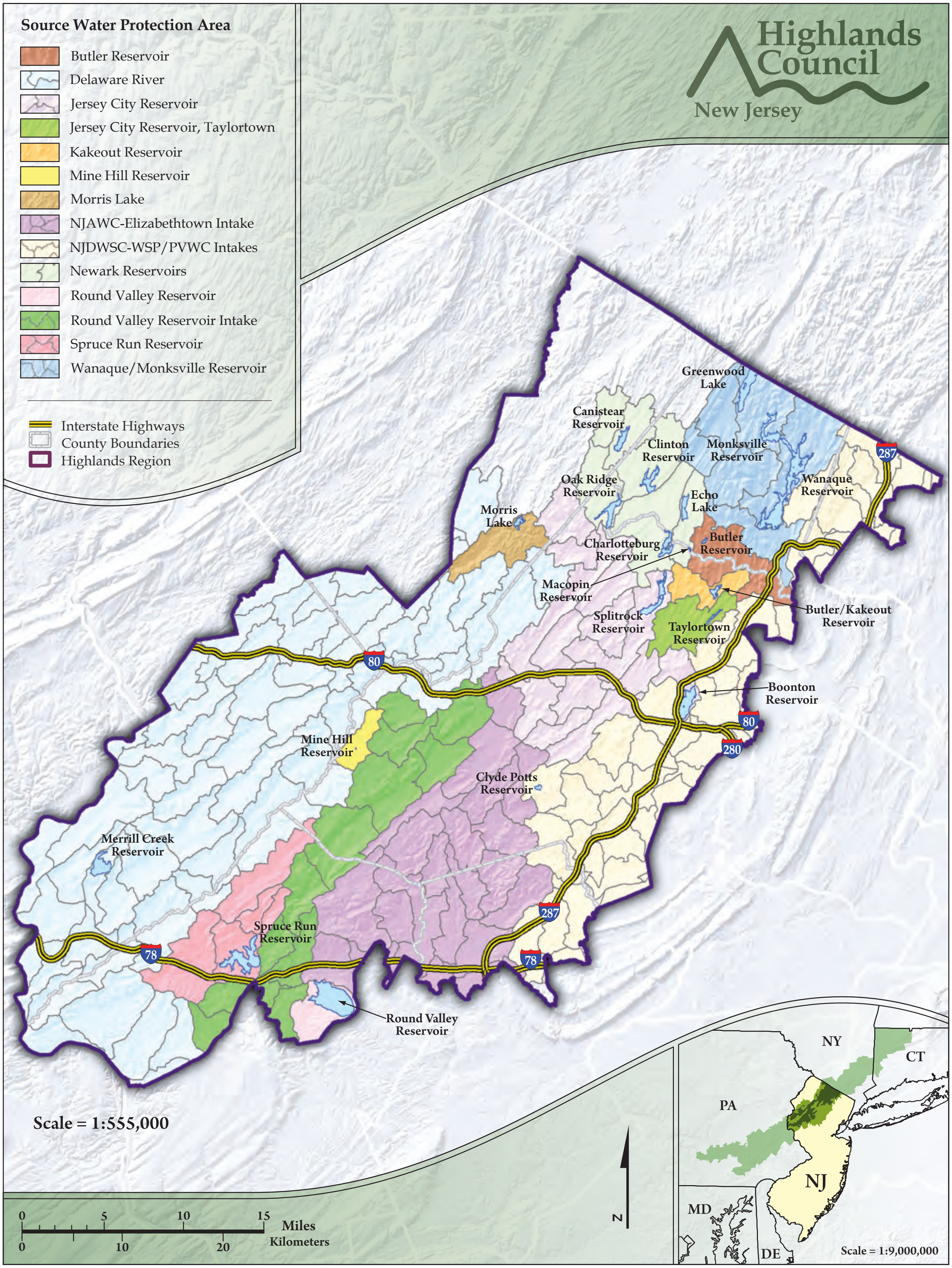
SURFACE WATER SUPPLY SYSTEMS

The largest surface water supply systems of the Highlands provide water to urban and suburban parts of northern and central New Jersey. There are a few surface water supply systems for potable water supply that provide water primarily to municipalities of the Highlands Region.

The following systems are located in the Highlands Region, as illustrated in the figure *Source Water Protection Areas and Reservoirs*:

- Town of Boonton – The Town of Boonton owns the Taylortown Reservoir, which is located on a tributary to the Rockaway River on the border of Montville and Kinnelon Townships. It is a small reservoir for municipal supply. The reservoir relies entirely on natural stream flow (i.e., there are no facilities for pumped storage).
- Town of Butler – The Town of Butler owns Kakeout Reservoir, which is located on a tributary to the Pequannock River in neighboring Kinnelon Township. It is a small reservoir for municipal supply. The reservoir relies entirely on natural stream flow.
- Hackettstown Municipal Utilities Authority – The MUA owns three small reservoirs on tributaries to the Musconetcong River, the Upper Mine Hill, Lower Mine Hill & Burd Reservoirs. These are small reservoirs for local supply. The reservoirs rely entirely on natural stream flow.
- City of Jersey City – Jersey City owns two reservoirs, Boonton and Splitrock. Boonton Reservoir is on the border between Parsippany-Troy Hills Township, Mountain Lakes Borough and the Town of Boonton, and impounds the Rockaway River. Splitrock Reservoir is located in Rockaway Township, on a tributary to the Rockaway River. Jersey City draws water from the Boonton Reservoir for treatment and delivery to Jersey City, Hoboken, and neighboring areas. Splitrock Reservoir stores water that can be released to the Boonton Reservoir. The reservoirs rely entirely on natural stream flow.
- City of Newark – Newark owns the Pequannock Reservoir System, consisting of five reservoirs located in the Pequannock River Watershed of Passaic and Morris Counties. They are (from upstream to downstream) the Canistear, Oak Ridge, Clinton, Echo Lake and Charlottesburg. Newark draws water from the Charlottesburg Reservoir for treatment and delivery to the city. The other four reservoirs store water than can be released to the Charlottesburg Reservoir. The reservoirs rely entirely on natural stream flow.
- Town of Newton – Newton owns Lake Morris, a small reservoir in Sparta Township that is located on a tributary to the Wallkill River. The reservoir relies entirely on natural stream flow.
- New Jersey Water Supply Authority – The Authority owns two reservoirs, Round Valley and Spruce Run, which are both located at the southern end of the Highlands Region, in the South Branch Raritan River watershed. Spruce Run Reservoir is fed by natural stream flow, while Round Valley Reservoir is almost entirely reliant on water pumped from the South Branch Raritan River. Neither is used directly for water supply; but used to augment stream flow to the Raritan River for subsequent withdrawal by downstream customers. The safe yield for the reservoirs listed below does not include the safe yield from the Delaware & Raritan Canal (65 MGD).
- North Jersey District Water Supply Commission – The Commission owns two reservoirs, Monksville and Wanaque, both within the Wanaque River watershed. Monksville Reservoir relies entirely on natural stream flow, and is used to store water that can be released to the Wanaque Reservoir, immediately downstream. The Wanaque Reservoir, however, is fed both by stream flow and by pumping from two sources – the Ramapo Pump Station on the Ramapo River, and the Wanaque South Project (co-owned by United Water-NJ) along the lower Pompton River. The Commission withdraws water from the Wanaque Reservoir for treatment and delivery to a wide variety of

SOURCE WATER PROTECTION AREAS AND RESERVOIRS



customers. Some of those customers, in turn, have their own separate reservoir systems (e.g., Newark).

- Southeast Morris County Municipal Utilities Authority – The Authority owns Clyde Potts Reservoir, which is located on a tributary of the Whippany River in Mendham Township. This is a small reservoir used as part of a conjunctive use system, i.e., combining ground and surface water sources for local supply. The reservoir relies entirely on natural stream flow.
- United Water-NJ – This investor-owned company owns the Hackensack Reservoir System, which is located in the Hackensack River watershed, outside the New Jersey Highlands. These reservoirs are fed by natural stream flow. However, United Water-NJ is also a part owner of the Wanaque South Project (with the North Jersey District Water Supply Commission, discussed above) and derives part of its system safe yield from water derived from the Pompton River, located within the Highlands. This water is pumped into the Oradell Reservoir.

SAFE YIELDS OF HIGHLANDS SURFACE WATER SUPPLIES

The term "safe yield" when applied to surface water supply systems is generally defined as the amount of water than can be routinely supplied through future conditions, including a repeat of the "drought of record", which for the Highlands Region is the drought of 1964 through 1966, without creating undesirable effects and after compliance with requirements for maintaining minimum passing flows. Water supply systems may have the ability to supply greater amounts of water on any given day, or during non-drought conditions, but drought periods are a critical limiting factor in defining safe yield.

Because stream flows during drought periods will fall below the minimum levels necessary to support public water supplies, safe yields are based on the ability of reservoirs to store water during periods of higher flow and then release it both to the public water supply system, which defines the safe yield, and to downstream water uses, to maintain the passing flow, described below.

Safe yield is determined through the use of hydrologic models that assess the water budget of the reservoir or reservoir system over time. These models may be developed in advance of reservoir construction, after the reservoir has been in operation for some time, or both. Very small reservoirs may lack formal safe yield models, but all of the larger reservoirs and reservoir systems have them. While some of the models are in the public domain, others are not. Some of these models have recently been updated, such as the 2005 model for the Raritan Basin System of the NJ Water Supply Authority (Shallcross 2005). Some have detailed documentation and software code available, while others do not. Therefore, the safe yields may not all be current and the actual safe yields may be somewhat different from the documented values. For this reason, the safe yields in the table entitled Safe Yields of Highlands Reservoir Systems are listed as "nominal" safe yields, defined as the existing, documented safe yield values.

The New Jersey Department of Environmental Protection (NJDEP) has initiated a project to obtain updated and integrated safe yields for the various Passaic and Hackensack reservoir systems, as part of its statewide water supply planning efforts. NJDEP is developing guidance for safe yield model development, to ensure more consistency in the process. There are a number of reservoirs within or bordering the Highlands Region. Some are very small and supply only limited safe yields, primarily serving as the water supply source for municipalities within the Highlands Region. Other reservoirs are New Jersey's largest and provide critical water supplies for large populations in urban and suburban regions of the northern and central parts of the state. Safe yields have been identified for numerous reservoirs, as shown in the table below.

Safe Yields of Highlands Reservoir Systems

Surface Water Supply System	Reservoir or Reservoir System	Nominal Safe Yield (MGD)	Reference
Boonton (Town of)	Taylortown	1.5	NJDEP, 1992, Task 2 Report
Butler (Town of)	Kakeout	6	Task 2 Report, NJSWSP
Hackettstown Municipal Utilities Authority	Upper Mine Hill, Lower Mine Hill & Burd	0.5*	NJDEP-NJGS (NJDEP Water Allocation permit 5145 or 5146)
Jersey City (City of)	Boonton and Splitrock	56.8	Task 2 Report, NJSWSP
Newark (City of)	Pequannock System	49.1	Task 2 Report, NJSWSP
Newton	Lake Morris	No listing	Task 2 Report, NJSWSP
NJ Water Supply Authority	Round Valley and Spruce Run	176	NJWSA 2005
North Jersey District Water Supply Commission	Wanaque Reservoir and Wanaque South Project	173	Task 2 Report, NJSWSP
Southeast Morris County Municipal Utilities Authority	Clyde Potts	<1**	Task 2 Report, NJSWSP
United Water-NJ	Hackensack System ***	65	Task 2 Report, NJSWSP
Total		528.9	

**Based on the water allocation permits, rather than a safe yield study. Hackettstown system has an allocation of 1 MGD but a passing flow on Mine Hill Brook of 0.13 MGD combined with limited storage may make the total allocation not attainable during a drought of record.*

***Clyde Potts is used as part of a conjunctive supply system with the SEMCMUA well fields. Reservoir safe yield not assessed, but probably less than 1 MGD per William Hutchinson, Executive Director (personal conversation, 23 March 2006).*

****This is not a Highlands water supply system, but it does receive water through the Wanaque South Project, which is located on the Pompton River within the Highlands.*

PASSING FLOWS

Passing flows are used to provide stream flows below a reservoir, both for ecological maintenance and for supporting downstream water uses. In most cases these passing flow requirements are established through the water allocation permit process administered by NJDEP. One exception is the Raritan System, where three passing flows are statutory (along the South Branch and main stem Raritan River) and passing flows from the reservoirs are regulatory. Others have been the subject of litigation, with the results incorporated into water allocation permits. The State has the authority to reduce passing flows during a drought emergency declared by the Governor.

There actually are two types of passing flows – augmentation releases from reservoirs to maintain downstream flow at specified levels, and flow levels at which withdrawals from streams must cease. The latter category applies to direct stream withdrawals for water uses such as golf course irrigation. Passing flows that restrict pumping also apply to pumped storage projects (e.g., Wanaque Reservoir, Round Valley Reservoir) that transfer water from streams to reservoirs that are not naturally within the watersheds of those streams. No water can be pumped to these reservoirs when stream flows are or would be equal to or lower than the passing flows. Passing flows for several systems are identified in the table entitled *Passing Flows of Highlands Reservoirs and Surface Water Intakes*.

Given the nature of the reservoirs in this table, it is worth noting that only the Newark System has multiple reservoirs in the same watershed with a passing flow only established for the furthest downstream reservoir. In the North Jersey District Water Supply Commission's system, the Monksville Reservoir discharges directly to the Wanaque Reservoir, negating the need for a passing flow. In the Jersey City and Raritan Systems, all reservoirs have passing flows. The implications of the Newark System requirements are that stream flows downstream of the upper reservoirs are apparently not protected.

The passing flow requirement for a reservoir has a major impact on the reservoir safe yield. Higher passing flow requirements will lower safe yields, all other factors being equal, because during a drought the passing flow competes with the reservoir's ability to meet public water supply demand. Therefore, safe yields increase with lower passing flows, while downstream water uses benefit from higher passing flows. Ecosystems also benefit from providing flow patterns that at least approximate natural patterns. NJDEP has a responsibility to address all of these interests through water allocation permits (except for the Raritan System, as noted above, where the passing flows are set by statute).

Historically, NJDEP has used a specific volume per square mile to set the passing flow for reservoirs (with due consideration for the effects of any upstream allocations), which addresses differences in watershed size but not in watershed characteristics. In other situations, detailed ecological and hydrologic studies have provided watershed-specific passing flow requirements to protect downstream ecosystems and other interests.

As a result, passing flows during the most severe droughts can exceed the natural base flow (e.g., the incoming stream and ground water flows to the reservoir when precipitation has not recently occurred). Rainfall events during droughts can exceed passing flows, and therefore will be captured in the reservoir as storage.

Implications of Safe Yields for Water Availability

The Water Supply Management Act of 1981 (WSMA, N.J.S.A. 58:1A-1 et seq.) provides NJDEP with the authority and responsibility to allocate water supplies to applicants for all water diversions above 50,000 gallons per day in the Highlands Preservation Area (N.J.S.A. 58:1A-5.1) and 100,000 gallons per day elsewhere in the state (N.J.S.A. 58:1A-5). The WSMA does not provide specific thresholds for NJDEP decisions, but rather lists findings that NJDEP must make in granting an allocation. NJDEP must among other points allocate "to assure the citizens of the State an adequate supply of water under a variety of conditions." The WSMA places limits on the ability of NJDEP to allocate quantities below current usage plus those "reasonably required for a demonstrated future need."

Under two narrative requirements of the WSMA, at N.J.S.A. 58:1A-5(b), NJDEP also must ensure that:

"(2) Only the permitted quantity of water is diverted and that the water is only used for its permitted purpose;

(3) The water quality of the water source is maintained and the water standards for the use of the water are met;"

Passing Flows of Highlands Reservoirs and Surface Water Intakes

Surface Water Supply System	Reservoir or Reservoir System	Passing Flows (MGD)	Reference
Boonton (Town of)	Taylortown	No listing	Task 2 Report, NJSWSP
Butler (Town of)	Kakeout	No listing	Task 2 Report, NJSWSP
Hackettstown Municipal Utilities Authority	Upper and Lower Mine Hill	No listings	Task 2 Report, NJSWSP
	Burd		
Jersey City (City of)	Boonton	7	Task 2 Report, NJSWSP
	Splitrock	5	Task 2 Report, NJSWSP
Newark (City of)	Pequannock System	0.4 12.3*	Task 2 Report, NJSWSP NJDEP, 2004
Newton	Lake Morris	No listing	Task 2 Report, NJSWSP
NJ Water Supply Authority Raritan River System	Spruce Run Reservoir	5	NJWSA 2005
	South Branch Raritan River, Stanton Station	40	NJWSA 2005
	Raritan River, Manville	70	NJWSA 2005
	Raritan River, Bound Brook	90	NJWSA 2005
North Jersey District Water Supply Commission	Wanaque Reservoir	10	Task 2 Report, NJSWSP
	Ramapo River Pump Station	40**	Task 2 Report, NJSWSP
	Wanaque South Project	92.6***	Personal communication, Dr. Pen Tao, 17 May 2006
	Monksville Reservoir	0****	Task 2 Report, NJSWSP
Southeast Morris County Municipal Utilities Authority	Clyde Potts	0.13	Personal communication, William Hutchinson, 05/16/06

* The Pequannock River TMDL for temperature includes a flow requirement that has been incorporated into the water allocation permit for this river system but is being contested at the time of this report. Therefore, both the pre-existing and new passing flows are provided.

**Ramapo River Pump Station may not be used during the months of July and August

*** Wanaque South Project Pump Station may not be used during the months of July and August, when the 24-hour dissolved oxygen level drops below 5 mg/L, or when the project would cause the river temperature to rise above 28o C. The DO restriction has not been a factor in pumping since the early 1990's, subsequent to wastewater treatment plant upgrades, and the temperature restriction reportedly has never been a factor.

**** Monksville Reservoir discharges directly to the Wanaque Reservoir with no intervening stream; no passing flow is required.

The Water Allocation Rules at N.J.A.C. 7:19-8 provide some additional information regarding the process for determining whether a proposed new or increased water allocation may be granted that affects surface water supplies. N.J.A.C. 7:19-6.3 allows NJDEP to mandate the preparation of a safe yield by any surface water purveyor, and requires that contracts for water sales not exceed that safe yield. N.J.A.C. 7:19-2.2, regarding applications for water allocation permits, requires that applicants assess the "expected impacts of the diversion both on the resource and on other users of that resource," including information establishing "that the plans for the proposed diversion are just and equitable to the other water users affected thereby, and that the withdrawal does not adversely affect other existing withdrawals, either ground or surface;" and states that failure to do so will result in denial of the permit. Note that the latter test is two-pronged. The diversion must be both "just and equitable" and "not adversely affect other existing withdrawals."

New or increased water diversions upstream of reservoirs therefore may be limited or rejected unless they can prove that they will not harm the existing safe yield, which would "adversely affect other existing withdrawals." Safe yield models are generally developed using a combination of water movement into the reservoir, passing flows to the stream below the reservoir, and operational protocols. If the safe yield for a reservoir is based upon the full existing water flow from a watershed or watersheds, then it may be very difficult for a new, upstream diversion to prove that it does not harm the downstream safe yield, unless the new diversion is non-consumptive, is operational only when it would not reduce reservoir storage or is balanced by mitigation measures.

Most water diversions are at least partially consumptive, most water uses are operational during dry periods when they would reduce reservoir storage, and few, if any diversions include mitigation of stream flow impacts. A new, upstream reservoir may be able to address these constraints by providing passing flows in critical periods, but previous NJDEP studies have identified no potential major reservoir sites in the Highlands area (URS, 1984). Therefore, new storage sites would be small, at best, and inherently would be limited to providing very limited additional safe yields. Another possibility is for increased consumptive uses to be balanced by increased recharge or return flows, to eliminate impacts on stream base flow or overall flow.

For this reason, available water from watersheds upstream of Highlands reservoirs may face major constraints due to the existing safe yields (as documented in water allocation permits for the reservoir systems) and the statutory requirement that no harm come to existing withdrawals.

In addition, many tributary watersheds to Highlands reservoirs are in the Preservation Area, where NJDEP must ensure "maintenance of stream base flows." This provision complements and strengthens the constraints resulting from existing safe yields. There is one possible exception to the restrictions on new, upstream diversions. Some reservoirs may have safe yields that do not require maintenance of the full, existing or natural stream flow regime (e.g., where stream flows have been artificially increased in the years since the safe yield model was developed). In these cases, and especially where the diversions are within the Planning Area, additional diversions may be viable. However, a number of the safe yield models are either dated and lack documentation on flow assumptions, or have been prepared very recently and are not in the public domain. The result is no detailed analysis exists that identifies which surface water supply systems do or do not require the full historic flow from upstream areas to maintain their safe yields. Given this, the assumption must be that all safe yields are based on and require maintenance of the historic stream flows. This assumption is conservative and appropriate for the Regional Master Plan, with the understanding that specific water supply watersheds can be evaluated in more detail at a later date as needed.

ANALYSIS OF GROWTH IN AREAS THAT RELY ON HIGHLANDS WATER SUPPLIES

This section provides the results of a New Jersey Geological Survey (NJGS) analysis of 2030 growth projections for water systems outside of the Highlands that utilize water from within the Highlands. The data used to develop the spreadsheet come from the NJGS New Jersey Water Transfer Model: 5-04 load (NJWaTr). This MS Access database contains information from multiple NJDEP programs, as well as information from other state and federal sources.

The analysis work focused on the North Jersey District Water Supply Commission, Passaic Valley Water Commission, City of Newark-Pequannock, and Jersey City-Rockaway water supply systems. The NJ American Water Company Elizabethtown system was also included, as it has sources and serves municipalities both inside and outside of the Highlands. It should be noted the City of Newton, outside of the Highlands, appears to periodically receive up to 1 MGD of water from its supply in Sparta Township, which is located within the Highlands.

FUTURE WATER DEMAND

The Metropolitan Planning Organization (MPO) municipal population projection data were used to estimate 2030 population growth for each of the water systems receiving water from the Highlands. Municipal population growth data were compiled from the North and South Jersey Transportation Planning Authorities, and the Delaware Valley Transportation Planning Authority in Spring 2005. Bulk sales information contained in the NJWaTr model was used to determine which water systems receive water from within the Highlands.

The 2030 MPO municipal population growth was assigned to a water supply system based on the areal percentage of the municipality covered by the service area of each water system. In other words, if 80% of a municipality was covered by Water Company A, 10% was covered by Water Company B, and 10% was not covered by a water company (and therefore assumed to be served by private domestic wells), the 2030 total municipal population growth for that municipality was distributed to each water system or source using the same percentages. Future population was then summed for each water system and compared to current Bureau of Safe Drinking Water population data to calculate a percentage increase in population. The Department's Water Purveyor Service Areas (1998 Public Community System) GIS coverage was used to calculate the service area and municipality areal intersections. Uncertainly in this analysis is introduced by errors with the GIS shape file and uneven water use within a service area.

Each water supply system typically delivers water to residential, commercial and industrial users. The percentage of total water use that goes to each type of user varies by system. In this analysis, the 2030 percentage increase in population is used as a surrogate for percentage increase in water demand. This implies that the per capita use rates and the ratio of residential, commercial and industrial users will remain the same. This analysis also assumes that the 1999 water transfer patterns remain the same in 2030, i.e., that the current sources will supply water in the same proportions that they did in 1999. Any bulk sales contracts or modifications that have been formalized since 1999 are not reflected in these tables, as information was not available for them.

SUMMARY OF RESULTS

The table titled *Potable Water Systems outside the Highlands that Utilize Water Originating within the Highlands by Source* contains information for each of the five main water supply systems located within the Highlands and the volumes of water they currently and are projected to transfer outside of the Highlands. The table contains "from" and "to" system names, the current and projected growth for each receiving system, the volume transferred in 1999, and the projected volume transferred in 2030 based on the population growth analysis. It also compares the volumes transferred to the safe yield of the "from" system. The "to" systems may appear multiple times if they receive water from more than one of the "from" systems. The table is included to provide a picture of the distribution of transfers and the relative changes projected over time for each of the "to" systems. The safe yields are included to give a qualitative comparison of demand and surface water availability on an annual basis.

The table *Potable Water Systems inside the Highlands that Utilize Water Originating from Highlands Sources* contains transfers from the five main systems referenced in the previous table to water systems located within the Highlands. This table was included so all of the transfers from the five main water systems could be accounted for. The table *Summary of Population Growth for Potable Water Systems Outside the Highlands Region that Utilize Water Originating with the Highlands Region* summarizes current and projected growth for each of the systems that receive water from within the Highlands. These systems all appear as "to" sites in the first table referenced in this summary of results. Each "to" system is listed only once in the table.

The table *Total System Withdrawals for Five Potable Water Systems for the 1990 to 1999 Period* summarizes the total systems withdrawals for each of the five major potable water systems supplying water as discussed. It is included to put the 1999 volumes used in the other tables into perspective. The table indicates that 1999 volumes are within a reasonable range of the volumes and trends observed over the 1990s decade.

The figure titled *Service Areas and Projected Change in Water Demand* shows a map of the water systems that receive water from one of the five sources located within the Highlands. The receiving water systems are color-coded based on the 2030 population growth.

CONCLUSIONS

Projections of water demands to the year 2030 indicate that several reservoirs in the Highlands Region may have insufficient amounts of water to provide for anticipated future water needs. In collaboration with the Highlands Council, the New Jersey Geological Survey developed projections of population growth to the year 2030 focusing on major public community water systems outside the Highlands Region, yet served by Highlands water. The growth analysis projects that sustainable capacity will be exceeded by major cities like Newark, Jersey City, and Hackensack.

The results of this analysis clearly identify the complex nature of the Northeast New Jersey water supply systems. NJGS was not able to assess demand against safe yield for Passaic Valley Water Commission (PVWC) because that system engages in a very large amount of "water wheeling," moving water from one area to another by both purchasing and selling large quantities of water. PVWC is a customer of North Jersey District Water Supply Commission (NJDWSC), and so draws safe yield both from its own system and NJDWSC, but also provides water to many customers itself.

NJDWSC provides water to many customers, including United Water-NJ through its Hackensack system. During a severe drought, these customers will draw more water than they did in 1999, making an assessment of "committed flows" difficult. As a major example, United Water-NJ and Newark tend to take water from NJDWSC primarily during dry periods, but not when their own reservoirs have sufficient yields to handle system needs. For this reason, they can show a safe yield deficit on their own reservoirs that is addressed by their contracts with NJDWSC, as long as NJDWSC has available yield to make up the differences.

Potable Water Systems Outside The Highlands Region that Utilize Surface Water Originating Within The Highlands by Source

In NJ Highlands		Outside NJ Highlands									
From DWSA	From DWSA Name	To DWSA	To DWSA Name	PWSID	Current Population	2000-2030 DWSA Pop. Change	Per. Pop. Change 2000-2030	1999 Transfer (mgy)	1999 Per. Of Safe Yield	2030 Volume (mgy)	2030 Per. Of Safe Yield
DW Service Area 1613001	**North Jersey District WSC**	**Combined NJDWSC** [1]	--		**1,631,783**	**254,424**	16%	**41,047**	65%	48,220	76%
		DW Service Area 159	CEDAR GROVE WATER DEPT	704001	12,300	898	8%	677	1%	733	1%
		DW Service Area 164	Glen Ridge Water Department	708001	8,000	643	9%	145	0%	158	0%
		DW Service Area 166	Montclair Water Bureau	713001	38,652	5,973	16%	1,686	3%	1,948	3%
		DW Service Area 167	NEWARK CITY	714001	273,000	39,567	14%	13,465	21%	15,395	24%
		DW Service Area 169	Nutley Water Department	716001	27,362	1,960	8%	1,386	2%	1,496	2%
		DW Service Area 200	BAYONNE MUA	901001	61,000	9,590	23%	3,563	6%	4,377	7%
		DW Service Area 205	KEARNY W DEPT	907001	40,500	5,092	16%	2,257	4%	2,613	4%
		DW Service Area 313	LINCOLN PARK WATER DEPT	1416001	10,000	40	1%	372	1%	375	1%
		DW Service Area 423	Passaic Valley Water Commission	1605002	314,900	66,695	22%	12,312	19%	15,023	24%
		DW Service Area 428	Wayne Twp Water Div	1614001	46,485	10,801	20%	2,869	5%	3,442	5%
		DW Service Area 43	United Water - Hackensack [2]	238001	784,084	111,810	15%	2,312	4%	2,658	4%
		DW Service Area 44	NORTH ARLINGTON W DEPT	239001	15,500	1,355	12%	3	0%	3	0%
DW Service Area 204	**United Water - Jersey City**	**Combined UW-JC**	--		**1,071,881**	**186,467**	17%	**18,609**	90%	23,585	114%
		DW Service Area 204	United Water - Jersey City	906001	228,997	62,566	28%	16,298	79%	20,919	101%
		DW Service Area 43	United Water - Hackensack	238001	784,084	111,810	15%	2,312	11%	2,665	13%
		DW Service Area 203	HOBOKEN WATER SERVICES	905001	39,000	8,551	22%	unknown	na	na	na
		DW Service Area 40	LYNDHURST WATER DEPARTMENT	232001	19,800	3,540	34%	unknown	na	na	na
DW Service Area 423	**Passaic Valley Water Commission**	**Combined PVWC** [3]	--		**1,936,488**	**326,732**	17%	**17,050**	na	na	na
		DW Service Area 423	Passaic Valley Water Commission	1605002	314,900	66,695	22%	17,823	65%	21,748	79%
		DW Service Area 159	CEDAR GROVE WATER DEPT	704001	12,300	898	8%	80	0%	86	0%
		DW Service Area 163	Fairfield Water Dept	707001	8,000	339	9%	544	2%	594	2%
		DW Service Area 167	NEWARK CITY	714001	273,000	39,567	14%	0	0%	0	0%
		DW Service Area 168	NORTH CALDWELL WATER DEP	715001	6,000	-663	-9%	11	0%	10	0%
		DW Service Area 169	Nutley Water Department	716001	27,362	1,960	8%	1,386	5%	1,496	5%
		DW Service Area 173	VERONA WATER DEPARTMENT	720001	13,641	1,568	12%	515	2%	574	2%
		DW Service Area 174	WEST CALDWELL W DEPT	721001	10,485	1,238	18%	6	0%	7	0%
		DW Service Area 202	HARRISON W DEPT	904001	14,425	3,258	23%	379	1%	465	2%
		DW Service Area 204	United Water- JC [4]	906001	228,997	62,566	28%	0	0%	0	0%
		DW Service Area 231001	Lodi Water Department [5]	231001	22,598	3,082	12%	0	0%	0	0%
		DW Service Area 313	LINCOLN PARK WATER DEPT	1416001	10,000	40	1%	372	1%	375	1%
		DW Service Area 35	ELMWOOD PARK WATER DEPT	211001	18,925	2,440	13%	826	3%	932	3%
		DW Service Area 36	Fairlawn Water Dept	217001	32,000	2,028	7%	664	2%	707	3%
		DW Service Area 38	Garfield Water	221001	29,786	5,073	18%	647	2%	763	3%
		DW Service Area 420	HALEDON BOROUGH WATER DEPT.	1603001	9,642	3,347	32%	424	2%	557	2%
		DW Service Area 421	Hawthorne Water Dept	1604001	19,099	3,139	17%	0.1	0%	0.1	0%
		DW Service Area 422	NJ American Water Co- Little Falls	1605001	11,247	1,702	14%	3,922	14%	4,453	16%
		DW Service Area 426	TOTOWA W DEPT	1612001	9,512	2,641	27%	509	2%	644	2%
		DW Service Area 428	Wayne Twp Water Div [6]	1614001	46,485	10,801	20%	0	0%	0	0%
		DW Service Area 43	United Water- Hackensack [7]	238001	784,084	111,810	15%	0	0%	0	0%
		DW Service Area 44	NORTH ARLINGTON W DEPT	239001	15,500	1,355	12%	610	2%	685	3%
		DW Service Area 441	WEST PATERSON W DEPT	1616001	6,500	763	16%	261	1%	303	1%
		DW Service Area 51	Wallington Water Dept	265001	12,000	1,085	10%	384	1%	422	2%
DW Service Area 167	**Newark City**	**DW Service Area 167**	**Newark City** [8]	**714001**	**273,000**	**39,567**	14%	**17,258**	96%	19,730	110%
DW Service Area 526	**NJAWC-Elizabethtown**	**DW Service Area 526**	**NJAWC-Elizabethtown** [9]	**2004002**	**609,241**	**135,450**	19%	**35,098**	64%	41,704	76%

Notes:

All volumes are in millions of gallons per year (mgy)

1- NJDWSC safe yield caclulated using 173 mgd (includes United Water's 39.5 portion)

2- UW- Hackensack has ownership of 39.5 mgd from NJDWSC's Wanaque South Project

3- PVWC purchased 12,312 mgy and sold 12,327 mgy in 1999, total use reduced by purchases

Combined 1999 and 2020 Percent of SY and 2030 demand not calculated due to complications from large purchases and sales by PVWC

4- UW- JC no reported purchases during 1990s

5- Lodi purchased 485 mgy in 1997

6- Wayne no reported purchases during 1990s

7- UW-Hackensack purchased 0 mgy in 1998, 21 mgy in 1997, and 93 mgy in 1996

8- Newark purchased 13,465 mgy from NJDWSC in 1999

9- Less than 1% of the population served by NJAWC- Elizabethtown is located in the Highlands Region. 1999 volume includes water used within the entire system. E-town sold 13,772 mgy in 1999.

10- Sparta Water Department within the Highlands has transferred water to Newton Water Department outisde of the Highlands on an emergency basis (110 mgy in 2000 and 347 mgy in 2001).

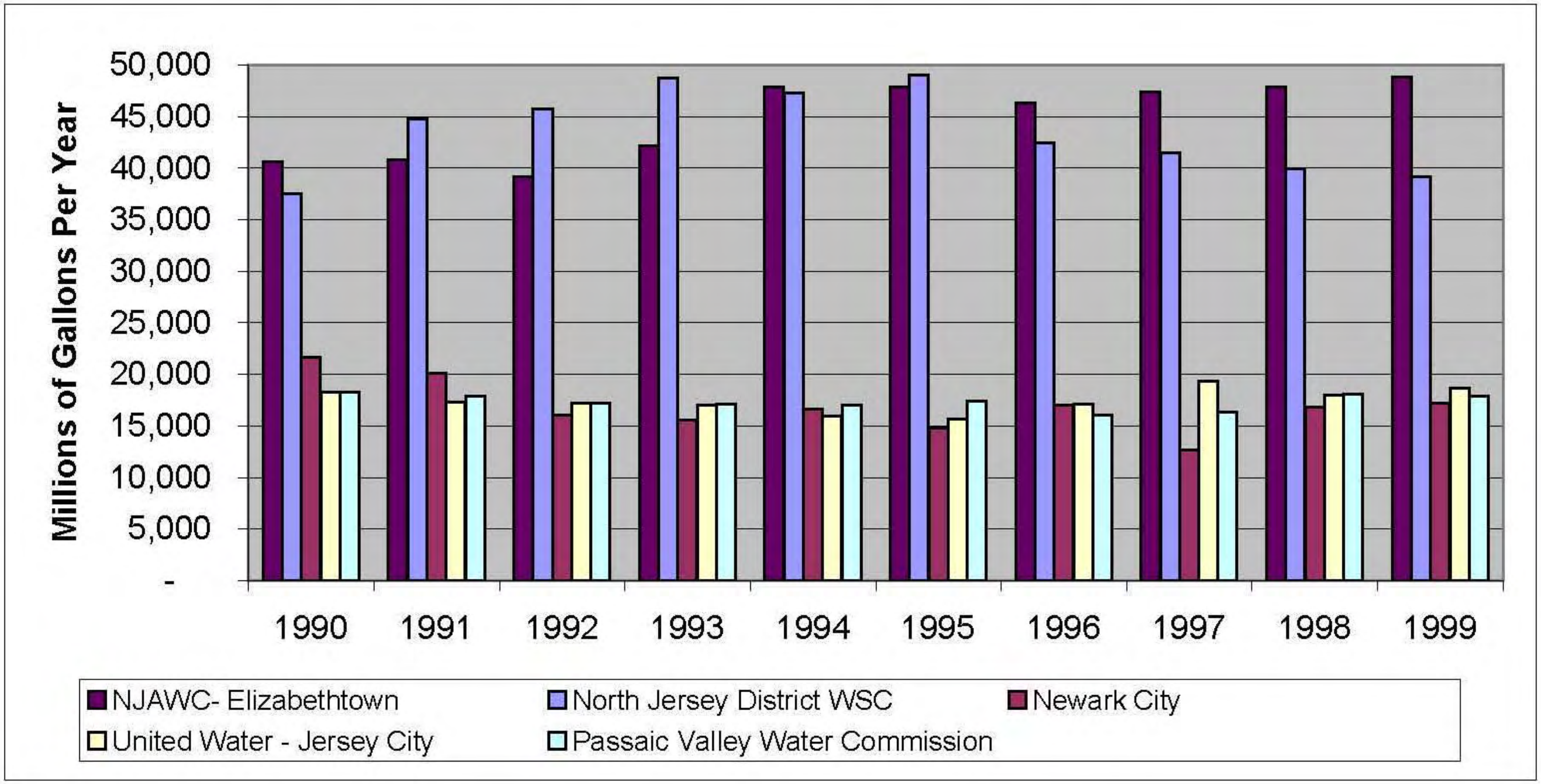
Potable Water Systems Inside The Highlands Region that Utilize Water Originating from Highlands Sources

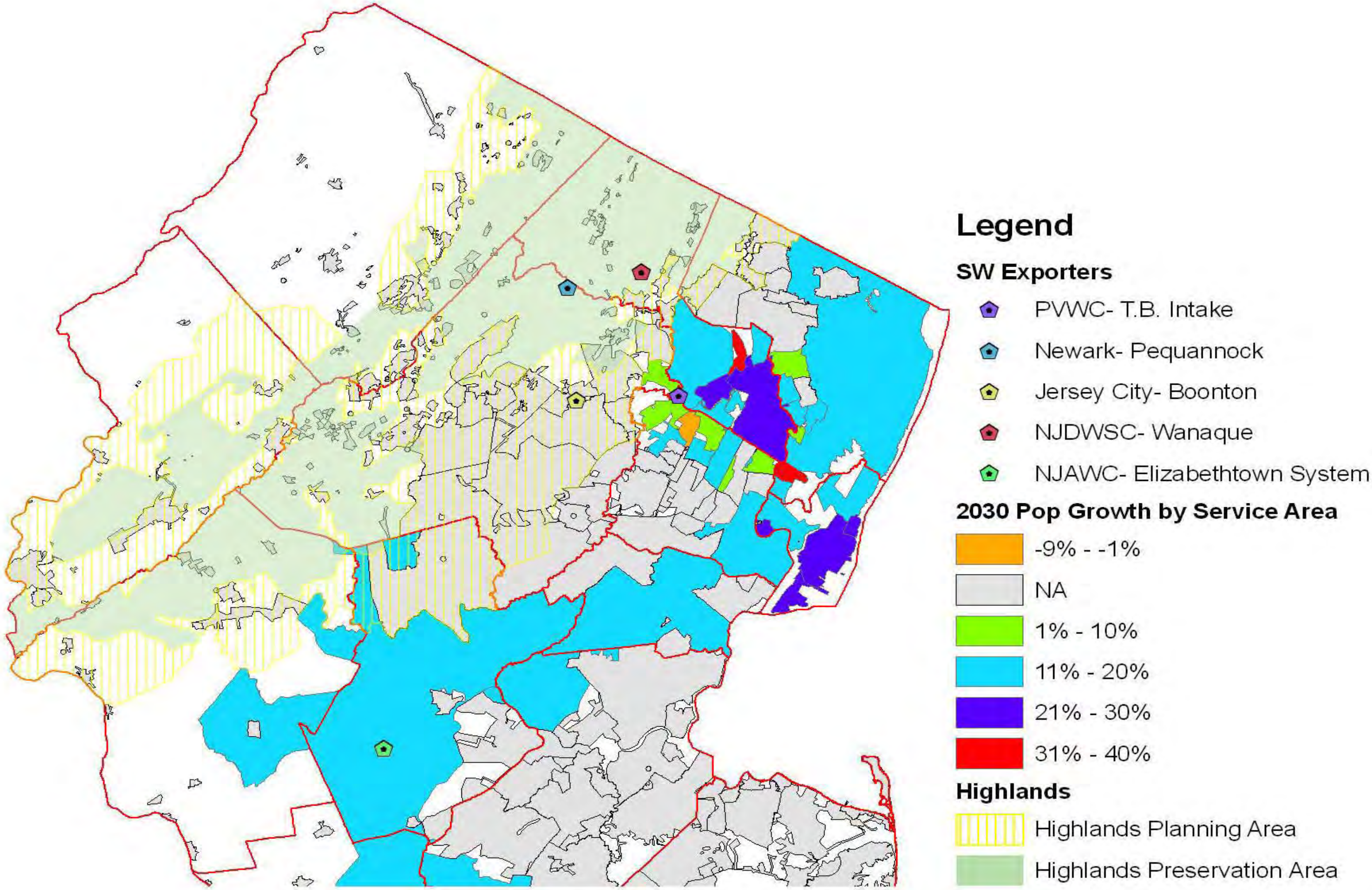
From DWSA	From DWSA Name	To DWSA	To DWSA Name	PWSID	BSDW Population	1999 Volume (mgy)
DW Service Area 1613001	North Jersey District WSC	DW Service Area 339	Riverdale Boro Water Dept	1433001	3,000	38
		DW Service Area 419	BLOOMINGDALE WATER DEPT	1601001	5,000	177
		DW Service Area 425	Ringwood Water Dept	1611002	8,634	64
DW Service Area 423	Passaic Valley Water Commission	DW Service Area 321	Southeast Morris County MUA	1424001	64,500	504
		DW Service Area 339	Riverdale Boro Water Dept	1433001	3,000	43
		DW Service Area 419	BLOOMINGDALE WATER DEPT	1601001	5,000	177
		DW Service Area 425	Ringwood Water Dept	1611002	8,634	63

Summary of Population Growth for Potable Water Systems Outside The Highlands Region that Utilize Water Originating within The Highlands Region

#	DWSA Name	DWSA	PWSID	BSDW Current Population	2030 Population Increase	Percentage Change
1	BAYONNE MUA	DW Service Area 200	901001	61,000	9,590	23%
2	CEDAR GROVE WATER DEPT	DW Service Area 159	704001	12,300	898	8%
3	ELMWOOD PARK WATER DEPT	DW Service Area 35	211001	18,925	2,440	13%
4	Fairfield Water Dept	DW Service Area 163	707001	8,000	339	9%
5	Fairlawn Water Dept	DW Service Area 36	217001	32,000	2,028	7%
6	Garfield Water	DW Service Area 38	221001	29,786	5,073	18%
7	Glen Ridge Water Department	DW Service Area 164	708001	8,000	643	9%
8	HALEDON BOROUGH WATER DEPT.	DW Service Area 420	1603001	9,642	3,347	32%
9	HARRISON W DEPT	DW Service Area 202	904001	14,425	3,258	23%
10	Hawthorne Water Dept	DW Service Area 421	1604001	19,099	3,139	17%
11	HOBOKEN WATER SERVICES	DW Service Area 203	905001	39,000	8,551	22%
12	KEARNY W DEPT	DW Service Area 205	907001	40,500	5,092	16%
13	LINCOLN PARK WATER DEPT	DW Service Area 313	1416001	10,000	40	1%
14	Lodi Water Department	DW Service Area 231001	231001	22,598	3,082	12%
15	LYNDHURST WATER DEPARTMENT	DW Service Area 40	232001	19,800	3,540	34%
16	Montclair Water Bureau	DW Service Area 166	713001	38,652	5,973	16%
17	NEWARK CITY	DW Service Area 167	714001	273,000	39,567	14%
18	NJ American Water Co- Little Falls	DW Service Area 422	1605001	11,247	1,702	14%
19	NJAWC- Elizabethtown	DW Service Area 526	2004002	609,241	135,450	19%
20	NORTH ARLINGTON W DEPT	DW Service Area 44	239001	15,500	1,355	12%
21	NORTH CALDWELL WATER DEP	DW Service Area 168	715001	6,000	-663	-9%
22	Nutley Water Department	DW Service Area 169	716001	27,362	1,960	8%
23	Passaic Valley Water Commission	DW Service Area 423	1605002	314,900	66,695	22%
24	TOTOWA W DEPT	DW Service Area 426	1612001	9,512	2,641	27%
25	United Water- Hackensak	DW Service Area 43	238001	784,084	111,810	15%
26	United Water- JC	DW Service Area 204	906001	228,997	62,566	28%
27	VERONA WATER DEPARTMENT	DW Service Area 173	720001	13,641	1,568	12%
28	Wallington Water Dept	DW Service Area 51	265001	12,000	1,085	10%
29	Wayne Twp Water Div	DW Service Area 428	1614001	46,485	10,801	20%
30	WEST CALDWELL W DEPT	DW Service Area 174	721001	10,485	1,238	18%
31	WEST PATERSON W DEPT	DW Service Area 441	1616001	6,500	763	16%
	Combined			**2,752,681**	**495,571**	**18%**

Total System Withdrawals for Five Potable Water Systems for the 1990 to 1999 Period





Service Areas and Projected Change in Water Demand

The NJ American-Elizabethtown and Jersey City systems are easier to assess. The former relies on safe yield from the Raritan System, provided for by the NJ Water Supply Authority's Raritan Basin System, with additional ground water supplies in several parts of the NJ American-Elizabethtown service area. The latter system relies on its two reservoirs, which show a projected 2030 deficit based on anticipated growth in Jersey City. If that deficit occurs, it raises questions about any contracts for water sales from that system to other communities and whether Jersey City could get additional supply from another system with available safe yield.

For the other systems, the best approach may be to look at the aggregate safe yields of the supplies (NJDWSC, Newark, PVWC and United Water-NJ) and compare them to the total 2030 demands. These systems are all both physically and contractually interconnected, and deficits in one purveyor's system could be addressed through contractual arrangements with another interconnected system. Another approach would require research into the detailed contractual relationships, which can change over time. NJDEP will need to address this issue in more detail through the updated NJ Statewide Water Supply Plan.

WATER QUALITY AND SAFE YIELDS

The New Jersey Statewide Water Supply Plan (NJDEP, 1996a) emphasizes the need to protect ambient water quality so that water supplies are not degraded or lost to use.

In general, surface water supply treatment systems have become more sophisticated over time. Water purveyors have adopted techniques such as ozonation (a water treatment process that destroys bacteria and other microorganisms through an infusion of ozone), ultraviolet radiation (also used for treating pathogens), and activated carbon filtration (for removal of, among other substances, industrial chemical contaminants) to purify water supplies. However, ambient water quality degradation can significantly affect the provision of potable water, including an increase in the costs of running such systems, and result in the need to upgrade treatment further to protect public health.

Water purveyors have adopted or are moving to what is referred to as a "multi-barrier approach" to water supply, involving source water protection to limit contamination of raw water coming to the treatment plant, in concert with treatment to achieve safe drinking water standards (or better), and post-treatment chlorination to ensure that bacteria do not contaminate the potable water in the distribution system.

As noted earlier, the Highlands Act recognizes the importance of protecting the quality and quantity of the resource, in order to, among other things, protect and maintain water supplies. This protection is embodied in the Act as a major purpose for improved planning and justification for imposition of more stringent land use regulations.

Source water protection is a relatively new term, included in the federal Safe Drinking Water Act Amendments (SDWAA) of 1996. The 1996 federal legislation required all states to develop source water assessments that informed water supply purveyors (public community and public non-community) and their customers about potential risks to source water quality. The NJDEP was New Jersey's lead for this process, described at www.state.nj.us/dep/watersupply/swap.htm. Each water supply system now has a source water assessment report that inventories potential risks and establishes vulnerability levels for their source waters. The risks and vulnerability levels are combined to assess the susceptibility of water supplies by classes of contaminants. NJDEP has also identified potential pollutant sources within source water areas for Highlands Region reservoir systems and surface water supplies.

All surface water supplies are considered to have a high susceptibility to pathogens (disease-causing viruses and bacteria) and to the creation of disinfection by-products, which may be toxic or carcinogenic. In both cases, natural contaminants are a significant issue, but land uses and human activity can increase the risk to water supply systems. Susceptibility to contamination by nutrients, pesticides and inorganic chemicals is heavily dependent on the nature of the source water area, including land use and other human activity. Susceptibility to radon and radionuclide contamination is considered low for all surface water supplies, based on water quality monitoring results. Source water protection for surface water supplies and for public community water supply wells is addressed in more detail in a separate section of this Technical Report.

The 1996 SDWAA do not require specific actions for source water protection and NJDEP does not require water purveyors to conduct source water protection activities for existing water supply sources. There are only limited requirements for new potable sources. The lack of such requirements reflects the fact that water supply watersheds generally are not owned in full by the water purveyor, among other factors. Water purveyors have no regulatory authority to impose requirements on other landowners. New Jersey relies on its many pollution control programs (e.g., control of point source discharges; stormwater from construction sites, municipal systems and industries; septic systems; underground storage tanks; waste management facilities) and its remedial programs for hazardous waste sites to protect water supplies. Water supply treatment requirements are in place to address any contamination that may occur despite these control programs.

Historically, surface water supplies have been subject to potential contamination, which has been addressed in part by the imposition of wastewater treatment requirements. No major surface water supplies have been abandoned as a result of contamination of the water resource in recent decades, due to improvements in water supply treatment technology and the lack of feasible alternatives to existing supplies. Some very small supplies have been abandoned because more stringent drinking water standards made treatment too expensive to justify. Therefore, while it is clear that source water protection is a critical component in protecting water supplies, and surface water supply contamination can result in increases in treatment costs, it is unlikely to result in loss of a major supply as long as surface water quality standards are met for the source waters.

There are three potential situations where surface water safe yields can be impaired due to the degradation of ambient water quality:

- As noted above, there are some small reservoirs with very limited safe yields. As operation and treatment costs increase, source water quality degradation could compromise the economic viability of continued facility operation and result in their abandonment;
- Pumped storage to reservoirs can result in water quality impacts that foster "taste and odor" complaints and elevated treatment by-products due to algal growths in the reservoir, resulting in decisions to pump from these reservoirs more selectively or less often; and
- Safe yields may need to be limited so that ecological impacts in the watershed are minimized.

One example of this limitation exists where thresholds for dissolved oxygen and temperature in the source river restrict pumping to a reservoir. As noted above, the Wanaque South Pumping Station may only pump to the Wanaque Reservoir from September through June, and when dissolved oxygen levels exceed 5.0 mg/L. In this case, the restrictions are in place to protect the river from the effects of pumping, rather than to protect the reservoir from contaminants in the river. Water quality improvements in the Pompton River have lessened the impact of the dissolved oxygen requirement, but degradation could raise concerns in the future.

POTENTIAL IMPACTS OF CLIMATE CHANGE

Surface water supply issues may be complicated by future changes in climate, such as those predicted from global warming models. Most models address climate change over large areas and do not directly address the question of surface water safe yields. However, a USGS report (Ayers, 1994) studied potential impacts on Delaware River basin water supplies. The report found that:

> "Daily simulations of basin stream flow indicate that climate has the strongest effect on maximum daily flow, mean daily flow, evapotranspiration, and 7-day low flow. These results indicate that the differences in most of the hydrologic characteristics for small basins in the Delaware River basin are due to differences in climate from one part of the basin to another."
>
> Further, "Simulations of daily and monthly stream flow indicate that a transient warming trend would increase the proportion of winter precipitation that falls as rain, increase winter runoff, reduce snow accumulation, and reduce spring runoff in the northern part of the basin. A warming of 4°C could increase basin-wide evapotranspiration and reduce annual basin runoff by as much as 25 percent if current precipitation patterns continue. An increase in precipitation of about 3 percent would be needed to counteract decreases in stream flow that would result from each 1°C of warming."

However, the report also noted: "Distinguishing carbon dioxide-induced changes in climate from natural variability and measurement error is difficult."

While climate change research over the last ten years has improved estimates of climate change predictions for this region, the natural variability in stream flows and precipitation still pose problems for analysis of the impact of climate change. However, the Ayers report provides a starting point for considering such impacts, where precipitation changes would have a greater influence on watershed flows than temperature changes.

The USEPA 1997 publication "Climate Change and New Jersey" notes that:

> "Over the next century, New Jersey's climate may change even more. Based on projections given by the Intergovernmental Panel on Climate Change and results from the United Kingdom Hadley Centre's climate model (HadCM2), a model that accounts for both greenhouse gases and aerosols, by 2100 temperatures in New Jersey could increase about 4°F (with a range of 2-8°F) in winter and spring, and slightly more in summer and fall, if greenhouse gas emissions are not controlled. Precipitation is projected to increase by 10-20% (with a range of 0-40%), with slightly less change in spring and slightly more in winter. The amount of precipitation on extreme wet (or snowy) days most likely would increase, but changes in the lengths of wet or dry spells are not clear. The frequency of extreme hot days in summer is expected to increase along with the general warming trend. It is not clear how severe storms such as hurricanes would change."

The impact of more rainfall in more intense storms, with drier periods between due to higher temperatures, cannot easily be estimated. The increase in rainfall could help storage, but having more precipitation runoff rather than recharge could harm storage. Additional analysis of scenarios using safe yield models would be necessary to determine the sensitivity of safe yields to changing runoff conditions.

SOURCE WATER AND WELLHEAD PROTECTION

The Highlands Act authorizes the Highlands Council to:

> "…develop model land use ordinances and other development regulations, for consideration and possible adoption by municipalities in the planning area, that would help protect the environment, including but not limited to, ordinances and other development regulations pertaining to … wellhead and water supply protection…; and to provide guidance and technical assistance in connection therewith to those municipalities wellhead and water supply protection."

The resource assessment required by the act includes these considerations, including the identification of Source Water Protection Areas (SWPA) and Wellhead Protection Areas (WHPA) for potable water sources when determining the land use capacity of the Highlands Region. The objective is to determine the areas supplying potable water through ground water well systems and surface water intakes, and the potential sources of pollution to these sources.

To protect public health, assessing the quality of Highlands Region surface and ground water systems is critical in determining management strategies for water resource protection, including SWPA, WHPA and other potable water protection programs and mechanisms. In addition, protecting potable water supplies and their sources makes economic sense. If potable water is contaminated, the costs of treatment, remediation, monitoring and providing alternate supplies, especially short term replacement water, can be extremely expensive. Source water protection focuses on preserving and protecting public potable water sources.

Source water protection includes contaminant source management and contingency planning. Contaminant source management is developed to prevent potential contaminants from being in close proximity to the potable water source. Such management may be accomplished by implementing land use zoning ordinances to control future activities and development that may harm a water supply source. An example of this is prohibiting gas stations in source water areas. Contaminant source management may also include subdivision regulations that require larger lot sizes and siting of septic systems away from source water areas, hazardous waste collection programs, land acquisition, land donation and conservation easements. In any case, contaminant source management strategies will vary by location due to such factors as soil and geology types, water table levels and existing land uses.

Contingency planning is also very important in source water protection efforts. A contingency plan develops alternative water sources, and should be established for ground or surface water contamination events, or water system failure. Contingency planning also plans long term for additional sources of potable water to account for such things as population growth.

EXISTING REGULATORY FRAMEWORK

Though most Americans receive high quality potable water every day from public water systems and private potable wells, potable water safety cannot be taken for granted. Potential and real threats to potable water include improperly disposed chemicals, leaking underground storage tanks, animal wastes, pesticides, human wastes, wastes injected deep underground and naturally-occurring substances. Also, potable water that is not properly treated or disinfected, or which travels through an improperly maintained distribution system may pose a health risk.

The Federal Safe Drinking Water Act (SDWA) was established to protect the quality of all above ground or underground sources of potable water in the United States. The SDWA requires many actions to protect potable water supplies and their sources, such as rivers, lakes, reservoirs, springs and ground water wells. The SDWA authorizes the United States Environmental Protection Agency (USEPA) to set national health-based standards for potable water to protect against both naturally-occurring and man-made contaminants that may be found in potable water. In addition, the Federal Clean Water Act (CWA) addresses surface water quality by regulating wastewater treatment plants, water discharges and surface water as it is used for recreation, wildlife habitat and fishing.

The Federal Safe Drinking Water Act directed all states to establish Well Head Protection Programs (WHPP), of which WHPA delineations are one component. New Jersey adopted its Wellhead Protection Program Plan in 1991. The 1986 amendments also identified many more contaminants for regulatory control, thereby potentially increasing the contaminants that may be found in a WHPA.

Under the 1996 SDWA amendments, all states are required to establish a Source Water Assessment Programs (SWAP) for public water systems. SWAP plans incorporate the following four fundamental steps:

- Delineate the source water assessment area of each ground and surface water source of public potable water.
- Inventory significant and potential contamination sources within the source water assessment area. Information on contaminant sources can be found in numerous regulatory program databases, including New Jersey Pollution Discharge Elimination System permits; Resource Conservation Recovery Act; Superfund Amendments and Reauthorization Act Title III; and Underground Injection Control. In addition, the NJDEP New Jersey Environmental Management Systems (NJEMS) database is a useful tool to track New Jersey environmental permitting and known contaminated sites. Potential contaminant sources include, but are not limited to sewage disposal, runoff from urban and industrial areas, farm livestock and agriculture, forestry soil disturbance, mining activities, solid and hazardous waste disposal facilities including landfills, and spills from traffic accidents.
- Determine the public water system source's susceptibility to identified contaminants. This assessment should determine the potential for a water supply to intersect with contaminants and their sources at concentrations that pose health concerns. Priorities for protection can then be set by the public and regulatory agencies.
- Summarize assessment for the public and incorporate public education and participation. This last provides tools to the public and local authorities to make informed decisions regarding potable water source protection.

New Jersey passed the Safe Drinking Water Act in 1977, with the most recent New Jersey Safe Drinking Water Act (NJSDWA) Regulations, N.J.A.C. 7:10, adopted by NJDEP on November 4, 2004.

The two types of public water systems regulated in New Jersey are community and non-community systems. A community water system has at least 15 service connections used by year round residents, or regularly serves at least 25 year round residents. An example is a municipal system that services single family residential homes.

A non-community water system is a public water system used by individuals other than year round residents for at least sixty days of the year. This type of water system can be either non-transient or transient. A non-transient, non-community water system serves 25 or more of the same people over a period of six months or more during the year. Examples include such facilities as schools, factories and office buildings. A transient, non-community water system serves year round, but does not serve the same individuals during that time period. Examples include rest stop areas, restaurants and motels.

All Public Community Water Systems and Non-community Water Systems in New Jersey (both ground and surface water sources) have been assessed and their source water assessment reports are available through the NJDEP web site at http://www.nj.gov/dep/swap. Source water assessments provide information for watershed assessment and planning, and can assist in improving land use planning for the Highlands Region. Additional information from these source water assessment reports relevant to the Highlands Region can be found in the technical report entitled Watersheds and Water Quality.

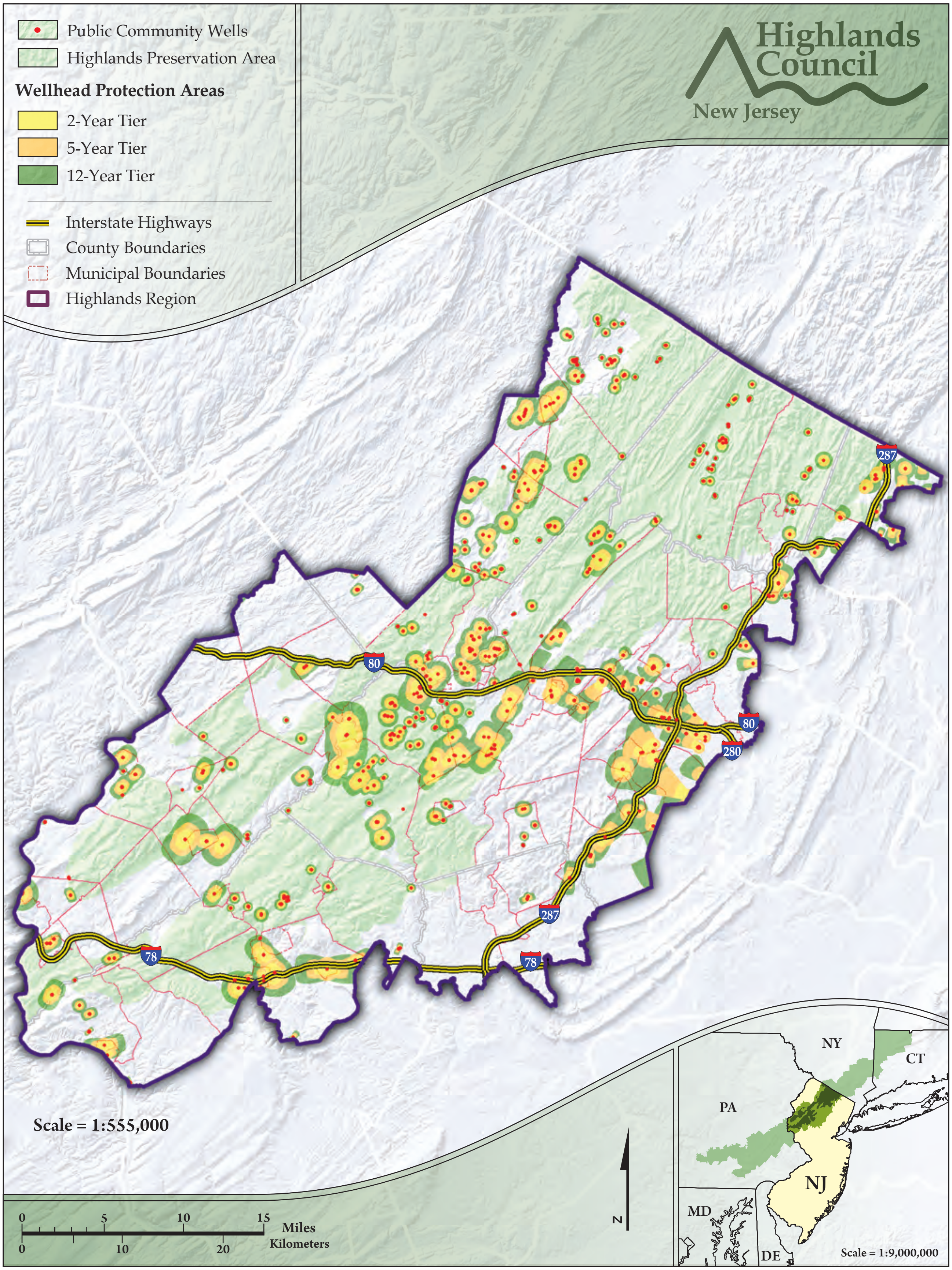
MAPPING OF SOURCE WATER ASSESSMENT AREAS

A Wellhead Protection Area (WHPA) is defined as a mapped area around a public community or non-community water supply well that delineates the horizontal extent of ground water captured by pumping at a specific rate. Once a well is located on the NJDEP Geographic Information System (GIS) database, a source water assessment for ground water is mapped in three tiers. Tier 1 is a two-year time of travel, i.e., the ground water within this tier flows to the well within a two year time period. Tier 2 is equivalent to a five-year time of travel, while Tier 3 is equivalent to a twelve-year time of travel. These travel times were selected to reflect the potential for bacterial and viral contaminant movement (Tier 1), limitations on technological options for preventing long-lived contaminants from reaching a well without interfering with well function (Tier 2) and the longest times of travel customarily seen in New Jersey for plumes of long-lived contaminants (Tier 3).

NJDEP performed ground water source delineations for all public community water systems using the Combined Model/Calculated Fixed Radius Method. Public non-community water systems were delineated using the Calculated Fixed Radius Method. Other methods for ground water source delineations, such as the arbitrary fixed radius method or analytical methods that use computer models and a variety of data points, were not used because they were considered too simple for accuracy or too complex for statewide use, respectively. The WHPAs for public community water supply systems in the Highlands Region are shown in figure *Wellhead Protection Areas*. In many instances wells are located in close proximity to the developed areas they support, posing a significant risk of contamination.

For surface water, the source water area includes the entire drainage area that flows past the intake point. This delineation includes all surface waters within United States Geological Survey (USGS) 14 digit Hydrologic Unit Code (HUC 14) subwatersheds that contribute to the intake, as well as all overland flow to the intake. In addition, a five-year ground water flow delineation is utilized to account for ground water contributions to surface water base flow.

WELLHEAD PROTECTION AREAS



It should be noted that where ground water and surface water intersect and directly influence each other, a comprehensive delineation of both sources should be performed using a Sample Conjunctive (i.e., both surface and ground water) Delineation.

The source water protection areas for the major reservoirs and water supply intakes were previously discussed in this report under the section entitled Surface Water Availability

SOURCE WATER ASSESSMENT PROCESS

The majority of the population in the Highlands Region receives their drinking water from wells. The proper delineation of WHPAs and their protection is therefore to protect public health of particular importance within the Highlands Region.

Source Water Assessment Reports identify the susceptibility of public water system sources to potential contamination, and include a section on the methods used in the analysis. All source water assessments were performed by the NJDEP in cooperation with and utilizing susceptibility models developed by USGS. Models were created for numerous contaminant categories in both ground water and surface water. Susceptibility is determined on several factors such as location, well integrity, land use, and amount and type of potential contaminants within the source water assessment area.

The susceptibility models were created using existing analytical data and a selected set of public water system wells and intakes located throughout the state, and then applied to all public water systems. Results of susceptibility models show that for both surface water and ground water, urban and agricultural land use are the most common variables affecting a source's susceptibility rating.

Each water source receives a susceptibility rating of high, medium or low for each of the following contaminant categories:

- Nutrients - Nutrients include nitrogen and phosphorous. Nutrients can cause eutrophic conditions within surface water sources.
- Pathogens – This includes disease-causing organisms such as bacteria, protozoa and viruses.
- Pesticides - Pesticides are manmade chemicals used to control bacteria, fungi, weeds, rodents and insects.
- Volatile Organic Compounds - Common types of Volatile Organic Compounds (VOCs) include chemicals that are used as solvents, degreasers and gasoline components.
- Inorganic Substances (Metals) – This includes mineral-based compounds that are both naturally occurring and anthropogenic. Inorganic substances include arsenic, cadmium, copper, lead, mercury and asbestos.
- Radionuclides/Radon - Common sources include the decay of naturally occurring radioactive minerals, leaching of subsurface material (e.g., rocks and sedimentary materials) into ground water, and improper disposal of radioactive waste. Radionuclides are a category of contaminant that is both naturally occurring (radon) and anthropogenic (radium).
- Disinfection Byproduct Precursors - Disinfection byproducts (DBP) are formed when the disinfectants used to kill pathogens during treatment react with dissolved organic material present in the water. A common source of DBP precursors is naturally occurring organic material such as leaves in surface water. Chlorine is the most common disinfectant used in New Jersey and is highly reactive, resulting in disinfection byproducts.

For surface water, inorganic substances, DBP precursors and pathogens had the highest percentage of pollutant sources with a high susceptibility rating. For unconfined ground water wells, nutrients, volatile organic compounds and radon/radionuclides had the highest percentage of sources with a high susceptibility rating. For confined ground water wells, only DBP precursors had a high percentage of water supply sources with a high susceptibility rating.

The NJSDWA regulations at N.J.A.C. 7:10-11.7 have minimum standards for protecting ground water supply sources. The regulations require that public community water systems acquire and control all land within a 50-foot radius of any ground water source that the system utilizes for its water supply, or control the land via lease or easement with NJDEP approval. Prohibited within this 50-foot radius are major and minor pollutant sources, as well as any non-water system related activity. Also specifically prohibited within 50 feet of a well are installation of storm and sanitary sewer lines (with watertight construction being required within 100 feet), industrial waste lines, septic tanks, distribution boxes and dry wells. Septic leach fields and seepage pits are prohibited within 200 feet of a well. In addition, manholes and connections to a sanitary sewer system are prohibited within 100 feet, unless the well is constructed in a confined aquifer. The NJSDWA regulations recommend, but do not require, minimum land acquisition around wells, that the land be upgradient of the well and equivalent to a Tier 1 WHPA.

USEPA, U.S. Departments of Agriculture and Interior and other federal agencies offer numerous financial incentives to protect source water areas. Information on these programs can be found at http://www.epa.gov/safewater/protect/pdfs/guide_swp_swp_funding_matrix.pdf. An example is the Drinking Water State Revolving Fund, established by the Federal SDWA. The Fund is administered by USEPA, and it provides direct funds to states for building or upgrading water treatment plants, other potable water construction projects and land acquisition and conservation easements.

The USEPA also provides numerous resources for community planners, public water supply operators and the general public to assist in their source water protection efforts. They include, but are not limited to on-line Source Water Protection courses; fact sheets that discuss Best Management Practices (BMPs); and a guide to numerous information sources related to source water protection.

Both local and state agencies utilize a "multiple barrier" approach to protecting or treating potable water contamination. The first and least expensive barrier is selection and then protection of a potable water source. An example is construction of a ground water well at the appropriate location (away from contaminant sources), at appropriate depths (different aquifer zone than potential contaminants) and with proper construction methods to seal off potential contaminants. Secondary barriers include potable water treatment for known contaminants, circulation to avoid stagnation, system integrity checks to avoid cross contamination, and routing sanitary surveys to assess system integrity.

Regional authorities such as the New Jersey Highlands Council or regional agreements by various concerned entities can play a critical role in protecting potable water resources. Streams and drainage basins usually cross municipal, county or even state boundaries. Thus, while local initiatives are important, even greater source water protection benefits can be realized if the initiatives are enlarged to a regional scale. This enlargement in scale can result in such things as close cooperation among municipal officials and state lawmakers to implement appropriate statutory and regulatory controls, and dedication of funds for source water protection efforts.

Local zoning is also an important source water and wellhead protection tool including, but not limited to, limitations or prohibition of certain land uses that may serve as a source of contamination to a WHPA. Certain local health related regulations can also be utilized to protect source water and wellhead areas, including restrictions on potential contaminant sources such as requiring septic system maintenance. Land conservation measures such as the purchase, easement and donation of open space can also be utilized by local governments to help protect source water areas.

There are numerous local and national groups with an active interest in protecting potable water sources. Locally, the New Jersey Water Association (NJWA) is a statewide association of water and wastewater utilities in New Jersey, providing technical assistance with consumer confidence reports, equipment demonstrations, ground water protection planning and educational outreach to schools. It also provides training, technical assistance, advocacy, and a variety of other services and benefits to water districts, water associations and municipalities under 10,000 in population.

The NJWA ground water protection planning includes assistance with development of Wellhead Protection Plans for water purveyors and users. These plans include delineation of a WHPA, identification of potential contaminant sources, management plans for the WHPA and development of contingency plans. A number of the water departments or purveyors in the Highlands Region have completed Wellhead Protection Plans for water systems under the NJWA purview. They include, but are not limited to the Pompton Lakes Municipal Utilities Authority, Jefferson Township Water Department, Mount Olive Water and Sewer Department and Mount Olive Villages.

The Groundwater Foundation is a nonprofit organization dedicated to educating the public to care and work for ground water resources. The Foundation has published a workshop guide titled "Source Water Assessment & Protection" (www.groundwater.org/gi/swap/swap.html). The guide's aim is to provide the public with information on performing source water assessments and steps to protect source water.

There are a variety of Best Management Practices (BMPs) that can be implemented at the local or regional level to promote source water protection efforts, including water conservation, which can reduce contaminant movement towards a well or intake; adoption of agricultural or lawn management BMPs to reduce pesticide, fertilizer, herbicide or rodenticide contamination reaching a well or intake; diversion berms to keep animal waste away from watercourses; proper use and handling of hazardous materials; proper use and maintenance of machinery that stores or uses hazardous materials; use and manufacture of environmentally sound products; use of secondary containment structures for above ground storage tanks that contain hazardous substances; leak detection and ground water monitoring for underground storage tanks; and use of devices to collect, separate and store contaminated wastewater for proper disposal.

BMPs related to septic systems management include minimal horizontal and vertical setbacks; adequate design, operation and maintenance, sanitary sewer overflows, monitoring and maintenance of sewer systems and system upgrades.

Lawn and garden fertilizer and pesticide BMPs include use of proper application rates, types and timing; use of low maintenance plants and grasses; protection or installation of vegetative buffer strips near water bodies; integrated pest management; plant rotation; and selection of pesticide-resistant plants. Above and underground storage tanks require proper installation, adequate containment, monitoring, maintenance and corrosion protection, spill protection, leak detection and proper closure.

BMPs applicable to livestock and pet waste include proper storage and treatment of manure; clean water diversion; manure composting; proper land application of manure; and fencing off of water source areas and proper disposal of pet waste. Small quantity chemical users should use waste reduction and proper handling, chemical management plans and proper storage and disposal. Vehicle washing BMPs include proper drainage controls; non-polluting cleaning agents; installation of oil/water separators; wastewater collection sumps, sediment traps and wastewater recycling.

REMEDIAL MEASURES

Source water protection is focused on the prevention of future contamination within SWPAs and WHPAs. However, New Jersey has a legacy of contamination from past land use and waste management practices that can affect existing water supply sources. Many public water supply wells have either been closed or required advanced treatment to address contamination.

In New Jersey, contaminated sites are regulated under one or more state and federal statutes. State statutes include the Brownfield and Contaminated Site Remediation Act, Industrial Site Recovery Act, Solid Waste Management Act, Spill Compensation & Control Act, Underground Storage of Hazardous Substances Act and Water Pollution Control Act. Federal statutes include the Comprehensive Environmental Response, Compensation and Liability Act, the Superfund Amendments and Reauthorization Act, and the Resource Conservation and Recovery Act Corrective Action Program.

Remediation of contaminated ground water, surface water and soils is overseen, and sometimes undertaken, by the NJDEP Site Remediation and Waste Management Program (SRWMP). The SRWMP publishes the Known Contaminated Sites Report, which gives basic information on approximately 14,000 sites in New Jersey where contamination has been confirmed. WHPA in the Highlands may be included in or affected by some of these sites.

SUPPORTING INFORMATION

Acknowledgments
Glossary
References
Appendix

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GLOSSARY

Consumptive Use – That part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock or otherwise removed from the immediate water environment other than by transport through pipelines and other conveyances as potable water or wastewater

Current Water Availability Deficit Areas (Current Deficit Areas) – Subwatersheds where Net Water Availability is less than zero based upon maximum monthly consumptive and depletive uses..

Depletive Use – Those waters uses that physically transfer water from one watershed to another through pipelines and other conveyances as potable water or wastewater, resulting in a loss of water to the originating watershed.

Existing Water Availability Constrained Areas (Existing Constrained Areas) – Subwatersheds that contribute flows to a Current Water Availability Deficit Area are considered Existing Water Availability Constrained Areas.

Ground Water Availability – Ground Water Availability is defined as the rate of ground water use that can occur in an area without contravening the goals and objectives of the Highlands Act. It is that portion of the Ground Water Capacity of a subwatershed that can be provided for human use without harm to other ground water users, aquatic ecosystems or downstream users. This value is modified as needed to protect downstream potable water supply intakes and reservoirs for surface water supplies, and to protect downstream flows in subwatersheds with deficits in Net Water Availability.

Ground Water Capacity – The natural ability of a subwatershed to support stream flow over time, during dry weather climatic conditions. In the specific context of water availability calculations by subwatershed, it is the Low Flow Margin derived from the September median flow minus the 7Q10 value for that portion of each HUC14 within the Highlands Region..

Hydrologic Unit Code – Hydrologic Unit Codes (HUCs) are used to identify the boundaries and the geographic area of drainage basins for the purpose of water data management. A HUC14 is a 14-digit hydrological unit code delineated by the U.S. Geological Survey that refers to a specific sub-watershed. There are 183 HUC14s that are located entirely or partially within the Highlands Region. HUC14s range in size from approximately three to 21 square miles. The HUC14 unit is used because it is the smallest drainage area delineation that is uniformly available for the Highlands Region.

Low Flow Margin of Safety Method – This method is an ecologically-oriented approach for the purpose of defining Ground Water Capacity based on a margin between two stream low flow statistics. The low flow statistic used traditionally in quantifying surface water safe yields is the lowest total flow over seven consecutive days during a ten-year period, the 7Q10. The 7Q10 is also often used to define an extreme low flow condition. A critical flow regime for aquatic ecology is the lowest monthly flow, which in New Jersey and the Highlands Region tends to occur most years in September. The "Low Flow Margin" is the difference between the September median flow in a stream and the 7Q10 flow. The Low Flow Margin of Safety is the Low Flow Margin multiplied by a percentage based on the ecological sensitivity of the subwatershed, and is equivalent to total Ground Water Availability.

Net Water Availability – The value resulting from subtracting the impacts of maximum monthly consumptive and depletive water uses (as adjusted for water imports and wastewater returns) from Ground Water Availability,

Passing Flow - The volume of water required by statute or NJDEP permit to be flowing past a specified point in a river or stream in a specified time - generally measured per hour or per day. Passing flows may be used to trigger cessation of withdrawals or releases from storage to augment flows.

Safe Yield - The annual amount of water that can be provided for human use from a source of supply over a repeat of the drought of record, reflecting passing flows requirements, demand patterns, watershed conditions and precipitation patterns.

Source Water Protection Area - The area contributing water flow to a potable water supply well or surface water intake used for a public water supply system, from which pollutants if present could move to the intake or well. A wellhead protection area is an example of an SWP area.

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APPENDIX

A Analysis of Alternative Ground Water Recharge Scenarios
B Preliminary Results of Ground Water Capacity Analysis
C Summary Statistics of Water Use by Use Type
D Ground Water Capacity, Ground Water Availability, and Net Water Availability by HUC 14

APPENDICES

Appendix A – Analysis of Alternate Ground Water Recharge Scenarios

Highlands Area GWR Quintile Rank

Highlands Area Drought GWR Quintile Rank:

HUC14 GWR Quintile Rank

Highlands Area HUC 14 Drought GWR Quintile Rank

Highlands Area HUC14 GWR Volume Rank

Highlands Area HUC14 Drought GWR Volume Rank

HUC 14 Location in Highlands Area

Franklin Pond Creek HUC14

Pohatcong Creek (Springtown to Merrill Creek)

Raritan River South Branch (Stonemill Gage to Califon)

Mulhockaway Creek

Highlands Area GWR Quintile Rank

Highlands Area HUC14 GWR Quintile Rank

Highlands Area HUC14 GWR Volume Rank

Highlands Area 2002 HUC14 Drought GWR Volume Rank

Highlands Area 2002 HUC14 Drought GWR Volume Top 2 Rank

Appendix B – Preliminary Results of Ground Water Capacity Analysis

Preliminary Results Summarizing Selected Flow Statistics, Ground Water Use and Ground Water Capacity within HUC14 Watersheds, New Jersey Highlands

Base and Low-Flow Statistics at Selected Continuous-Record Stream-Flow Gaging Stations, Low-Flow Partial-Record Stations, and Gaging Stations Analyzed as a Partial-Record Station in the New Jersey Highlands

Mean Annual Base Flow for the 10-Year Recurrence Interval, New Jersey Highlands

Mean Annual Base Flow for the 25-Year Recurrence Interval, New Jersey Highlands

Low-Flow Margin Defined as the September Median Minus the 7-Day 10-Year Low-Flow Discharge, New Jersey Highlands

Comparison of Low Flow Values for Selected Basins, Excluding Stream Basins Lacking Base Flow Statistics

Comparison of Base Flow Values for HUC14 Subwatersheds

Appendix C – Summary Statistics of Water Use by Use Type

Total Water Use by Use Type- Maximum Month in MGD

Ground and Surface Water Use by HUC14 – Full Allocation Volumes in MGD

Appendix D – Water Availability Analysis

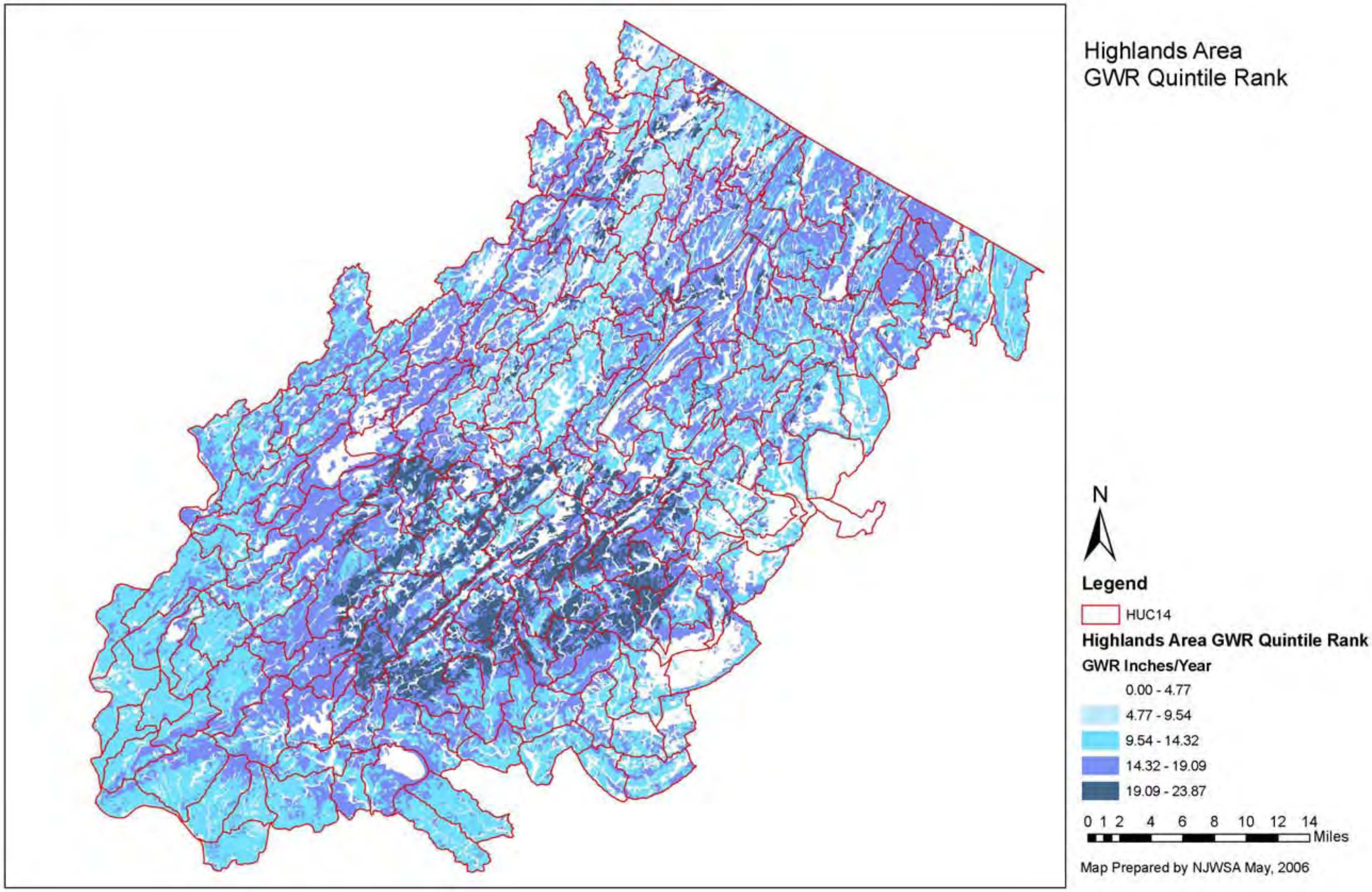
Ground Water Capacity by HUC14

Ground Water Availability by HUC14

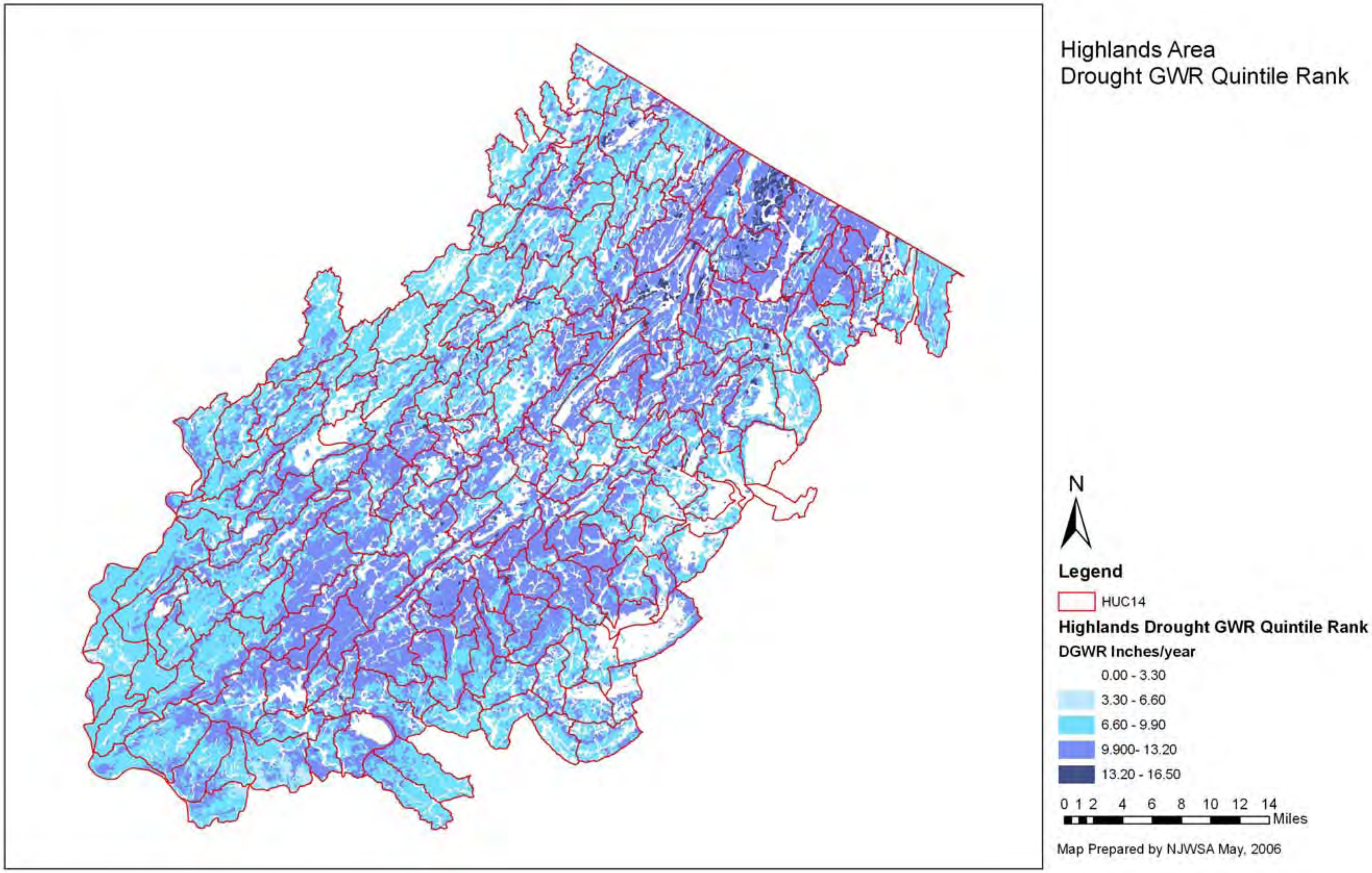
Net Water Availability by HUC14

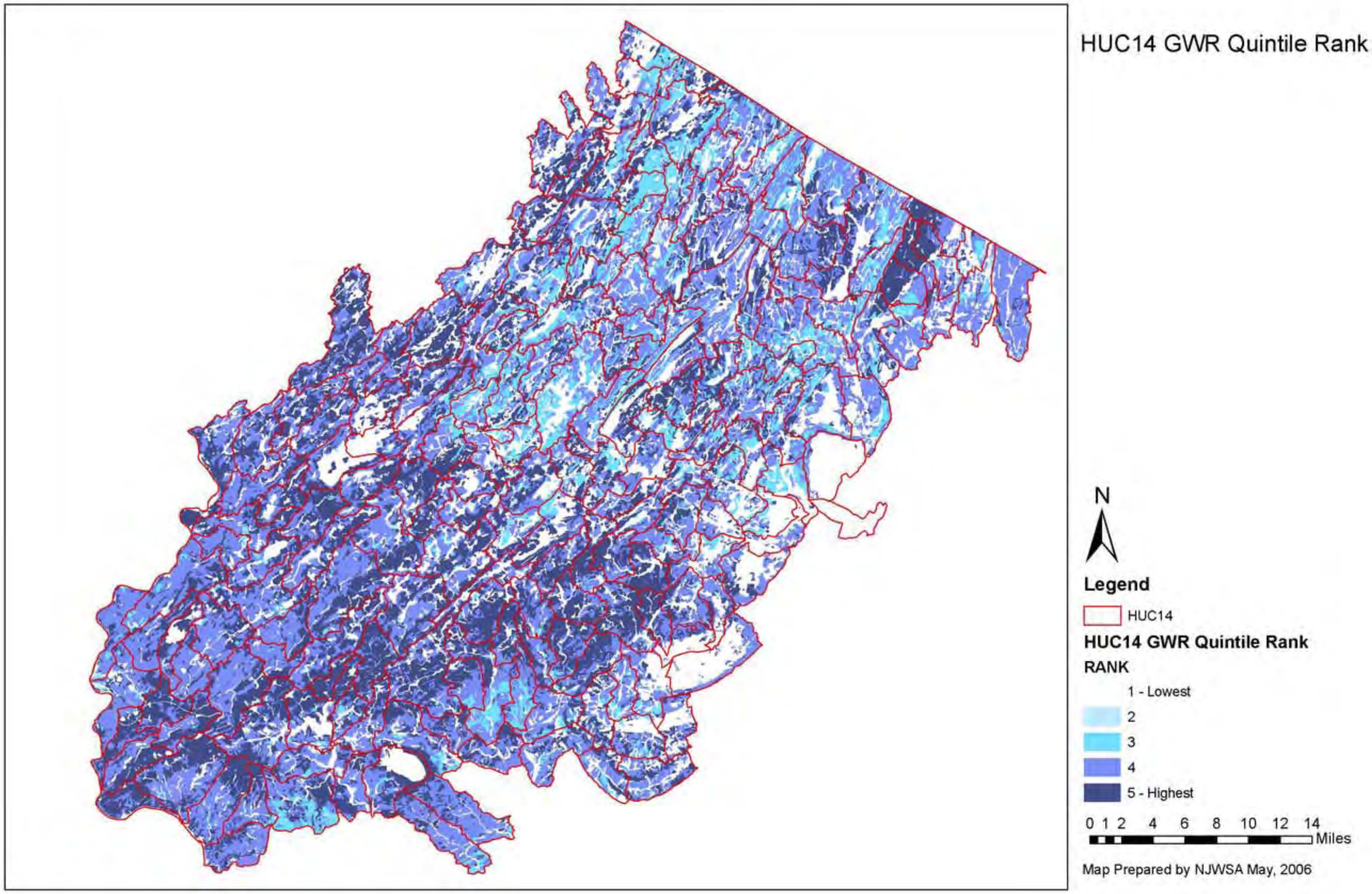
APPENDIX A

Highlands Area
GWR Quintile Rank

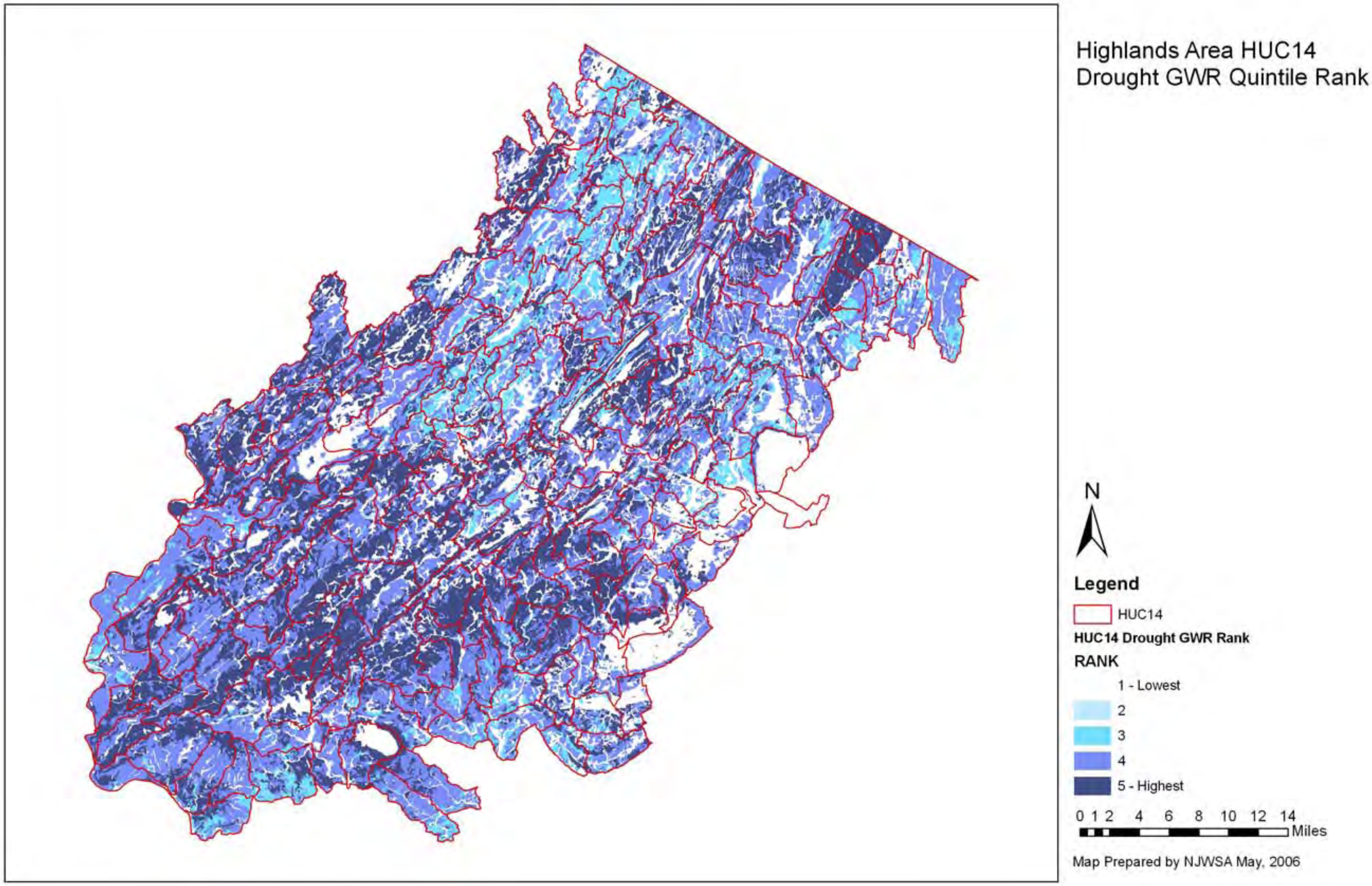


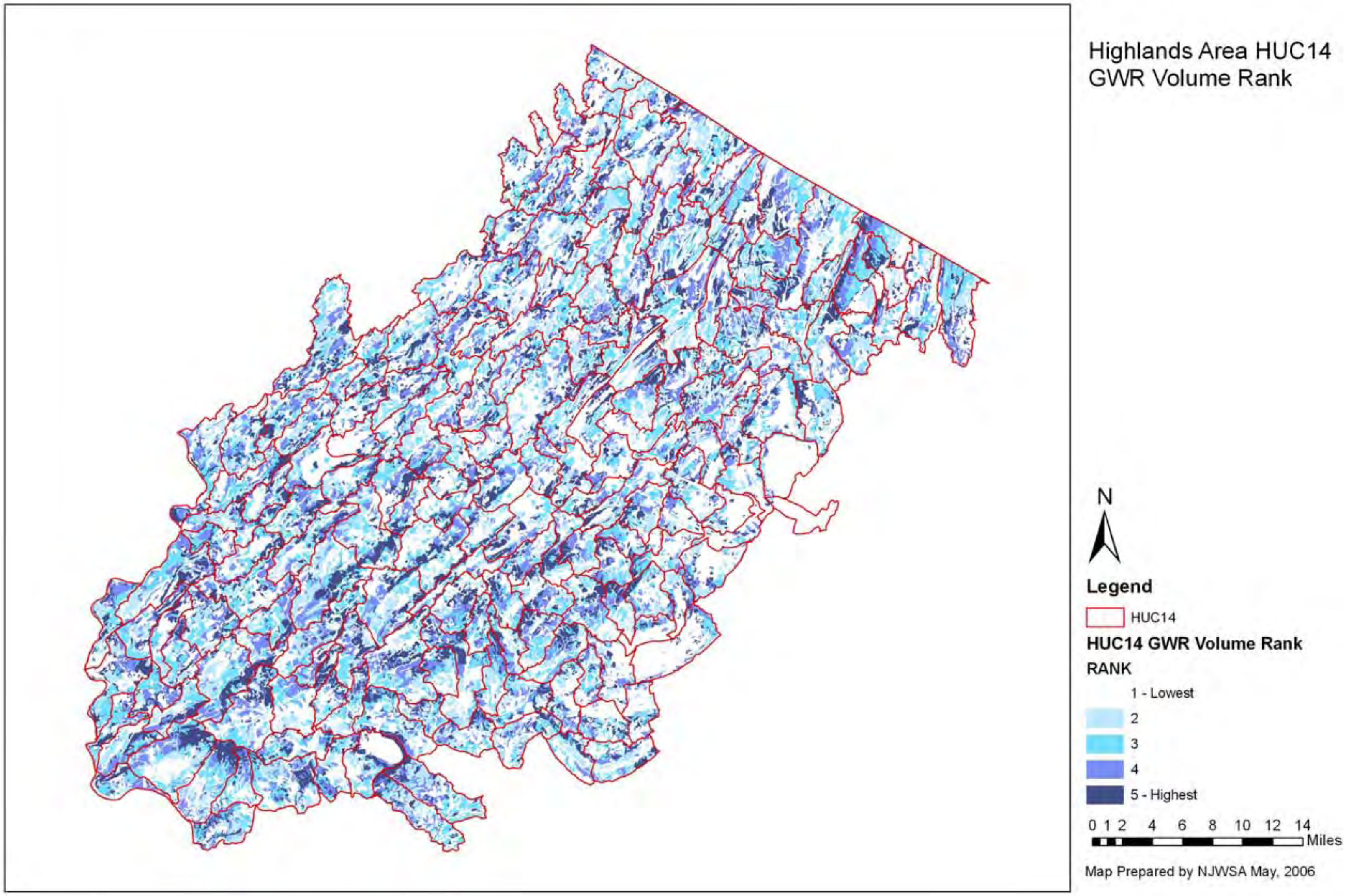
Map Prepared by NJWSA May, 2006

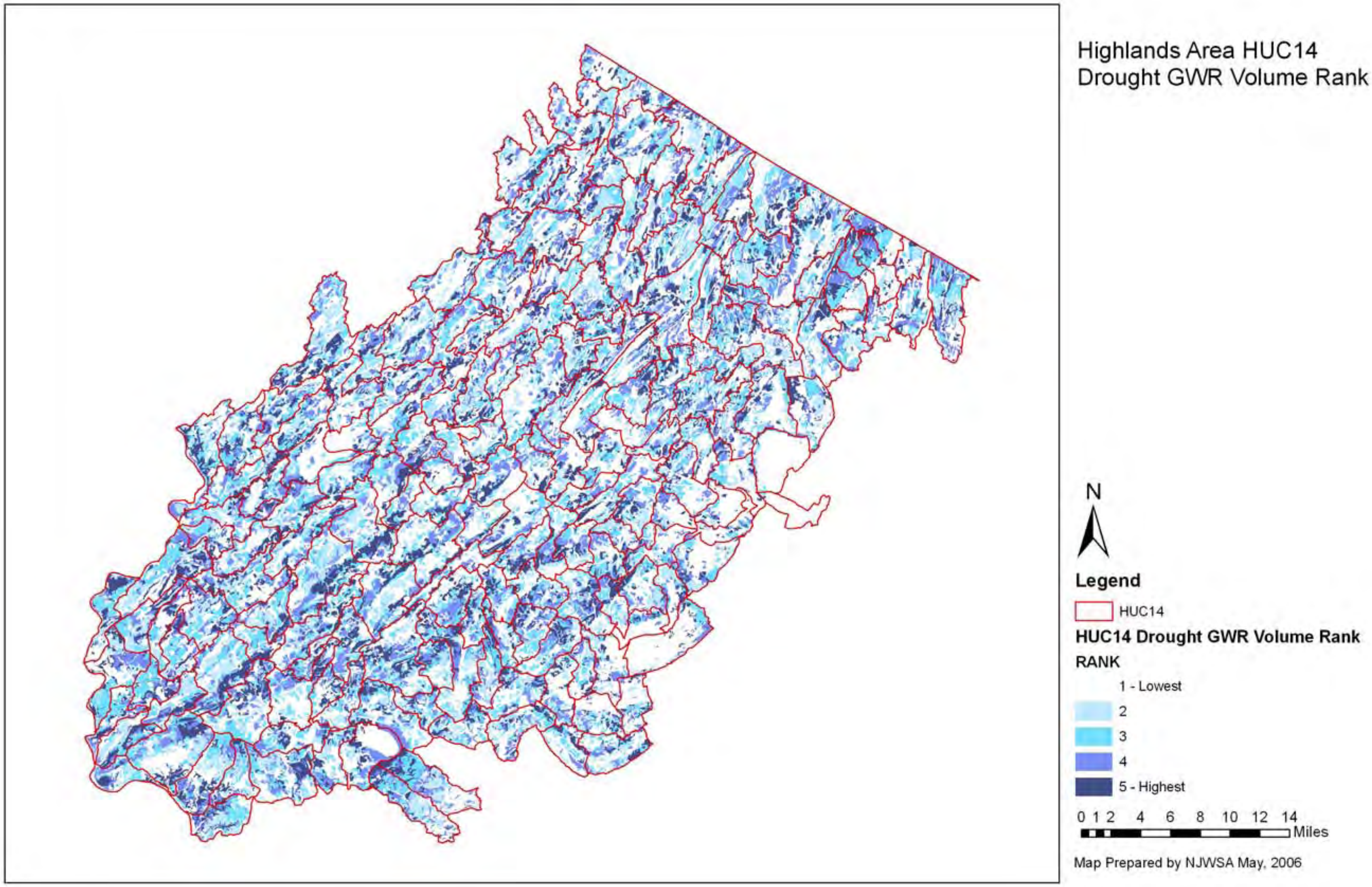

Highlands Area
Drought GWR Quintile Rank
N
Legend
HUC14
Highlands Drought GWR Quintile Rank
DGWR Inches/year
0.00 - 3.30
3.30 - 6.60
6.60 - 9.90
9.900- 13.20
13.20 - 16.50
0 1 2 4 6 8 10 12 14
Miles
Map Prepared by NJWSA May, 2006



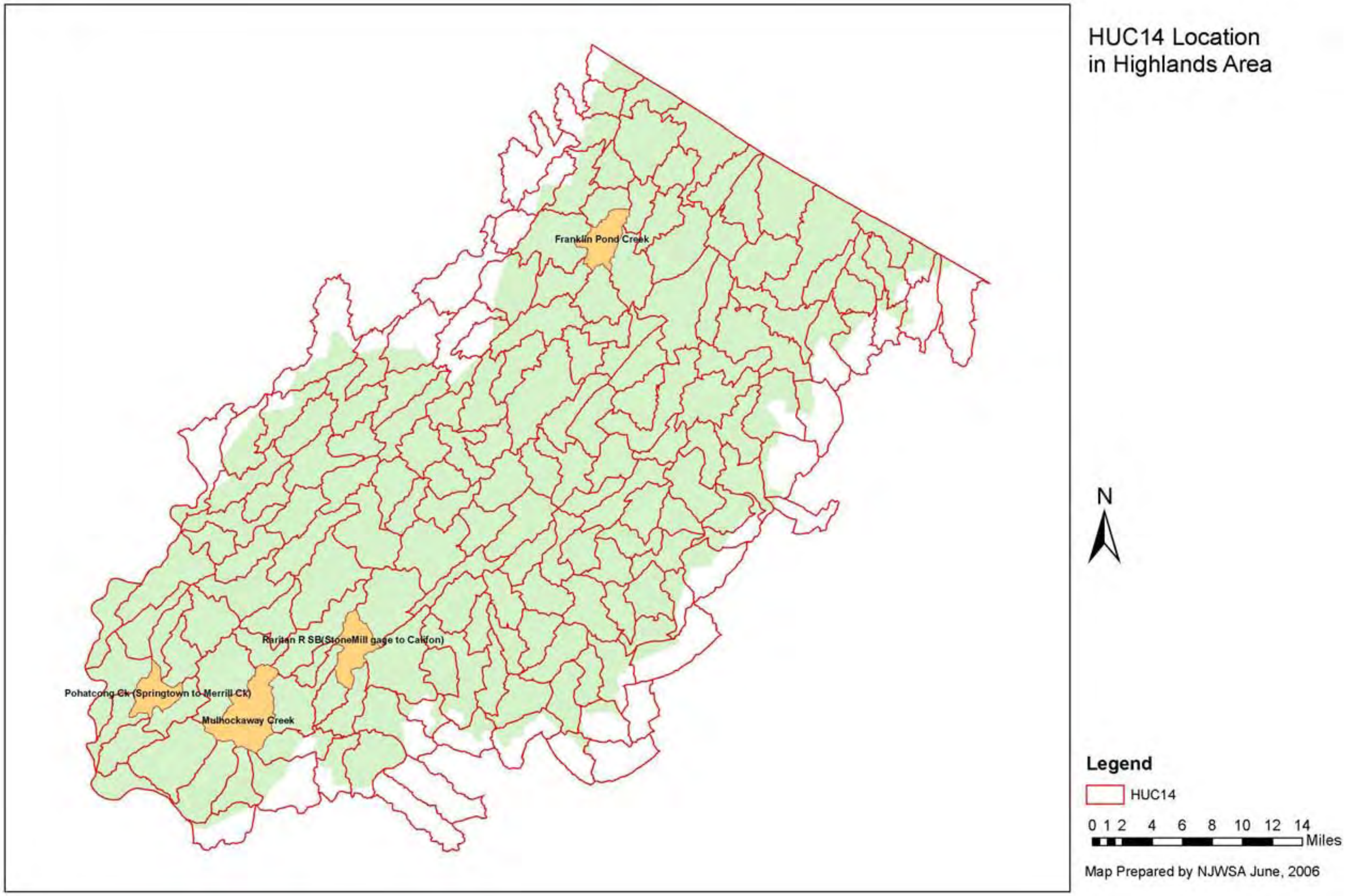
HUC14 GWR Quintile Rank
N
Legend
HUC14
HUC14 GWR Quintile Rank
RANK
1 - Lowest
2
3
4
5 - Highest
0 1 2 4 6 8 10 12 14
Miles
Map Prepared by NJWSA May, 2006


Highlands Area HUC14
Drought GWR Quintile Rank
N
Legend
HUC14
HUC14 Drought GWR Rank
RANK
1 - Lowest
2
3
4
5 - Highest
0 1 2 4 6 8 10 12 14
Miles
Map Prepared by NJWSA May, 2006


Highlands Area HUC14
GWR Volume Rank
N
Legend
HUC14
HUC14 GWR Volume Rank
RANK
1 - Lowest
2
3
4
5 - Highest
0 1 2 4 6 8 10 12 14
Miles
Map Prepared by NJWSA May, 2006



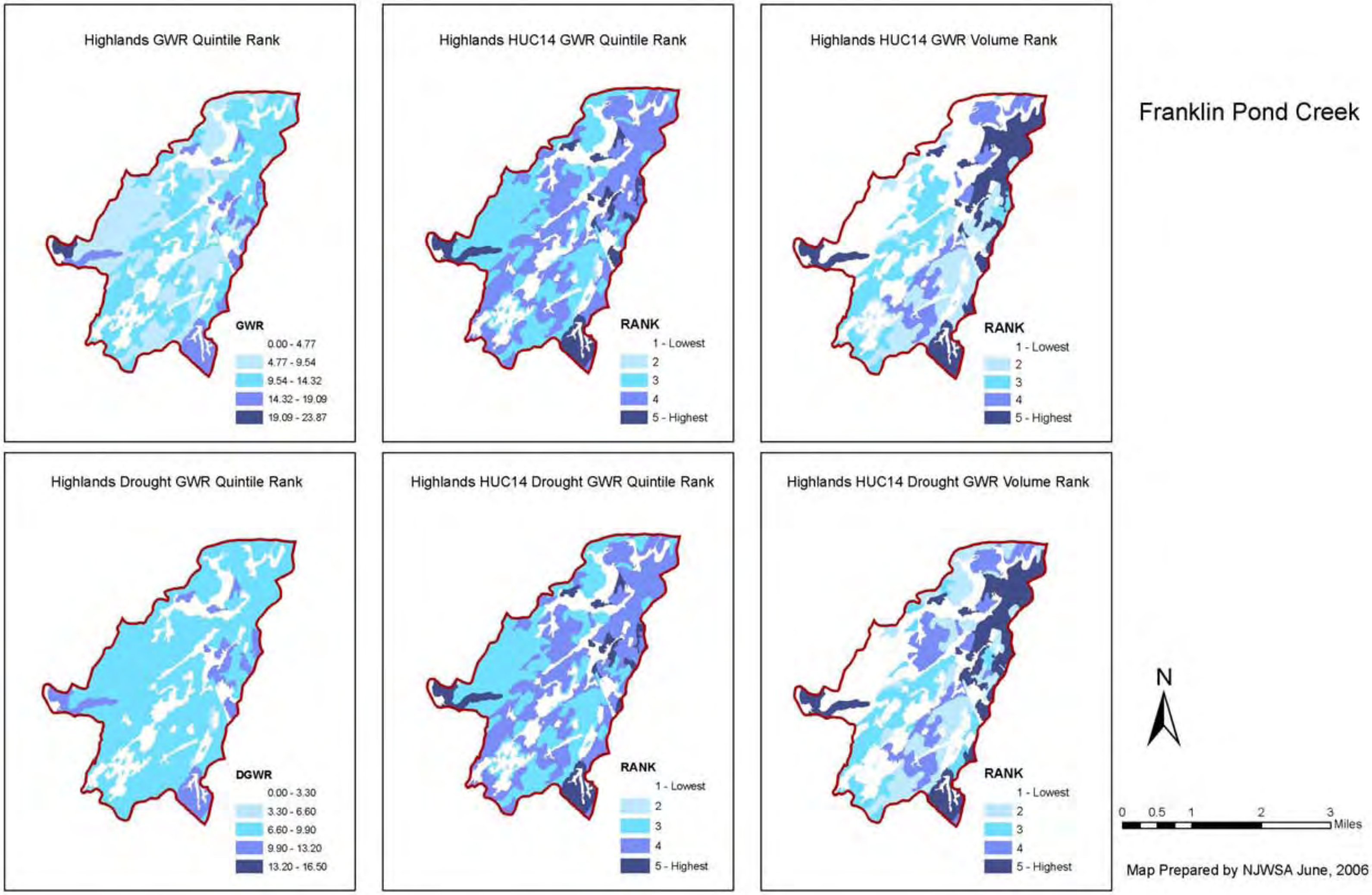
Highlands Area HUC14
Drought GWR Volume Rank
N
Legend
HUC14
HUC14 Drought GWR Volume Rank
RANK
1 - Lowest
2
3
4
5 - Highest
0 1 2 4 6 8 10 12 14
Miles
Map Prepared by NJWSA May, 2006



HUC14 Location in Highlands Area

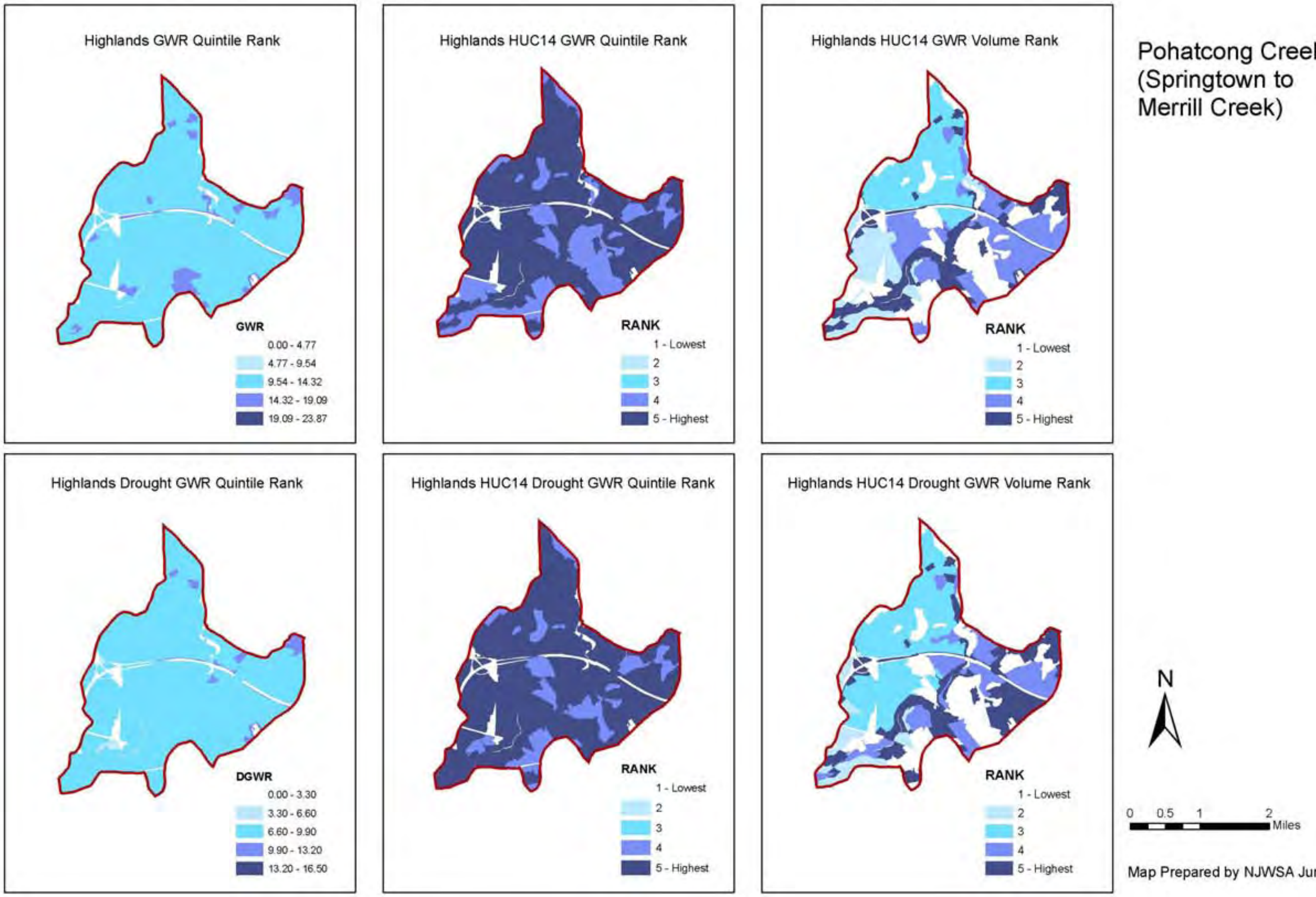
Map Prepared by NJWSA June, 2006

Franklin Pond Creek

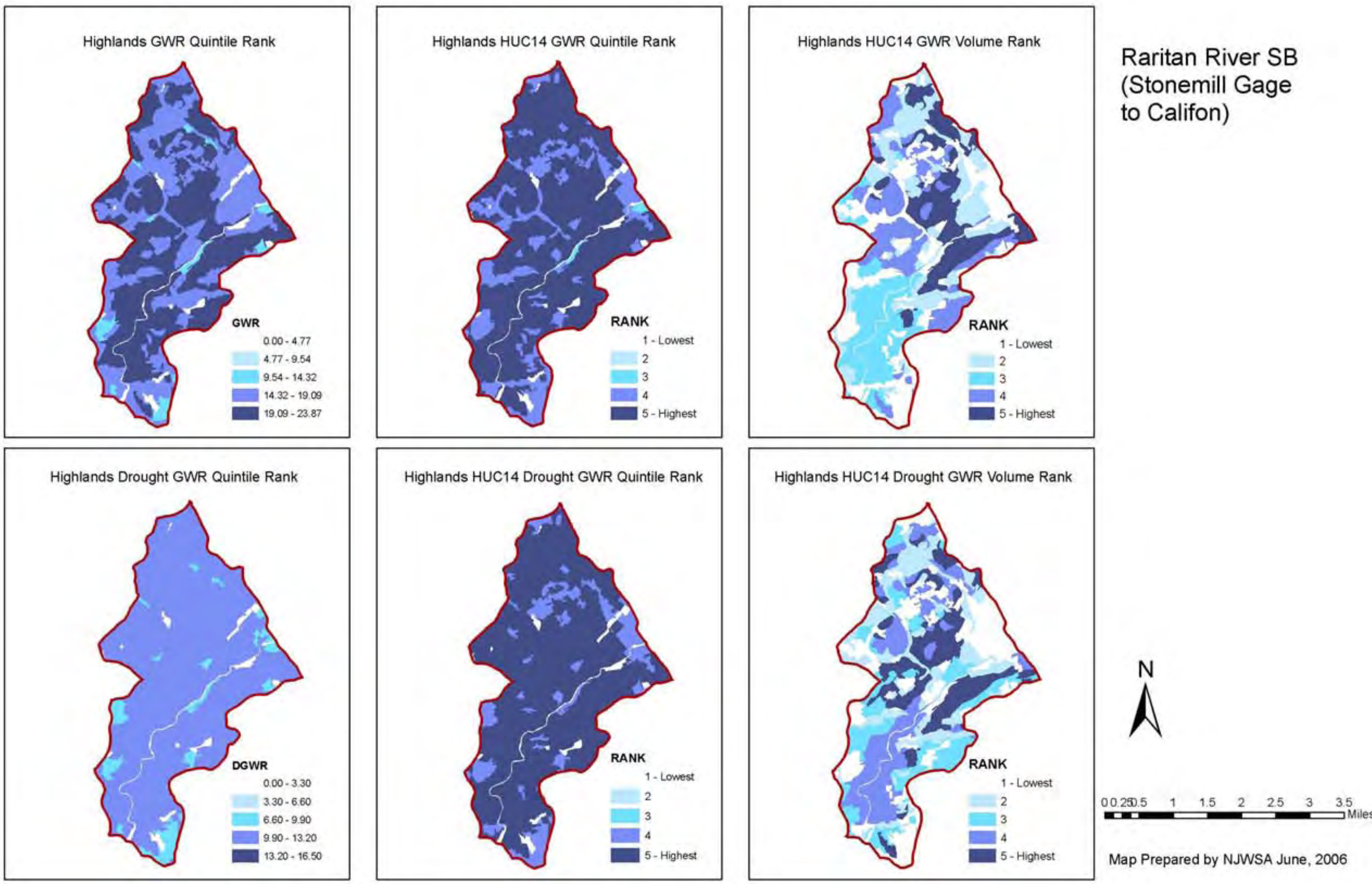


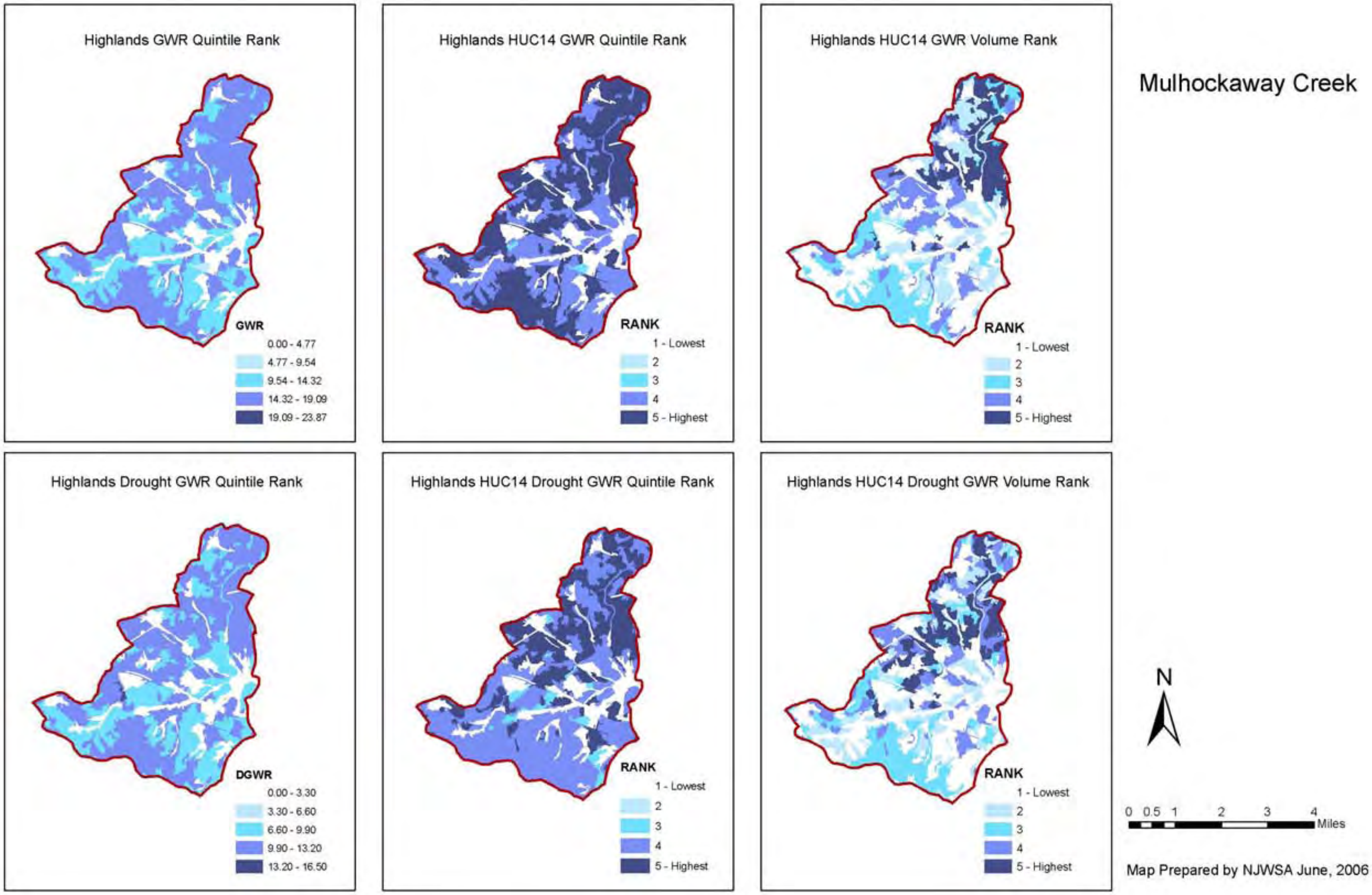
Map Prepared by NJWSA June, 2006

Pohatcong Creek (Springtown to Merrill Creek)

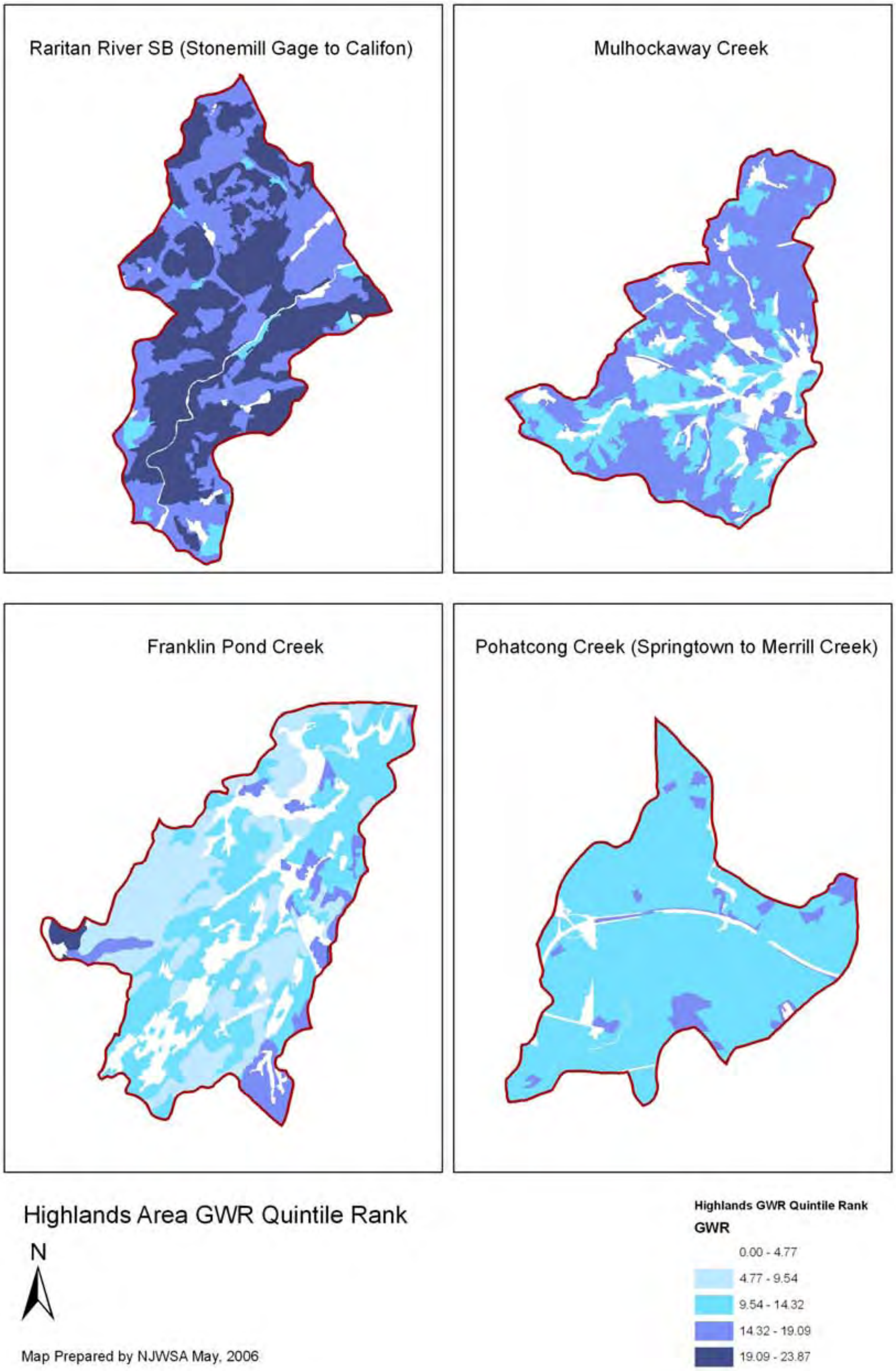


Map Prepared by NJWSA June, 2006


Raritan River SB (Stonemill Gage to Califon)
Highlands GWR Quintile Rank
GWR
0.00 - 4.77
4.77 - 9.54
9.54 - 14.32
14.32 - 19.09
19.09 - 23.87
Highlands HUC14 GWR Quintile Rank
RANK
1 - Lowest
2
3
4
5 - Highest
Highlands HUC14 GWR Volume Rank
RANK
1 - Lowest
2
3
4
5 - Highest
Highlands Drought GWR Quintile Rank
DGWR
0.00 - 3.30
3.30 - 6.60
6.60 - 9.90
9.90 - 13.20
13.20 - 16.50
Highlands HUC14 Drought GWR Quintile Rank
RANK
1 - Lowest
2
3
4
5 - Highest
Highlands HUC14 Drought GWR Volume Rank
RANK
1 - Lowest
2
3
4
5 - Highest
N
0 0.25 0.5 1 1.5 2 2.5 3 3.5
Miles
Map Prepared by NJWSA June, 2006

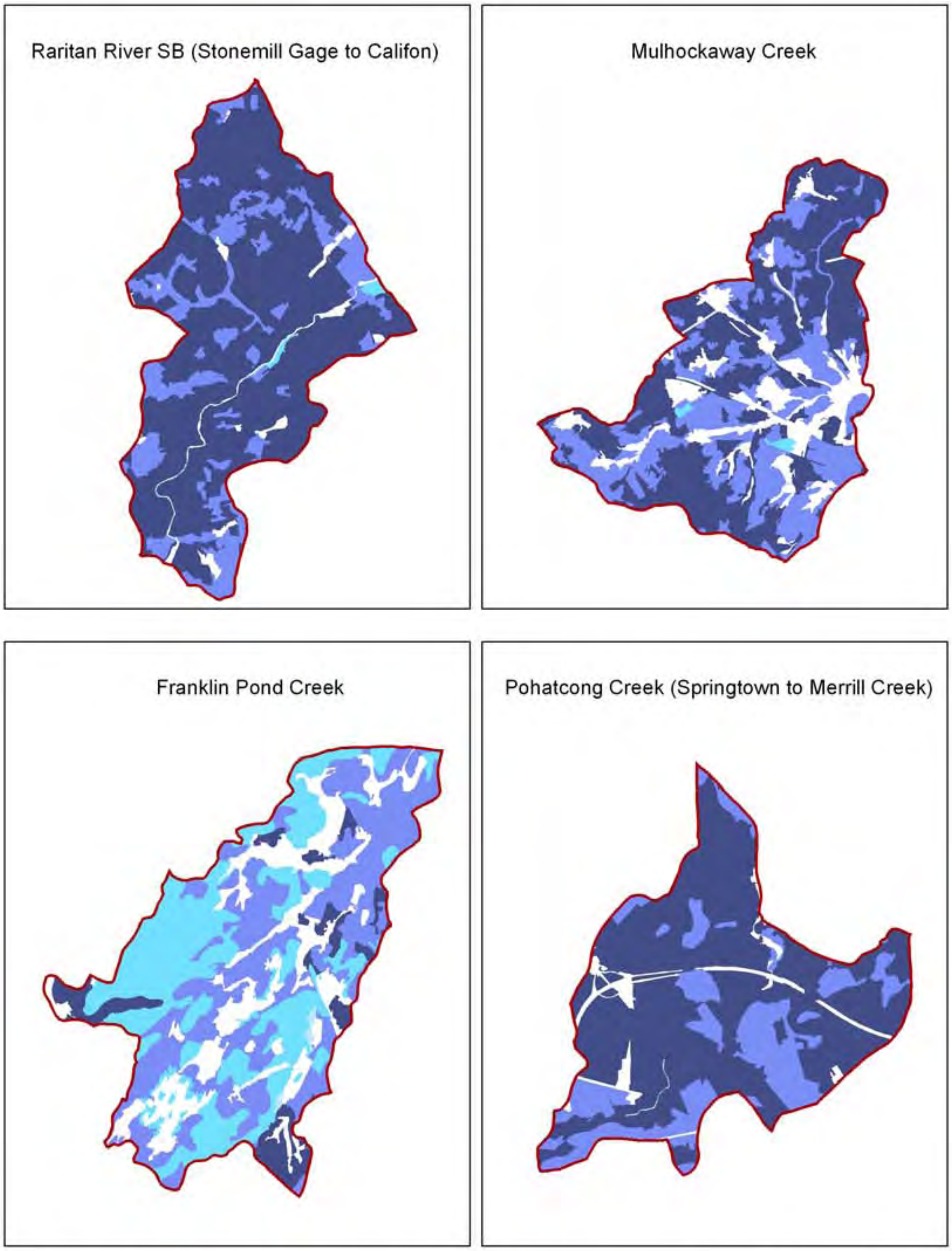


Mulhockaway Creek
Highlands GWR Quintile Rank
GWR
0.00 - 4.77
4.77 - 9.54
9.54 - 14.32
14.32 - 19.09
19.09 - 23.87
Highlands HUC14 GWR Quintile Rank
RANK
1 - Lowest
2
3
4
5 - Highest
Highlands HUC14 GWR Volume Rank
RANK
1 - Lowest
2
3
4
5 - Highest
Highlands Drought GWR Quintile Rank
DGWR
0.00 - 3.30
3.30 - 6.60
6.60 - 9.90
9.90 - 13.20
13.20 - 16.50
Highlands HUC14 Drought GWR Quintile Rank
RANK
1 - Lowest
2
3
4
5 - Highest
Highlands HUC14 Drought GWR Volume Rank
RANK
1 - Lowest
2
3
4
5 - Highest
N
0 0.5 1 2 3 4
Miles
Map Prepared by NJWSA June, 2006



Highlands Area GWR Quintile Rank

Map Prepared by NJWSA May, 2006



Highlands Area HUC14 GWR Quintile Rank

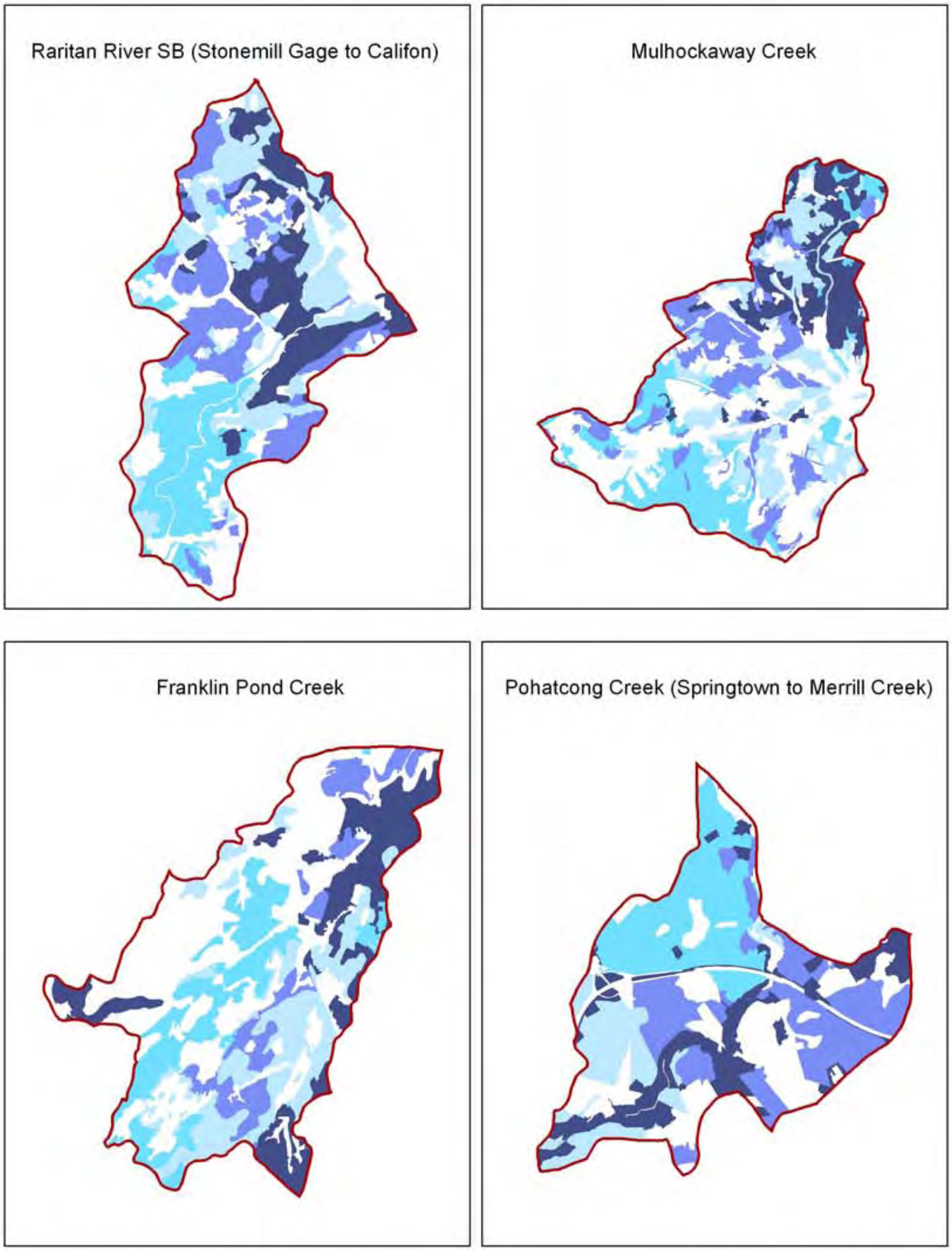
N

Highlands GWR HUC14 Quintile Rank

RANK

1 - Lowest
2
3
4
5 - Highest

Map Prepared by NJWSA May, 2006



Highlands Area HUC14 GWR Volume Rank

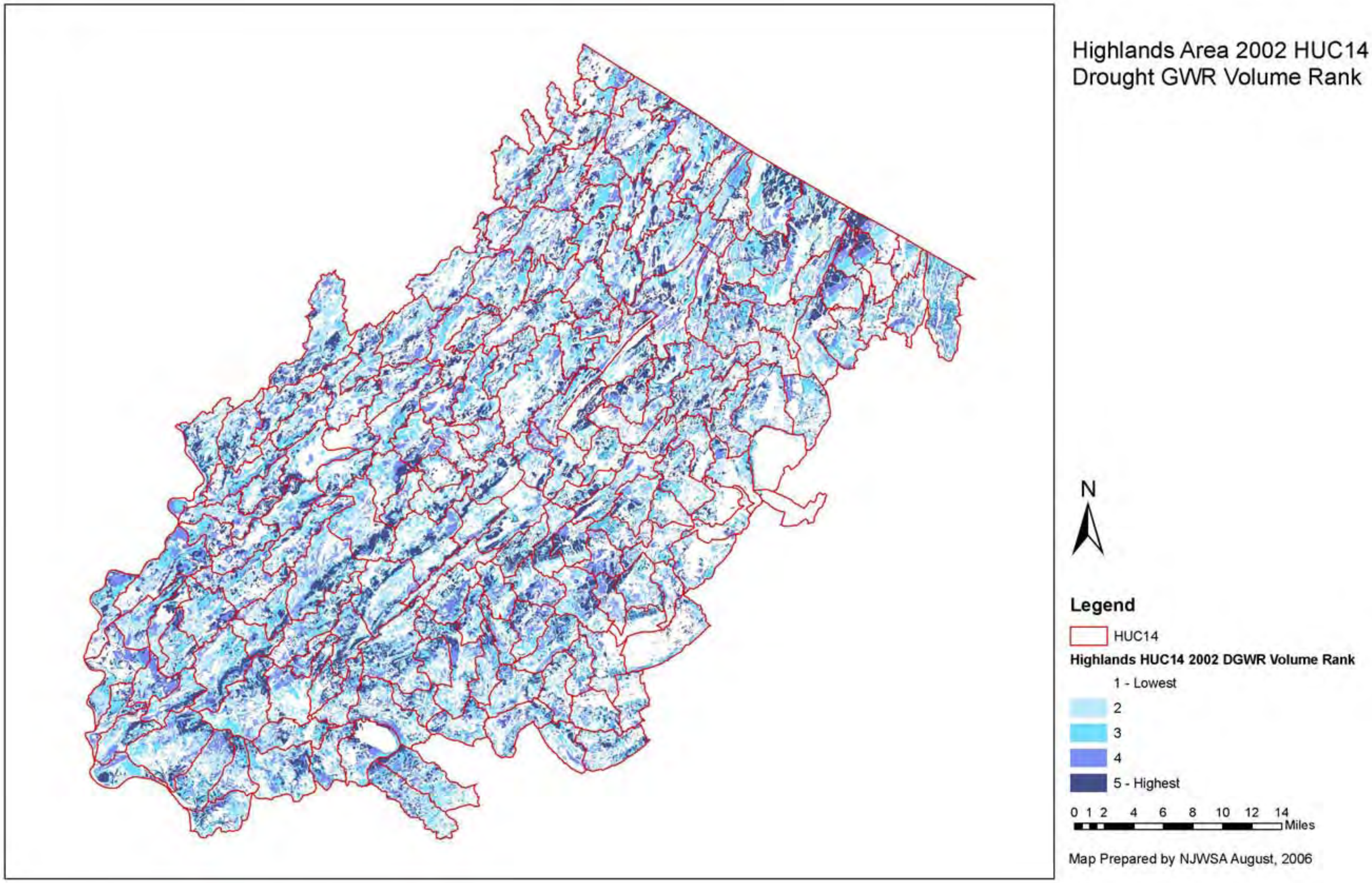
N

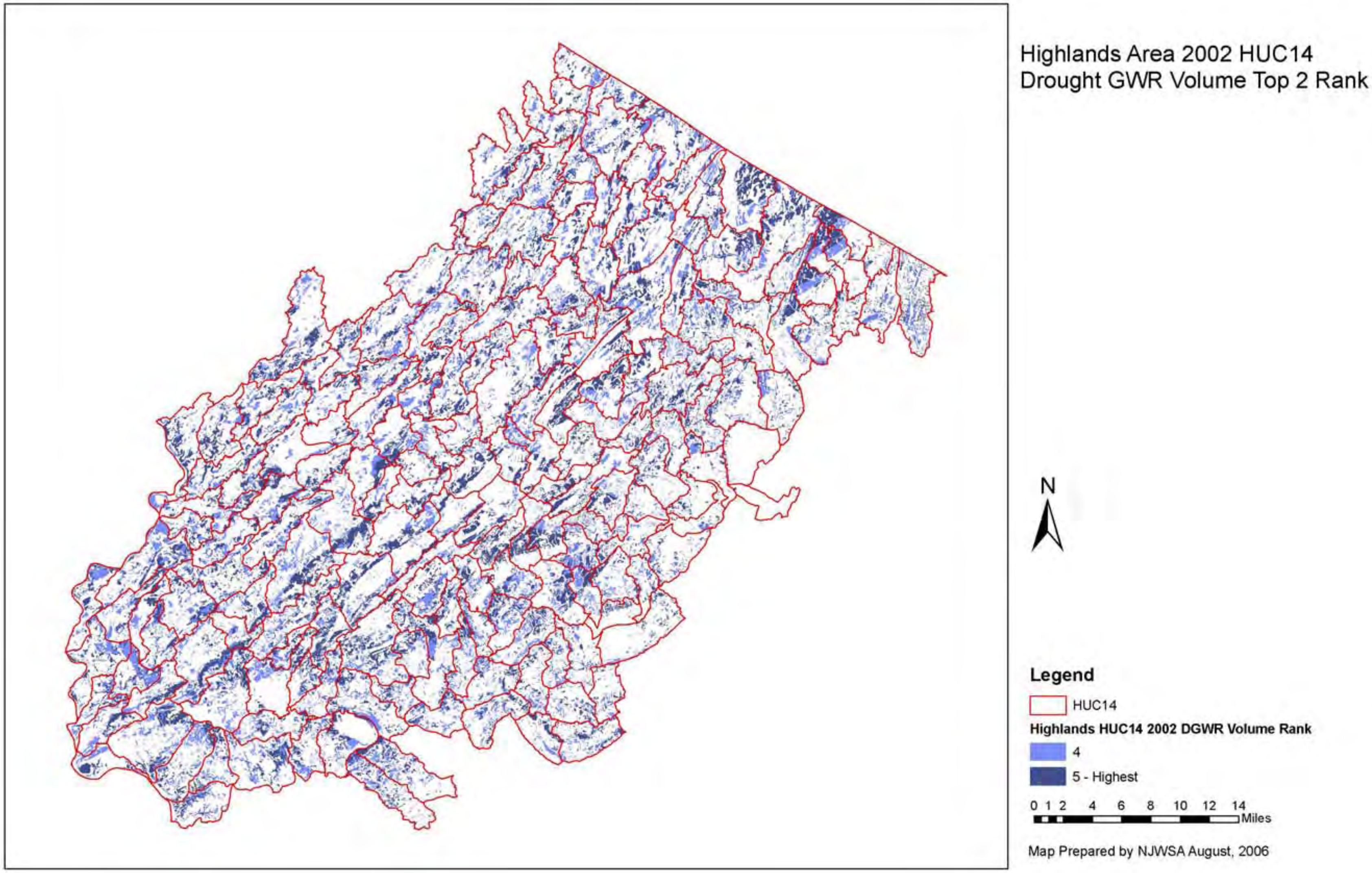
Highlands GWR HUC14 Volume Rank

RANK

- 1 - Lowest
- 2
- 3
- 4
- 5 - Highest

Map Prepared by NJWSA May, 2006


Highlands Area 2002 HUC14
Drought GWR Volume Rank
N
Legend
HUC14
Highlands HUC14 2002 DGWR Volume Rank
1 - Lowest
2
3
4
5 - Highest
0 1 2 4 6 8 10 12 14
Miles
Map Prepared by NJWSA August, 2006


Highlands Area 2002 HUC14
Drought GWR Volume Top 2 Rank
N
Legend
HUC14
Highlands HUC14 2002 DGWR Volume Rank
4
5 - Highest
0 1 2 4 6 8 10 12 14
Miles
Map Prepared by NJWSA August, 2006

APPENDIX B

Preliminary results summarizing selected flow statistics, ground-water use and ground-water capacity within HUC14 watersheds, New Jersey Highlands. [WMA, watershed management area; REG, regression method; DAR, drainage area ratio method; BF10, base flow at the 10-year recurrence interval; BF25, base flow at the 25-year recurrence interval; QSep50, median September discharge; Q710, 7-day 10-year low flow; LFM, low flow margin calculated as QSep50 - Q710; GWC10A, ground-water capacity calculated as BF10 minus consumptive ground-water use; GWC10B, ground-water capacity calculated as BF10 minus maximum monthly consumptive ground-water use; GWC10C, ground-water capacity calculated as BF10 minus consumptive ground-water use at full allocation; GWC10D, ground-water capacity calculated as BF10 minus total ground-water use;]

HUC 14 number	WMA	Map key	Drainage area mi^2	Method	Base flow Mgal/d	Base flow Mgal/d/mi^2	BF_{10} Mgal/d	BF_{10} Mgal/d/mi^2	BF_{25} Mgal/d	BF_{25} Mgal/d/mi^2	$QSep_{50}$ Mgal/d	$QSep_{50}$ Mgal/d/mi^2	Q_{710} Mgal/d	Q_{710} Mgal/d/mi^2	LFM Mgal/d	LFM Mgal/d/mi^2	$GWC_{10}A$, Mgal/d	$GWC_{10}A$, Mgal/d/m^{i2}	$GWC_{10}B$, Mgal/d	$GWC_{10}B$, Mgal/d/m^{i2}	$GWC_{10}C$, Mgal/d	$GWC_{10}C$, Mgal/d/m^{i2}	$GWC_{10}D$, Mgal/d	$GWC_{10}D$, Mgal/d/m^{i2}	$GWC_{25}A$, Mgal/d	$GWC_{25}A$, Mgal/d/m^{i2}	$GWC_{25}B$, Mgal/d	$GWC_{25}B$, Mgal/d/m^{i2}	$GWC_{25}C$, Mgal/d	$GWC_{25}C$, Mgal/d/m^{i2}	$GWC_{25}D$, Mgal/d	$GWC_{25}D$, Mgal/d/m^{i2}	$GWC_{LFM}A$ Mgal/d	$GWC_{LFM}A$ Mgal/d/mi^2	$GWC_{LFM}B$ Mgal/d	$GWC_{LFM}B$ Mgal/d/mi^2	$GWC_{LFM}C$ Mgal/d	$GWC_{LFM}C$ Mgal/d/mi^2	$GWC_{LFM}D$ Mgal/d	$GWC_{LFM}D$ Mgal/d/mi^2
02040105040040	01	101	5.51	REG	3.86	0.70	2.51	0.46	2.07	0.37	0.96	0.17	0.22	0.04	0.74	0.13	2.50	0.45	2.50	0.45	2.50	0.45	2.46	0.45	2.06	0.37	2.06	0.37	2.06	0.37	2.01	0.37	0.73	0.13	0.73	0.13	0.73	0.13	0.69	0.12
02040105040050	01	102	13.46	DAR	10.74	0.80	7.61	0.57	6.55	0.49	4.68	0.35	1.88	0.14	2.79	0.21	7.54	0.56	7.45	0.55	7.38	0.55	7.16	0.53	6.47	0.48	6.38	0.47	6.32	0.47	6.10	0.45	2.72	0.20	2.63	0.20	2.56	0.19	2.34	0.17
02040105040060	01	103	13.82	DAR	11.03	0.80	7.82	0.57	6.72	0.49	4.80	0.35	1.93	0.14	2.87	0.21	7.79	0.56	7.77	0.56	7.75	0.56	7.58	0.55	6.69	0.48	6.68	0.48	6.66	0.48	6.48	0.47	2.84	0.21	2.82	0.20	2.80	0.20	2.63	0.19
02040105050010	01	104	18.95	REG	14.96	0.79	9.79	0.52	8.12	0.43	4.37	0.23	1.18	0.06	3.19	0.17	9.76	0.51	9.75	0.51	9.75	0.51	9.55	0.50	8.09	0.43	8.09	0.43	8.09	0.43	7.89	0.42	3.16	0.17	3.16	0.17	3.16	0.17	2.96	0.16
02040105060020	01	105	12.28	REG	9.50	0.77	6.22	0.51	5.16	0.42	2.46	0.20	0.62	0.05	1.84	0.15	6.15	0.50	6.13	0.50	6.10	0.50	5.50	0.45	5.09	0.41	5.07	0.41	5.04	0.41	4.44	0.36	1.77	0.14	1.75	0.14	1.72	0.14	1.12	0.09
02040105070010	01	106	5.37	REG	3.62	0.67	2.34	0.44	1.91	0.36	0.81	0.15	0.18	0.03	0.63	0.12	2.31	0.43	2.30	0.43	2.28	0.43	2.09	0.39	1.88	0.35	1.88	0.35	1.86	0.35	1.67	0.31	0.60	0.11	0.59	0.11	0.58	0.11	0.39	0.07
02040105070020	01	107	11.47	DAR	9.93	0.87	6.48	0.56	4.60	0.40	2.88	0.25	0.51	0.04	2.37	0.21	6.44	0.56	6.43	0.56	6.39	0.56	6.13	0.53	4.55	0.40	4.54	0.40	4.50	0.39	4.24	0.37	2.32	0.20	2.32	0.20	2.28	0.20	2.02	0.18
02040105070030	01	108	13.45	DAR	11.64	0.87	7.60	0.56	5.35	0.40	3.37	0.25	0.59	0.04	2.78	0.21	7.57	0.56	7.57	0.56	7.56	0.56	7.41	0.55	5.32	0.40	5.32	0.40	5.31	0.39	5.16	0.38	2.75	0.20	2.75	0.20	2.74	0.20	2.59	0.19
02040105070040	01	109	8.63	REG	7.49	0.87	4.98	0.58	4.13	0.48	2.87	0.33	0.87	0.10	2.00	0.23	4.97	0.58	4.97	0.58	4.97	0.58	4.88	0.57	4.12	0.48	4.12	0.48	4.12	0.48	4.03	0.47	1.99	0.23	1.99	0.23	1.99	0.23	1.90	0.22
02040105070050	01	110	9.42	REG	7.64	0.81	5.04	0.53	4.17	0.44	1.94	0.21	0.50	0.05	1.44	0.15	5.03	0.53	5.03	0.53	5.03	0.53	4.96	0.53	4.16	0.44	4.16	0.44	4.16	0.44	4.09	0.43	1.43	0.15	1.43	0.15	1.43	0.15	1.35	0.14
02040105070060	01	111	6.30	REG	3.52	0.56	2.23	0.35	1.85	0.29	0.73	0.12	0.13	0.02	0.60	0.09	2.15	0.34	2.03	0.32	1.38	0.22	1.85	0.29	1.78	0.28	1.65	0.26	1.00	0.16	1.48	0.23	0.52	0.08	0.40	0.06	-0.25	-0.04	0.22	0.04
02040105080010	01	112	7.52	REG	5.99	0.80	3.95	0.53	3.26	0.43	1.65	0.22	0.43	0.06	1.22	0.16	3.91	0.52	3.87	0.51	3.83	0.51	3.82	0.51	3.21	0.43	3.18	0.42	3.14	0.42	3.13	0.42	1.17	0.16	1.14	0.15	1.10	0.15	1.09	0.15
02040105080020	01	113	10.79	REG	7.87	0.73	5.12	0.47	4.25	0.39	2.32	0.21	0.58	0.05	1.74	0.16	5.11	0.47	5.11	0.47	5.11	0.47	5.05	0.47	4.24	0.39	4.24	0.39	4.24	0.39	4.18	0.39	1.73	0.16	1.73	0.16	1.73	0.16	1.67	0.15
02040105090010	01	114	9.49	REG	6.63	0.70	4.30	0.45	3.58	0.38	1.46	0.15	0.32	0.03	1.14	0.12	4.28	0.45	4.28	0.45	4.28	0.45	4.15	0.44	3.56	0.38	3.56	0.38	3.56	0.38	3.43	0.36	1.12	0.12	1.12	0.12	1.12	0.12	0.99	0.10
02040105090020	01	115	7.64	REG	6.66	0.87	4.44	0.58	3.68	0.48	1.73	0.23	0.47	0.06	1.26	0.16	4.41	0.58	4.31	0.56	3.36	0.44	4.32	0.57	3.64	0.48	3.55	0.46	2.59	0.34	3.56	0.47	1.22	0.16	1.13	0.15	0.17	0.02	1.14	0.15
02040105090030	01	116	8.23	REG	7.97	0.97	5.38	0.65	4.45	0.54	2.07	0.25	0.60	0.07	1.47	0.18	4.92	0.60	4.76	0.58	4.84	0.59	-3.61	-0.44	3.99	0.48	3.83	0.47	3.91	0.47	-4.54	-0.55	1.01	0.12	0.85	0.10	0.93	0.11	-7.52	-0.91
02040105090040	01	117	6.05	REG	5.08	0.84	3.38	0.56	2.79	0.46	1.09	0.18	0.27	0.04	0.82	0.13	3.36	0.56	3.36	0.56	3.36	0.56	3.26	0.54	2.77	0.46	2.77	0.46	2.77	0.46	2.67	0.44	0.80	0.13	0.80	0.13	0.80	0.13	0.70	0.12
02040105090050	01	118	7.71	REG	5.78	0.75	3.78	0.49	3.11	0.40	1.41	0.18	0.34	0.04	1.07	0.14	3.74	0.49	3.74	0.48	3.73	0.48	3.49	0.45	3.08	0.40	3.07	0.40	3.07	0.40	2.83	0.37	1.03	0.13	1.02	0.13	1.02	0.13	0.78	0.10
02040105090060	01	119	8.27	REG	7.14	0.86	4.75	0.57	3.94	0.48	1.96	0.24	0.53	0.06	1.42	0.17	4.72	0.57	4.71	0.57	4.62	0.56	4.43	0.54	3.90	0.47	3.89	0.47	3.80	0.46	3.61	0.44	1.39	0.17	1.38	0.17	1.29	0.16	1.10	0.13
02040105100010	01	120	8.32	REG	6.41	0.77	4.20	0.51	3.45	0.41	1.68	0.20	0.43	0.05	1.25	0.15	4.19	0.50	4.19	0.50	4.19	0.50	4.13	0.50	3.44	0.41	3.44	0.41	3.44	0.41	3.38	0.41	1.24	0.15	1.24	0.15	1.24	0.15	1.18	0.14
02040105100020	01	121	10.31	DAR	5.40	0.52	2.49	0.24	1.66	0.16	0.46	0.04	0.04	0.00	0.42	0.04	2.47	0.24	2.47	0.24	2.12	0.21	2.38	0.23	1.64	0.16	1.64	0.16	1.29	0.13	1.55	0.15	0.40	0.04	0.40	0.04	0.05	0.01	0.31	0.03
02040105100030	01	122	8.98	REG	6.62	0.74	4.31	0.48	3.55	0.39	1.98	0.22	0.51	0.06	1.47	0.16	4.30	0.48	4.30	0.48	4.30	0.48	4.23	0.47	3.54	0.39	3.54	0.39	3.54	0.39	3.46	0.39	1.46	0.16	1.46	0.16	1.46	0.16	1.38	0.15
02040105100040	01	123	9.06	REG	7.50	0.83	4.96	0.55	4.10	0.45	1.79	0.20	0.46	0.05	1.33	0.15	4.95	0.55	4.95	0.55	4.95	0.55	4.86	0.54	4.09	0.45	4.09	0.45	4.09	0.45	4.00	0.44	1.32	0.15	1.32	0.15	1.32	0.15	1.23	0.14
02040105110010	01	124	5.62	DAR	1.12	0.20	0.70	0.12	0.57	0.10	0.37	0.07	0.12	0.02	0.25	0.04	0.65	0.12	0.62	0.11	0.56	0.10	0.29	0.05	0.52	0.09	0.49	0.09	0.43	0.08	0.16	0.03	0.19	0.03	0.16	0.03	0.11	0.02	-0.16	-0.03
02040105110020	01	125	14.72	REG	12.24	0.83	8.07	0.55	6.71	0.46	3.41	0.23	0.93	0.06	2.48	0.17	8.03	0.55	8.02	0.54	8.00	0.54	7.71	0.52	6.66	0.45	6.65	0.45	6.64	0.45	6.35	0.43	2.44	0.17	2.43	0.16	2.41	0.16	2.12	0.14
02040105110030	01	126	7.87	REG	6.08	0.77	3.99	0.51	3.29	0.42	1.63	0.21	0.42	0.05	1.21	0.15	3.36	0.43	2.95	0.37	2.90	0.37	-1.32	-0.17	2.66	0.34	2.25	0.29	2.20	0.28	-2.02	-0.26	0.58	0.07	0.17	0.02	0.12	0.02	-4.09	-0.52
02040105120010	01	127	7.75	DAR	4.70	0.61	3.95	0.51	3.65	0.47	3.22	0.42	2.14	0.28	1.08	0.14	3.93	0.51	3.91	0.50	3.90	0.50	3.82	0.49	3.63	0.47	3.61	0.47	3.60	0.46	3.52	0.45	1.06	0.14	1.04	0.13	1.03	0.13	0.95	0.12
02040105120020	01	128	11.99	REG	8.56	0.71	5.55	0.46	4.58	0.38	3.11	0.26	0.83	0.07	2.28	0.19	5.52	0.46	5.48	0.46	5.23	0.44	5.37	0.45	4.55	0.38	4.52	0.38	4.26	0.36	4.40	0.37	2.25	0.19	2.22	0.18	1.96	0.16	2.10	0.18
02040105140010	01	129	10.08	REG	7.21	0.72	4.67	0.46	3.81	0.38	2.13	0.21	0.56	0.06	1.57	0.16	4.65	0.46	4.65	0.46	4.41	0.44	4.53	0.45	3.79	0.38	3.79	0.38	3.54	0.35	3.67	0.36	1.55	0.15	1.55	0.15	1.31	0.13	1.43	0.14
02040105140020	01	130	12.49	REG	9.40	0.75	6.12	0.49	5.03	0.40	2.80	0.22	0.75	0.06	2.06	0.16	5.98	0.48	5.95	0.48	5.92	0.47	4.97	0.40	4.90	0.39	4.86	0.39	4.83	0.39	3.89	0.31	1.92	0.15	1.88	0.15	1.85	0.15	0.91	0.07
02040105140030	01	131	10.76	REG	7.86	0.73	5.10	0.47	4.18	0.39	2.24	0.21	0.58	0.05	1.66	0.15	5.09	0.47	5.09	0.47	5.09	0.47	5.01	0.47	4.17	0.39	4.17	0.39	4.17	0.39	4.09	0.38	1.64	0.15	1.64	0.15	1.64	0.15	1.57	0.15
02040105140040	01	132	5.63	DAR	5.05	0.90	4.00	0.71	3.61	0.64	2.49	0.44	1.30	0.23	1.19	0.21	4.00	0.71	4.00	0.71	4.00	0.71	3.94	0.70	3.60	0.64	3.60	0.64	3.60	0.64	3.55	0.63	1.18	0.21	1.18	0.21	1.18	0.21	1.13	0.20
02040105140050	01	133	6.95	REG	4.32	0.62	2.75	0.40	2.21	0.32	1.28	0.18	0.32	0.05	0.97	0.14	2.74	0.39	2.74	0.39	2.74	0.39	2.69	0.39	2.21	0.32	2.21	0.32	2.21	0.32	2.15	0.31	0.96	0.14	0.96	0.14	0.96	0.14	0.90	0.13
02040105140060	01	134	6.33	REG	3.36	0.53	2.09	0.33	1.65	0.26	1.60	0.25	0.43	0.07	1.16	0.18	2.08	0.33	2.08	0.33	2.08	0.33	2.00	0.32	1.64	0.26	1.64	0.26	1.64	0.26	1.56	0.25	1.15	0.18	1.15	0.18	1.15	0.18	1.08	0.17
02040105140070	01	135	5.86	REG	4.02	0.69	2.60	0.44	2.12	0.36	1.02	0.17	0.24	0.04	0.78	0.13	2.56	0.44	2.56	0.44	2.54	0.43	2.27	0.39	2.08	0.35	2.08	0.35	2.06	0.35	1.79	0.31	0.73	0.13	0.73	0.13	0.72	0.12	0.45	0.08
02040105150010	01	136	6.44	DAR	4.72	0.73	2.44	0.38	1.81	0.28	0.40	0.06	0.03	0.00	0.37	0.06	2.42	0.38	2.42	0.38	2.42	0.38	2.28	0.35	1.80	0.28	1.80	0.28	1.80	0.28	1.66	0.26	0.35	0.05	0.35	0.05	0.35	0.05	0.21	0.03
02040105150020	01	137	18.88	REG	12.44	0.66	7.96	0.42	6.63	0.35	3.46	0.18	0.81	0.04	2.65	0.14	7.72	0.41	7.66	0.41	7.63	0.40	6.01	0.32	6.38	0.34	6.33	0.34	6.30	0.33	4.68	0.25	2.41	0.13	2.35	0.12	2.32	0.12	0.70	0.04
02040105150030	01	138	5.60	REG	3.94	0.70	2.57	0.46	2.13	0.38	0.92	0.16	0.20	0.04	0.71	0.13	2.38	0.42	2.34	0.42	2.27	0.40	1.11	0.20	1.94	0.35	1.90	0.34	1.83	0.33	0.67	0.12	0.52	0.09	0.48	0.09	0.41	0.07	-0.75	-0.13
02040105150040	01	139	8.00	DAR	9.28	1.16	5.25	0.66	4.15	0.52	1.16	0.15	0.15	0.02	1.01	0.13	5.18	0.65	5.16	0.64	5.13	0.64	4.65	0.58	4.08	0.51	4.06	0.51	4.03	0.50	3.55	0.44	0.93	0.12	0.91	0.11	0.88	0.11	0.41	0.05
02040105150050	01	140	10.07	REG	7.28	0.72	4.73	0.47	3.91	0.39	1.66	0.16	0.39	0.04	1.27	0.13	4.70	0.47	4.70	0.47	4.70	0.47	4.49	0.45	3.88	0.39	3.88	0.39	3.88	0.39	3.67	0.36	1.24	0.12	1.24	0.12	1.24	0.12	1.03	0.10
02040105150060	01	141	5.24	REG	3.37	0.64	2.16	0.41	1.77	0.34	0.67	0.13	0.14	0.03	0.53	0.10	2.15	0.41	2.15	0.41	2.15	0.41	2.09	0.40	1.76	0.34	1.76	0.34	1.76	0.34	1.70	0.32	0.52	0.10	0.52	0.10	0.52	0.10	0.45	0.09
02040105150070	01	142	6.95	REG	5.48	0.79	3.61	0.52	2.99	0.43	1.38	0.20	0.34	0.05	1.04	0.15	3.54	0.51	3.50	0.50	3.47	0.50	3.06	0.44	2.92	0.42	2.89	0.42	2.86	0.41	2.44	0.35	0.97	0.14	0.93	0.13	0.90	0.13	0.49	0.07
02040105150080	01	143	7.74	REG	6.99	0.90	4.67	0.60	3.87	0.50	1.66	0.21	0.45	0.06	1.21	0.16	4.66	0.60	4.66	0.60	4.66	0.60	4.56	0.59	3.85	0.50	3.85	0.50	3.85	0.50	3.75	0.48	1.20	0.15	1.20	0.15	1.20	0.15	1.09	0.14
02040105150090	01	144	4.95	DAR	1.43	0.29	0.60	0.12	0.41	0.08	0.14	0.03	0.01	0.00	0.12	0.02	0.58	0.12	0.58	0.12	0.57	0.12	0.46	0.09	0.39	0.08	0.39	0.08	0.38	0.08	0.27	0.05	0.10	0.02	0.10	0.02	0.09	0.02	-0.02	0.00
02040105150100	01	145	7.72	REG	7.58	0.98	5.13	0.66	4.24	0.55	2.21	0.29	0.67	0.09	1.54	0.20	5.00	0.65	4.94	0.64	4.97	0.64	4.14	0.54	4.11	0.53	4.06	0.53	4.08	0.53	3.25	0.42	1.41	0.18	1.35	0.18	1.38	0.18	0.55	0.07
02040105160010	01	146	14.50	REG	12.91	0.89	8.58	0.59	7.09	0.49	4.15	0.29	1.25	0.09	2.90	0.20	8.40	0.58	8.38	0.58	8.28	0.57	7.16	0.49	6.91	0.48	6.89	0.48	6.79	0.47	5.67	0.39	2.72	0.19	2.70	0.19	2.60	0.18	1.48	0.10
02040105160020	01	147	17.77	REG	14.77	0.83	9.70	0.55	7.93	0.45	5.56	0.31	1.76	0.10	3.81	0.21	9.66	0.54	9.64	0.54	9.14	0.51	9.41	0.53	7.90	0.44	7.87	0.44	7.38	0.42	7.64	0.43	3.77	0.21	3.75	0.21	3.25	0.18	3.52	0.20
02040105160030	01	148	7.77	REG	4.61	0.59	2.90	0.37	2.29	0.29	2.47	0.32	0.76	0.10	1.72	0.22	2.79	0.36	2.69	0.35	2.46	0.32	2.27	0.29	2.18	0.28	2.08	0.27	1.85	0.24	1.66	0.21	1.61	0.21	1.51	0.19	1.28	0.16	1.09	0.14
02040105160040	01	149	5.10	REG	2.97	0.58	1.87	0.37	1.47	0.29	1.37	0.27	0.39	0.08	0.98	0.19	1.85	0.36	1.85	0.36	1.83	0.36	1.70	0.33	1.45	0.28	1.45	0.28	1.44	0.28	1.30	0.26	0.95	0.19	0.95	0.19	0.94	0.18	0.81	0.16
02040105160050	01	150	14.49	REG	11.02	0.76	7.17	0.49	5.87	0.41	3.80	0.26	1.09	0.08	2.71	0.19	7.15	0.49	7.15	0.49	7.15	0.49	7.00	0.48	5.85	0.40	5.85	0.40	5.85	0.40	5.70	0.39	2.69	0.19	2.69	0.19	2.69	0.19	2.54	0.18
02040105160060	01	151	6.76	REG	4.36	0.64	2.78	0.41	2.23	0.33	1.27	0.19	0.32	0.05	0.95	0.14	2.76	0.41	2.75	0.41	2.75	0.41	2.59	0.38	2.21	0.33	2.19	0.32	2.20	0.33	2.04	0.30	0.92	0.14	0.91	0.13	0.92	0.14	0.76	0.11
02040105160070	01	152	7.48	REG	5.24	0.70	3.39	0.45	2.77	0.37	1.27	0.17	0.31	0.04	0.96	0.13	3.13	0.42	3.02	0.40	3.07	0.41	0.89	0.12	2.51	0.34	2.40	0.32	2.44	0.33	0.27	0.04	0.71	0.09	0.60	0.08	0.64	0.09	-1.53	-0.20
02020007010010	02	201	11.46	DAR	9.75	0.85	5.76	0.50	4.47	0.39	2.27	0.20	0.49	0.04	1.78	0.15	5.67	0.49	5.65	0.49	5.58	0.49	5.08	0.44	4.38	0.38	4.35	0.38	4.29	0.37	3.79	0.33	1.69	0.15	1.66	0.15	1.60	0.14	1.10	0.10
02020007010020	02	202	7.18	REG	4.87	0.68	3.15	0.44	2.60	0.36	0.96	0.13	0.21	0.03	0.76	0.11	3.11	0.43	3.10	0.43	3.07	0.43	2.84	0.40	2.56	0.36	2.55	0.35	2.52	0.35	2.29	0.32	0.72	0.10	0.71	0.10	0.68	0.09	0.45	0.06
02020007010030	02	203	7.17	REG	4.42	0.62	2.81	0.39	2.29	0.32	0.99	0.14	0.22	0.03	0.78	0.11	2.80	0.39	2.79	0.39	2.79	0.39	2.69	0.38	2.28	0.32	2.27	0.32	2.27	0.32	2.17	0.30	0.76	0.11	0.76	0.11	0.76	0.11	0.65	0.09
02020007010040	02	204	14.11	REG	11.30	0.80	7.43	0.53	6.18	0.44	3.04	0.22	0.79	0.06	2.25	0.16	7.31	0.52	7.22	0.51	7.17	0.51	6.66	0.47	6.07	0.43	5.97	0.42	5.92	0.42	5.41	0.38	2.14	0.15	2.04	0.14	1.99	0.14	1.48	0.11
02020007010050	02	205	5.47	REG	3.90	0.71	2.54	0.46	2.09	0.38	0.71	0.13	0.15	0.03	0.56	0.10	2.51	0.46	2.43	0.44	2.41	0.44	2.45	0.45	2.07	0.38	1.99	0.36	1.96	0.36	2.00	0.37	0.53	0.10	0.45	0.08	0.43	0.08	0.46	0.08
02020007010060	02	206	6.47	DAR	4.63	0.72	2.70	0.42	2.14	0.33	1.33	0.21	0.37	0.06	0.96	0.15	2.69	0.42	2.69	0.42	2.69	0.42	2.63	0.41	2.13	0.33	2.13	0.33	2.13	0.33	2.07	0.32	0.95	0.15	0.95	0.15	0.95	0.15	0.89	0.14
02020007010070	02	207	9.13	REG	7.47	0.82	4.94	0.54	4.09	0.45	1.80	0.20	0.46	0.05	1.34	0.15	4.78	0.52	4.25	0.47	4.65	0.51	4.02	0.44	3.93	0.43	3.41	0.37	3.80	0.42	3.18	0.35	1.18	0.13	0.66	0.07	1.05	0.12	0.42	0.05
02020007020070	02	208	13.27	REG	9.43	0.71	6.11	0.46	5.08	0.38	2.25	0.17	0.52	0.04	1.73	0.13	6.09	0.46	6.09	0.46	6.09	0.46	5.96	0.45	5.07	0.38	5.07	0.38	5.07	0.38	4.94	0.37	1.71	0.13	1.71	0.13	1.71	0.13	1.58	0.12
02020007030010	02	209	9.15	REG	6.56	0.72	4.27	0.47	3.54	0.39	1.52	0.17	0.35	0.04	1.17	0.13	4.24	0.46	4.23	0.46	4.21	0.46	4.04	0.44	3.51	0.38	3.50	0.38	3.48	0.38	3.32	0.36	1.14	0.12	1.13	0.12	1.11	0.12	0.95	0.10
02020007030030	02	210	5.19	REG	2.92	0.56	1.85	0.36	1.53	0.30	0.51	0.10	0.09	0.02	0.42	0.08	1.84	0.35	1.84	0.35	1.84	0.35	1.75	0.34	1.52	0.29	1.52	0.29	1.52	0.29	1.43	0.28	0.41	0.08	0.41	0.08	0.41	0.08	0.32	0.06
02020007030040	02	211	6.41	REG	3.53	0.55	2.23	0.35	1.84	0.29	0.64	0.10	0.11	0.02	0.52	0.08	2.21	0.35	2.21	0.35	2.21	0.35	2.11	0.33	1.83	0.28	1.83	0.28	1.83	0.28	1.72	0.27	0.51	0.08	0.51	0.08	0.51	0.08	0.41	0.06
02020007040010	02	212	5.41	DAR	5.24	0.97	3.39	0.63	2.76	0.51	1.27	0.23	0.31	0.06	0.96	0.18	3.33	0.61	3.31	0.61	3.23	0.60	2.87	0.53	2.69	0.50	2.68	0.49	2.60	0.48	2.24	0.41	0.89	0.16	0.87	0.16	0.79	0.15	0.43	0.08
02020007040020	02	213	14.95	DAR	14.46	0.97	9.37	0.63	7.63	0.51	3.50	0.23	0.85	0.06	2.64	0.18	9.32	0.62	9.31	0.62	9.31	0.62	8.87	0.59	7.58	0.51	7.56	0.51	7.56	0.51	7.13	0.48	2.59	0.17	2.58	0.17	2.58	0.17	2.14	0.14
02020007040030	02	214	5.58	REG	3.79	0.68	2.45	0.44	2.02	0.36	0.82	0.15	0.18	0.03	0.64	0.12	2.44	0.44	2.44	0.44	2.43	0.44	2.31	0.41	2.00	0.36	2.00	0.36	1.99	0.36	1.87	0.34	0.63	0.11	0.62	0.11	0.62	0.11	0.50	0.09
02020007040040	02	215	6.17	REG	3.48	0.56	2.20	0.36	1.79	0.29	0.85	0.14	0.18	0.03	0.68	0.11	2.18	0.35	2.18	0.35	2.18	0.35	2.05	0.33	1.77	0.29	1.77	0.29	1.77	0.29	1.64	0.27	0.66	0.11	0.66	0.11	0.66	0.11	0.53	0.09
02020007040050	02	216	14.34	REG	10.32	0.72	6.68	0.47	5.52	0.39	2.71	0.19	0.67	0.05	2.04	0.14	6.64	0.46	6.64	0.46	6.63	0.46	6.34	0.44	5.48	0.38	5.48	0.38	5.47	0.38	5.19	0.36	2.00	0.14	2.00	0.14	1.98	0.14	1.70	0.12
02020007040060	02	217	7.85	REG	5.75	0.73	3.75	0.48	3.08	0.39	1.52	0.19	0.38	0.05	1.14	0.15	3.72	0.47	3.72	0.47	3.72	0.47	3.56	0.45	3.06	0.39	3.06	0.39	3.06	0.39	2.90	0.37	1.12	0.14	1.12	0.14	1.12	0.14	0.96	0.12
02030103050010	03	301	5.41	REG	3.53	0.65	2.27	0.42	1.85	0.34	0.79	0.15	0.18	0.03	0.61	0.11	2.25	0.42	2.25	0.42	2.25	0.42	2.15	0.40	1.83	0.34	1.83	0.34	1.83	0.34	1.73	0.32	0.60	0.11	0.60	0.11	0.60	0.11	0.50	0.09
02030103050020	03	302	7.17	REG	4.86	0.68	3.13	0.44	2.57	0.36	1.23	0.17	0.29	0.04	0.94	0.13	3.11	0.43	3.11	0.43	3.11	0.43	2.97	0.41	2.55	0.36	2.55	0.36	2.54	0.35	2.41	0.34	0.92	0.13	0.92	0.13	0.92	0.13	0.78	0.11
02030103050030	03	303	10.48	REG	8.01	0.76	5.23	0.50	4.32	0.41	2.08	0.20	0.53	0.05	1.55	0.15	5.21	0.50	5.21	0.50	5.21	0.50	5.04	0.48	4.29	0.41	4.29	0.41	4.29	0.41	4.12	0.39	1.53	0.15	1.53	0.15	1.53	0.15	1.36	0.13
02030103050040	03	304	13.25	REG	9.61	0.72	6.22	0.47	5.09	0.38	2.85	0.22	0.76	0.06	2.10	0.16	6.18	0.47	6.18	0.47	6.18	0.47	5.91	0.45	5.05	0.38	5.05	0.38	5.05	0.38	4.78	0.36	2.06	0.16	2.06	0.16	2.06	0.16	1.78	0.13
02030103050050	03	305	18.37	REG	16.24	0.88	10.78	0.59	8.98	0.49	5.09	0.28	1.50	0.08	3.60	0.20	10.70	0.58	10.70	0.58	10.66	0.58	10.15	0.55	8.90	0.48	8.89	0.48	8.85	0.48	8.34	0.45	3.52	0.19	3.51	0.19	3.47	0.19	2.96	0.16
02030103050060	03	306	7.88	REG	6.11	0.78	4.01	0.51	3.30	0.42	1.48	0.19	0.37	0.05	1.11	0.14	3.98	0.51	3.98	0.51	3.98	0.50	3.80	0.48	3.27	0.41	3.27	0.41	3.26	0.41	3.09	0.39	1.08	0.14	1.08	0.14	1.08	0.14	0.90	0.11
02030103050070	03	307	7.30	REG	5.55	0.76	3.64	0.50	3.00	0.41	1.34	0.18	0.33	0.04	1.01	0.14	3.60	0.49	3.55	0.49	3.58	0.49	3.35	0.46	2.97	0.41	2.91	0.40	2.95	0.40	2.72	0.37	0.98	0.13	0.92	0.13	0.96	0.13	0.73	0.10
02030103050080	03	308	16.92	REG	13.77	0.81	9.06	0.54	7.56	0.45	3.51	0.21	0.91	0.05	2.60	0.15	8.85	0.52	8.78	0.52	8.63	0.51	7.41	0.44	7.34	0.43	7.28	0.43	7.12	0.42	5.90	0.35	2.39	0.14	2.32	0.14	2.17	0.13	0.95	0.06
02030103070010	03	309	5.43	REG	4.52	0.83	3.00	0.55	2.46	0.45	1.00	0.18	0.25	0.05	0.74	0.14	2.95	0.54	2.94	0.54	2.92	0.54	2.62	0.48	2.41	0.44	2.40	0.44	2.38	0.44	2.09	0.38	0.70	0.13	0.68	0.13	0.67	0.12	0.37	0.07
02030103070020	03	310	9.03	REG	7.60	0.84	5.03	0.56	4.17	0.46	1.71	0.19	0.44	0.05	1.27	0.14	5.00	0.55	4.99	0.55	4.98	0.55	4.72	0.52	4.13	0.46	4.12	0.46	4.11	0.46	3.85	0.43	1.23	0.14	1.23	0.14	1.22	0.13	0.96	0.11
02030103070030	03	311	14.62	REG	11.91	0.81	7.83	0.54	6.49	0.44	2.84	0.19	0.73	0.05	2.10	0.14	7.78	0.53	7.78	0.53	7.78	0.53	7.45	0.51	6.44	0.44	6.43	0.44	6.43	0.44	6.11	0.42	2.05	0.14	2.05	0.14	2.05	0.14	1.72	0.12
02030103070040	03	312	11.82	DAR	10.69	0.90	8.06	0.68	6.42	0.54	1.94	0.16	0.39	0.03	1.55	0.13	8.03	0.68	8.03	0.68	8.01	0.68	7.80	0.66	6.38	0.54	6.38	0.54	6.37	0.54	6.15	0.52	1.52	0.13	1.52	0.13	1.50	0.13	1.29	0.11
02030103070050	03	313	21.47	REG	16.23	0.76	10.55	0.49	8.76	0.41	4.22	0.20	1.07	0.05	3.15	0.15	10.48	0.49	10.48	0.49	10.45	0.49	10.00	0.47	8.69	0.40	8.69	0.40	8.67	0.40	8.21	0.38	3.08	0.14	3.07	0.14	3.05	0.14	2.59	0.12
02030103070060	03	314	5.99	REG	4.80	0.80	3.17	0.53	2.61	0.43	1.00	0.17	0.24	0.04	0.76	0.13	3.08	0.51	3.07	0.51	3.03	0.51	2.51	0.42	2.52	0.42	2.50	0.42	2.47	0.41	1.95	0.33	0.67	0.11	0.65	0.11	0.62	0.10	0.10	0.02
02030103070070	03	315	10.80	REG	8.57	0.79	5.63	0.52	4.66	0.43	2.21	0.20	0.57	0.05	1.64	0.15	5.44	0.50	5.42	0.50	5.35	0.49	4.16	0.38	4.47	0.41	4.45	0.41	4.38	0.41	3.19	0.30	1.45	0.13	1.43	0.13	1.35	0.13	0.16	0.02
02030103100010	03	316	5.81	REG	4.79	0.82	3.18	0.55	2.62	0.45	1.00	0.17	0.25	0.04	0.76	0.13	2.99	0.52	2.92	0.50	2.91	0.50	1.78	0.31	2.44	0.42	2.36	0.41	2.35	0.40	1.22	0.21	0.57	0.10	0.50	0.09	0.49	0.08	-0.64	-0.11
02030103100020	03	317	4.35	REG	2.66	0.61	1.71	0.39	1.42	0.33	0.60	0.14	0.12	0.03	0.48	0.11	1.65	0.38	1.60	0.37	1.62	0.37	1.30	0.30	1.36	0.31	1.31	0.30	1.33	0.31	1.00	0.23	0.43	0.10	0.37	0.09	0.39	0.09	0.07	0.02
02030103100030	03	318	6.72	REG	5.69	0.85	3.78	0.56	3.13	0.47	1.31	0.20	0.33	0.05	0.98	0.15	3.30	0.49	3.29	0.49	2.47	0.37	1.49	0.22	2.64	0.39	2.64	0.39	1.82	0.27	0.84	0.12	0.50	0.07	0.49	0.07	-0.33	-0.05	-1.31	-0.20
02030103100040	03	319	4.71	DAR	1.37	0.29	0.79	0.17	0.62	0.13	0.19	0.04	0.02	0.01	0.17	0.04	0.78	0.17	0.78	0.17	0.78	0.17	0.74	0.16	0.62	0.13	0.62	0.13	0.62	0.13	0.58	0.12	0.16	0.03	0.16	0.03	0.16	0.03	0.12	0.03
02030103100050	03	320	6.31	REG	5.83	0.92	3.92	0.62	3.23	0.51	1.25	0.20	0.33	0.05	0.92	0.15	3.80	0.60	3.47	0.55	3.63	0.57	2.98	0.47	3.11	0.49	2.78	0.44	2.94	0.47	2.30	0.36	0.80	0.13	0.47	0.07	0.63	0.10	-0.02	0.00
02030103100060	03	321	8.60	DAR	7.04	0.82	5.24	0.61	4.61	0.54	2.38	0.28	0.67	0.08	1.71	0.20	5.05	0.59	4.95	0.58	4.76	0.55	3.83	0.44	4.42	0.51	4.33	0.50	4.13	0.48	3.20	0.37	1.52	0.18	1.42	0.17	1.23	0.14	0.30	0.03
02030103100070	03	322	11.28	REG	8.27	0.73	5.39	0.48	4.49	0.40	2.02	0.18	0.47	0.04	1.55	0.14	5.30	0.47	5.21	0.46	5.19	0.46	4.66	0.41	4.41	0.39	4.31	0.38	4.30	0.38	3.77	0.33	1.46	0.13	1.36	0.12	1.35	0.12	0.82	0.07
02030103110010	03	323	13.11	DAR	10.11	0.77	5.94	0.45	4.75	0.36	1.82	0.14	0.21	0.02	1.61	0.12	5.60	0.43	5.44	0.42	5.24	0.40	3.32	0.25	4.41	0.34	4.26	0.32	4.05	0.31	2.14	0.16	1.27	0.10	1.12	0.09	0.91	0.07	-1.00	-0.08
02030103110020	03	324	10.87	REG	7.40	0.68	4.78	0.44	3.99	0.37	2.77	0.25	0.69	0.06	2.08	0.19	4.74	0.44	4.73	0.44	4.64	0.43	4.47	0.41	3.96	0.36	3.94	0.36	3.85	0.35	3.69	0.34	2.05	0.19	2.03	0.19	1.94	0.18	1.77	0.16
02030103140010	04	401	5.30	DAR	4.98	0.94	3.99	0.75	3.68	0.69	2.41	0.46	1.10	0.21	1.32	0.25	3.94	0.74	3.93	0.74	3.91	0.74	3.58	0.68	3.63	0.69	3.62	0.68	3.60	0.68	3.28	0.62	1.27	0.24	1.26	0.24	1.23	0.23	0.91	0.17
02030103140020	04	402	9.37	REG	6.68	0.71	4.35	0.46	3.63	0.39	2.38	0.25	0.60	0.06	1.77	0.19	4.09	0.44	3.95	0.42	3.96	0.42	2.40	0.26	3.37	0.36	3.23	0.34	3.24	0.35	1.68	0.18	1.52	0.16	1.38	0.15	1.39	0.15	-0.17	-0.02
02030103140040	04	403	13.63	DAR	9.02	0.66	5.24	0.38	4.68	0.34	3.82	0.28	0.86	0.06	2.95	0.22	4.69	0.34	4.54	0.33	4.50	0.33	1.03	0.08	4.13	0.30	3.98	0.29	3.94	0.29	0.47	0.03	2.40	0.18	2.25	0.17	2.21	0.16	-1.26	-0.09
02030103010010	06	601	10.13	REG	7.33	0.72	4.74	0.47	3.82	0.38	3.14	0.31	0.97	0.10	2.17	0.21	4.69	0.46	4.60	0.45	4.49	0.44	4.37	0.43	3.76	0.37	3.68	0.36	3.57	0.35	3.45	0.34	2.12	0.21	2.04	0.20	1.93	0.19	1.80	0.18
02030103010020	06	602	5.24	DAR	4.15	0.79	2.70	0.51	2.30	0.44	1.57	0.30	0.44	0.08	1.13	0.22	2.68	0.51	2.68	0.51	2.67	0.51	2.58	0.49	2.29	0.44	2.29	0.44	2.28	0.44	2.19	0.42	1.11	0.21	1.11	0.21	1.11	0.21	1.01	0.19
02030103010030	06	603	7.92	DAR	4.56	0.58	2.81	0.35	2.36	0.30	1.60	0.20	0.36	0.05	1.24	0.16	2.74	0.35	2.64	0.33	2.62	0.33	2.30	0.29	2.29	0.29	2.18	0.28	2.17	0.27	1.85	0.23	1.17	0.15	1.07	0.13	1.05	0.13	0.73	0.09
02030103010040	06	604	5.06	REG	3.62	0.72	2.36	0.47	1.95	0.39	1.32	0.26	0.34	0.07	0.98	0.19	2.10	0.42	1.96	0.39	1.56	0.31	0.45	0.09	1.70	0.34	1.55	0.31	1.15	0.23	0.04	0.01	0.73	0.14	0.58	0.12	0.18	0.04	-0.93	-0.18
02030103010050	06	605	5.15	REG	2.70	0.53	1.70	0.33	1.41	0.27	0.93	0.18	0.19	0.04	0.74	0.14	1.69	0.33	1.69	0.33	1.69	0.33	1.63	0.32	1.40	0.27	1.40	0.27	1.40	0.27	1.34	0.26	0.73	0.14	0.73	0.14	0.73	0.14	0.67	0.13
02030103010060	06	606	14.19	REG	6.41	0.45	3.94	0.28	3.32	0.23	2.17	0.15	0.39	0.03	1.77	0.12	3.89	0.27	3.82	0.27	3.75	0.26	3.84	0.27	3.27	0.23	3.20	0.23	3.13	0.22	3.22	0.23	1.73	0.12	1.65	0.12	1.58	0.11	1.67	0.12
02030103010070	06	607	8.89	REG	5.02	0.56	3.17	0.36	2.64	0.30	1.63	0.18	0.35	0.04	1.28	0.14	3.17	0.36	3.17	0.36	3.17	0.36	3.11	0.35	2.63	0.30	2.63	0.30	2.63	0.30	2.57	0.29	1.27	0.14	1.27	0.14	1.27	0.14	1.22	0.14
02030103010080	06	608	7.60	REG	4.81	0.63	3.07	0.40	2.52	0.33	1.90	0.25	0.49	0.06	1.41	0.19	3.06	0.40	3.06	0.40	2.99	0.39	3.01	0.40	2.51	0.33	2.50	0.33	2.43	0.32	2.46	0.32	1.40	0.18	1.40	0.18	1.32	0.17	1.35	0.18
02030103010090	06	609	5.44	DAR	3.06	0.56	1.75	0.32	1.47	0.27	0.68	0.13	0.09	0.02	0.59	0.11	1.75	0.32	1.75	0.32	1.75	0.32	1.71	0.31	1.46	0.27	1.46	0.27	1.46	0.27	1.42	0.26	0.58	0.11	0.58	0.11	0.58	0.11	0.55	0.10

Preliminary results summarizing selected flow statistics, ground-water use and ground-water capacity within HUC14 watersheds, New Jersey Highlands. [WMA, watershed management area; REG, regression method; DAR, drainage area ratio method; BF10, base flow at the 10-year recurrence interval; BF25, base flow at the 25-year recurrence interval; QSep50, median September discharge; Q710, 7-day 10-year low flow; LFM, low flow margin calculated as QSep50 - Q710; GWC10A, ground-water capacity calculated as BF10 minus consumptive ground-water use; GWC10B, ground-water capacity calculated as BF10 minus maximum monthly consumptive ground-water use; GWC10C, ground-water capacity calculated as BF10 minus consumptive ground-water use at full allocation; GWC10D, ground-water capacity calculated as BF10 minus total ground-water use.]

HUC 14 number	WMA	Map key	Drainage area mi²	Method	Base flow Mgal/d	Base flow Mgal/d/mi²	BF_{10} Mgal/d	BF_{10} Mgal/d/mi²	BF_{25} Mgal/d	BF_{25} Mgal/d/mi²	$QSep_{50}$ Mgal/d	$QSep_{50}$ Mgal/d/mi²	Q_{710} Mgal/d	Q_{710} Mgal/d/mi²	LFM Mgal/d	LFM Mgal/d/mi²	$GWC_{10}A$, Mgal/d	$GWC_{10}A$, Mgal/d/mi²	$GWC_{10}B$, Mgal/d	$GWC_{10}B$, Mgal/d/mi²	$GWC_{10}C$, Mgal/d	$GWC_{10}C$, Mgal/d/mi²	$GWC_{10}D$, Mgal/d	$GWC_{10}D$, Mgal/d/mi²	$GWC_{25}A$, Mgal/d	$GWC_{25}A$, Mgal/d/mi²	$GWC_{25}B$, Mgal/d	$GWC_{25}B$, Mgal/d/mi²	$GWC_{25}C$, Mgal/d	$GWC_{25}C$, Mgal/d/mi²	$GWC_{25}D$, Mgal/d	$GWC_{25}D$, Mgal/d/mi²	$GWC_{LFM}A$ Mgal/d	$GWC_{LFM}A$ Mgal/d/mi²	$GWC_{LFM}B$ Mgal/d	$GWC_{LFM}B$ Mgal/d/mi²	$GWC_{LFM}C$ Mgal/d	$GWC_{LFM}C$ Mgal/d/mi²	$GWC_{LFM}D$ Mgal/d	$GWC_{LFM}D$ Mgal/d/mi²
02030103010100	06	610	7.73	REG	4.67	0.60	2.97	0.38	2.45	0.32	1.51	0.20	0.34	0.04	1.17	0.15	2.95	0.38	2.95	0.38	2.95	0.38	2.82	0.36	2.44	0.32	2.44	0.32	2.44	0.32	2.30	0.30	1.15	0.15	1.15	0.15	1.15	0.15	1.01	0.13
02030103010110	06	611	6.68	REG	3.85	0.58	2.45	0.37	2.03	0.30	1.06	0.16	0.22	0.03	0.84	0.13	2.43	0.36	2.43	0.36	2.43	0.36	2.33	0.35	2.01	0.30	2.01	0.30	2.01	0.30	1.92	0.29	0.82	0.12	0.82	0.12	0.82	0.12	0.73	0.11
02030103010180	06	612	5.34	REG	3.83	0.72	2.51	0.47	2.04	0.38	1.06	0.20	0.25	0.05	0.82	0.15	2.37	0.44	2.29	0.43	2.27	0.42	1.46	0.27	1.91	0.36	1.83	0.34	1.80	0.34	1.00	0.19	0.68	0.13	0.60	0.11	0.58	0.11	-0.23	-0.04
02030103020010	06	613	6.05	DAR	5.50	0.91	4.41	0.73	3.98	0.66	1.91	0.32	0.63	0.10	1.28	0.21	4.40	0.73	4.40	0.73	4.40	0.73	4.30	0.71	3.97	0.66	3.97	0.66	3.97	0.66	3.87	0.64	1.27	0.21	1.27	0.21	1.27	0.21	1.18	0.19
02030103020020	06	614	6.27	DAR	5.70	0.91	4.57	0.73	4.12	0.66	1.98	0.32	0.65	0.10	1.33	0.21	4.56	0.73	4.56	0.73	4.56	0.73	4.52	0.72	4.12	0.66	4.12	0.66	4.12	0.66	4.07	0.65	1.32	0.21	1.32	0.21	1.32	0.21	1.28	0.20
02030103020030	06	615	7.77	DAR	7.63	0.98	5.13	0.66	4.67	0.60	3.64	0.47	1.79	0.23	1.85	0.24	5.13	0.66	5.12	0.66	5.09	0.66	5.12	0.66	4.67	0.60	4.67	0.60	4.64	0.60	4.66	0.60	1.85	0.24	1.85	0.24	1.82	0.23	1.84	0.24
02030103020040	06	616	5.61	REG	4.47	0.80	2.95	0.53	2.43	0.43	1.23	0.22	0.33	0.06	0.91	0.16	2.92	0.52	2.90	0.52	2.86	0.51	2.68	0.48	2.40	0.43	2.37	0.42	2.34	0.42	2.16	0.39	0.87	0.16	0.85	0.15	0.82	0.15	0.64	0.11
02030103020050	06	617	6.72	REG	4.83	0.72	3.15	0.47	2.61	0.39	1.36	0.20	0.32	0.05	1.03	0.15	3.13	0.47	3.13	0.46	3.10	0.46	3.04	0.45	2.60	0.39	2.59	0.39	2.57	0.38	2.50	0.37	1.02	0.15	1.01	0.15	0.99	0.15	0.92	0.14
02030103020060	06	618	5.09	DAR	2.55	0.50	1.54	0.30	1.40	0.27	1.01	0.20	0.40	0.08	0.61	0.12	0.89	0.18	0.68	0.13	0.68	0.13	-3.42	-0.67	0.75	0.15	0.54	0.11	0.54	0.11	-3.56	-0.70	-0.03	-0.01	-0.24	-0.05	-0.24	-0.05	-4.35	-0.85
02030103020070	06	619	10.38	REG	6.57	0.63	4.21	0.41	3.52	0.34	2.63	0.25	0.63	0.06	2.00	0.19	3.72	0.36	3.27	0.31	2.85	0.27	0.58	0.06	3.03	0.29	2.58	0.25	2.16	0.21	-0.11	-0.01	1.50	0.14	1.05	0.10	0.63	0.06	-1.64	-0.16
02030103020080	06	620	10.06	REG	6.88	0.68	4.45	0.44	3.72	0.37	2.37	0.24	0.58	0.06	1.79	0.18	3.74	0.37	3.35	0.33	3.38	0.34	-1.07	-0.11	3.00	0.30	2.62	0.26	2.65	0.26	-1.81	-0.18	1.07	0.11	0.69	0.07	0.72	0.07	-3.73	-0.37
02030103020090	06	621	6.04	REG	2.53	0.42	1.55	0.26	1.30	0.21	0.83	0.14	0.14	0.02	0.69	0.11	1.39	0.23	1.27	0.21	1.27	0.21	0.31	0.05	1.14	0.19	1.02	0.17	1.01	0.17	0.06	0.01	0.53	0.09	0.41	0.07	0.41	0.07	-0.55	-0.09
02030103020100	06	622	5.61	REG	2.66	0.47	1.66	0.29	1.38	0.25	0.83	0.15	0.15	0.03	0.68	0.12	1.40	0.25	1.34	0.24	1.25	0.22	-0.31	-0.05	1.13	0.20	1.06	0.19	0.98	0.17	-0.58	-0.10	0.42	0.08	0.36	0.06	0.27	0.05	-1.28	-0.23
02030103030010	06	623	8.56	DAR	9.57	1.12	5.98	0.70	4.94	0.58	3.12	0.37	0.85	0.10	2.28	0.27	5.94	0.69	5.92	0.69	5.92	0.69	5.70	0.67	4.91	0.57	4.89	0.57	4.89	0.57	4.67	0.55	2.24	0.26	2.22	0.26	2.22	0.26	2.00	0.23
02030103030020	06	624	4.84	REG	4.21	0.87	2.81	0.58	2.32	0.48	1.00	0.21	0.26	0.05	0.74	0.15	2.79	0.58	2.79	0.58	2.76	0.57	2.68	0.55	2.30	0.47	2.29	0.47	2.27	0.47	2.18	0.45	0.72	0.15	0.71	0.15	0.69	0.14	0.60	0.12
02030103030030	06	625	6.70	REG	5.87	0.88	3.91	0.58	3.23	0.48	1.38	0.21	0.37	0.05	1.02	0.15	3.89	0.58	3.88	0.58	3.88	0.58	3.71	0.55	3.20	0.48	3.19	0.48	3.20	0.48	3.02	0.45	0.99	0.15	0.98	0.15	0.99	0.15	0.81	0.12
02030103030040	06	626	7.97	REG	6.53	0.82	4.32	0.54	3.58	0.45	1.41	0.18	0.35	0.04	1.06	0.13	4.29	0.54	4.29	0.54	4.29	0.54	4.10	0.51	3.55	0.45	3.55	0.45	3.55	0.45	3.35	0.42	1.03	0.13	1.03	0.13	1.03	0.13	0.84	0.11
02030103030050	06	627	7.37	DAR	7.52	1.02	5.06	0.69	2.53	0.34	2.11	0.29	0.36	0.05	1.76	0.24	5.05	0.68	5.05	0.68	5.05	0.68	4.96	0.67	2.52	0.34	2.52	0.34	2.52	0.34	2.43	0.33	1.75	0.24	1.75	0.24	1.75	0.24	1.66	0.23
02030103030060	06	628	7.90	REG	5.60	0.71	3.64	0.46	3.02	0.38	1.30	0.16	0.29	0.04	1.01	0.13	3.53	0.45	3.48	0.44	3.35	0.42	2.78	0.35	2.91	0.37	2.86	0.36	2.73	0.35	2.16	0.27	0.90	0.11	0.85	0.11	0.71	0.09	0.14	0.02
02030103030070	06	629	9.10	REG	7.31	0.80	4.82	0.53	4.00	0.44	2.16	0.24	0.57	0.06	1.58	0.17	4.31	0.47	4.17	0.46	4.15	0.46	0.92	0.10	3.49	0.38	3.35	0.37	3.33	0.37	0.09	0.01	1.08	0.12	0.94	0.10	0.91	0.10	-2.32	-0.26
02030103030080	06	630	4.89	REG	3.93	0.80	2.60	0.53	2.13	0.44	1.05	0.22	0.28	0.06	0.78	0.16	2.59	0.53	2.59	0.53	2.59	0.53	2.50	0.51	2.12	0.43	2.12	0.43	2.12	0.43	2.03	0.42	0.76	0.16	0.76	0.16	0.76	0.16	0.68	0.14
02030103030090	06	631	7.33	REG	5.46	0.74	3.57	0.49	2.97	0.40	1.39	0.19	0.33	0.05	1.06	0.14	3.43	0.47	3.39	0.46	3.39	0.46	2.46	0.34	2.82	0.39	2.79	0.38	2.79	0.38	1.85	0.25	0.92	0.13	0.88	0.12	0.88	0.12	-0.05	-0.01
02030103030100	06	632	7.92	REG	6.22	0.78	4.08	0.51	3.34	0.42	1.70	0.21	0.45	0.06	1.25	0.16	4.07	0.51	4.07	0.51	4.07	0.51	3.98	0.50	3.33	0.42	3.33	0.42	3.33	0.42	3.24	0.41	1.23	0.16	1.23	0.16	1.23	0.16	1.14	0.14
02030103030110	06	633	14.76	REG	11.19	0.76	7.30	0.49	6.07	0.41	3.17	0.21	0.81	0.06	2.36	0.16	6.97	0.47	6.90	0.47	6.83	0.46	4.76	0.32	5.74	0.39	5.66	0.38	5.60	0.38	3.52	0.24	2.03	0.14	1.95	0.13	1.89	0.13	-0.19	-0.01
02030103030120	06	634	9.01	REG	6.98	0.77	4.57	0.51	3.78	0.42	2.00	0.22	0.52	0.06	1.48	0.16	4.56	0.51	4.56	0.51	4.56	0.51	4.47	0.50	3.77	0.42	3.77	0.42	3.77	0.42	3.67	0.41	1.47	0.16	1.47	0.16	1.47	0.16	1.37	0.15
02030103030130	06	635	12.28	DAR	7.80	0.64	4.37	0.36	3.54	0.29	1.62	0.13	0.19	0.02	1.43	0.12	4.31	0.35	4.30	0.35	4.28	0.35	3.86	0.31	3.48	0.28	3.48	0.28	3.46	0.28	3.04	0.25	1.37	0.11	1.37	0.11	1.34	0.11	0.92	0.08
02030103030140	06	636	5.28	REG	4.06	0.77	2.67	0.51	2.20	0.42	1.09	0.21	0.27	0.05	0.82	0.16	2.47	0.47	2.37	0.45	2.42	0.46	1.16	0.22	2.01	0.38	1.91	0.36	1.95	0.37	0.70	0.13	0.62	0.12	0.52	0.10	0.57	0.11	-0.69	-0.13
02030103030150	06	637	6.90	REG	4.60	0.67	2.97	0.43	2.46	0.36	1.14	0.17	0.25	0.04	0.89	0.13	2.96	0.43	2.96	0.43	2.96	0.43	2.89	0.42	2.45	0.36	2.45	0.36	2.45	0.36	2.38	0.34	0.88	0.13	0.88	0.13	0.88	0.13	0.81	0.12
02030103030160	06	638	7.91	DAR	7.58	0.96	4.34	0.55	3.74	0.47	2.94	0.37	1.33	0.17	1.61	0.20	4.31	0.54	4.31	0.54	4.31	0.54	4.09	0.52	3.71	0.47	3.71	0.47	3.71	0.47	3.49	0.44	1.58	0.20	1.58	0.20	1.58	0.20	1.36	0.17
02030103030170	06	639	8.02	REG	5.08	0.63	3.26	0.41	2.72	0.34	1.81	0.23	0.42	0.05	1.39	0.17	3.24	0.40	3.24	0.40	3.24	0.40	3.14	0.39	2.70	0.34	2.70	0.34	2.70	0.34	2.60	0.32	1.37	0.17	1.37	0.17	1.37	0.17	1.27	0.16
02030103040010	06	640	11.87	REG	8.91	0.75	5.85	0.49	4.83	0.41	2.68	0.23	0.67	0.06	2.02	0.17	5.80	0.49	5.79	0.49	5.78	0.49	5.43	0.46	4.77	0.40	4.76	0.40	4.75	0.40	4.41	0.37	1.97	0.17	1.96	0.16	1.95	0.16	1.60	0.13
02030105010010	08	801	9.27	DAR	6.56	0.71	4.34	0.47	3.70	0.40	2.81	0.30	1.00	0.11	1.81	0.20	4.22	0.46	4.22	0.45	4.11	0.44	3.49	0.38	3.59	0.39	3.58	0.39	3.47	0.37	2.85	0.31	1.70	0.18	1.69	0.18	1.58	0.17	0.96	0.10
02030105010020	08	802	7.31	DAR	5.48	0.75	3.85	0.53	3.35	0.46	2.65	0.36	1.06	0.15	1.59	0.22	3.43	0.47	3.30	0.45	3.16	0.43	0.60	0.08	2.93	0.40	2.80	0.38	2.66	0.36	0.10	0.01	1.16	0.16	1.03	0.14	0.89	0.12	-1.67	-0.23
02030105010030	08	803	5.03	DAR	4.49	0.89	3.07	0.61	2.68	0.53	1.92	0.38	0.61	0.12	1.31	0.26	3.01	0.60	3.00	0.60	2.98	0.59	2.62	0.52	2.62	0.52	2.61	0.52	2.59	0.52	2.23	0.44	1.25	0.25	1.23	0.25	1.22	0.24	0.85	0.17
02030105010040	08	804	6.66	DAR	5.95	0.89	4.07	0.61	3.55	0.53	2.54	0.38	0.81	0.12	1.73	0.26	4.02	0.60	3.99	0.60	3.94	0.59	3.69	0.55	3.50	0.53	3.48	0.52	3.43	0.51	3.17	0.48	1.68	0.25	1.65	0.25	1.60	0.24	1.35	0.20
02030105010050	08	805	15.25	DAR	12.85	0.84	8.98	0.59	7.76	0.51	6.37	0.42	2.46	0.16	3.92	0.26	8.85	0.58	8.81	0.58	8.65	0.57	7.93	0.52	7.63	0.50	7.59	0.50	7.43	0.49	6.71	0.44	3.79	0.25	3.75	0.25	3.59	0.24	2.87	0.19
02030105010060	08	806	14.88	REG	12.35	0.83	8.12	0.55	6.64	0.45	4.68	0.31	1.47	0.10	3.21	0.22	8.08	0.54	8.07	0.54	7.63	0.51	7.79	0.52	6.60	0.44	6.60	0.44	6.15	0.41	6.31	0.42	3.17	0.21	3.16	0.21	2.72	0.18	2.88	0.19
02030105010070	08	807	7.89	REG	7.16	0.91	4.78	0.61	3.89	0.49	2.20	0.28	0.68	0.09	1.51	0.19	4.76	0.60	4.76	0.60	4.76	0.60	4.62	0.59	3.87	0.49	3.87	0.49	3.87	0.49	3.73	0.47	1.49	0.19	1.49	0.19	1.49	0.19	1.35	0.17
02030105010080	08	808	4.62	REG	3.40	0.74	2.22	0.48	1.80	0.39	0.90	0.19	0.23	0.05	0.67	0.14	2.19	0.47	2.18	0.47	2.16	0.47	2.01	0.44	1.77	0.38	1.75	0.38	1.74	0.38	1.59	0.34	0.64	0.14	0.63	0.14	0.61	0.13	0.46	0.10
02030105020010	08	809	12.29	DAR	8.36	0.68	5.53	0.45	4.63	0.38	3.41	0.28	1.29	0.11	2.12	0.17	5.49	0.45	5.48	0.45	5.48	0.45	5.22	0.43	4.59	0.37	4.59	0.37	4.58	0.37	4.33	0.35	2.08	0.17	2.07	0.17	2.07	0.17	1.81	0.15
02030105020020	08	810	3.21	REG	2.10	0.65	1.35	0.42	1.06	0.33	0.65	0.20	0.18	0.06	0.47	0.15	1.33	0.42	1.33	0.41	1.33	0.41	1.24	0.39	1.04	0.32	1.04	0.32	1.04	0.32	0.95	0.30	0.46	0.14	0.46	0.14	0.45	0.14	0.37	0.11
02030105020030	08	811	14.70	DAR	10.55	0.72	7.10	0.48	6.03	0.41	3.96	0.27	1.50	0.10	2.47	0.17	7.08	0.48	7.08	0.48	7.08	0.48	6.89	0.47	6.01	0.41	6.01	0.41	6.01	0.41	5.82	0.40	2.44	0.17	2.44	0.17	2.44	0.17	2.26	0.15
02030105020040	08	812	12.19	REG	6.38	0.52	3.94	0.32	3.12	0.26	2.85	0.23	0.76	0.06	2.08	0.17	3.88	0.32	3.76	0.31	3.75	0.31	3.54	0.29	3.06	0.25	2.95	0.24	2.94	0.24	2.73	0.22	2.02	0.17	1.90	0.16	1.89	0.16	1.69	0.14
02030105020050	08	813	6.93	REG	3.82	0.55	2.38	0.34	1.88	0.27	1.66	0.24	0.45	0.07	1.21	0.17	2.23	0.32	2.14	0.31	2.05	0.30	1.21	0.17	1.73	0.25	1.64	0.24	1.54	0.22	0.71	0.10	1.06	0.15	0.96	0.14	0.87	0.13	0.04	0.01
02030105020060	08	814	14.22	DAR	9.26	0.65	5.99	0.42	5.05	0.36	3.28	0.23	1.09	0.08	2.19	0.15	5.92	0.42	5.79	0.41	5.66	0.40	5.75	0.40	4.97	0.35	4.84	0.34	4.71	0.33	4.81	0.34	2.11	0.15	1.99	0.14	1.85	0.13	1.95	0.14
02030105020070	08	815	8.22	REG	5.37	0.65	3.44	0.42	2.79	0.34	1.89	0.23	0.50	0.06	1.40	0.17	3.42	0.42	3.42	0.42	3.42	0.42	3.33	0.40	2.77	0.34	2.77	0.34	2.77	0.34	2.68	0.33	1.38	0.17	1.38	0.17	1.37	0.17	1.28	0.16
02030105020080	08	816	7.37	REG	4.03	0.55	2.51	0.34	1.98	0.27	1.76	0.24	0.48	0.06	1.28	0.17	2.49	0.34	2.49	0.34	2.49	0.34	2.36	0.32	1.96	0.27	1.96	0.27	1.96	0.27	1.83	0.25	1.26	0.17	1.26	0.17	1.26	0.17	1.13	0.15
02030105020090	08	817	11.27	REG	6.73	0.60	4.26	0.38	3.48	0.31	2.05	0.18	0.48	0.04	1.57	0.14	4.24	0.38	4.24	0.38	4.24	0.38	4.10	0.36	3.47	0.31	3.47	0.31	3.47	0.31	3.33	0.30	1.55	0.14	1.55	0.14	1.55	0.14	1.41	0.13
02030105040020	08	818	10.80	REG	5.43	0.50	3.34	0.31	2.65	0.25	2.78	0.26	0.75	0.07	2.03	0.19	3.31	0.31	3.31	0.31	3.31	0.31	3.09	0.29	2.62	0.24	2.62	0.24	2.62	0.24	2.40	0.22	2.00	0.18	2.00	0.18	2.00	0.18	1.77	0.16
02030105040030	08	819	12.44	DAR	6.39	0.51	4.05	0.33	3.27	0.26	1.64	0.13	0.27	0.02	1.37	0.11	4.00	0.32	3.95	0.32	3.97	0.32	3.74	0.30	3.23	0.26	3.18	0.26	3.20	0.26	2.97	0.24	1.33	0.11	1.28	0.10	1.30	0.10	1.07	0.09
02030105050010	08	820	6.27	REG	5.20	0.83	3.45	0.55	2.86	0.46	1.66	0.26	0.45	0.07	1.20	0.19	3.40	0.54	3.38	0.54	3.23	0.52	3.04	0.48	2.81	0.45	2.79	0.45	2.64	0.42	2.44	0.39	1.15	0.18	1.13	0.18	0.98	0.16	0.78	0.13
02030105050020	08	821	11.03	DAR	10.53	0.95	6.91	0.63	5.83	0.53	4.43	0.40	1.07	0.10	3.36	0.30	6.58	0.60	6.33	0.57	6.30	0.57	4.44	0.40	5.50	0.50	5.25	0.48	5.22	0.47	3.36	0.30	3.04	0.28	2.79	0.25	2.76	0.25	0.89	0.08
02030105050030	08	822	6.00	REG	4.44	0.74	2.90	0.48	2.36	0.39	1.48	0.25	0.40	0.07	1.08	0.18	2.85	0.47	2.84	0.47	2.48	0.41	2.54	0.42	2.31	0.39	2.30	0.38	1.95	0.32	2.01	0.33	1.03	0.17	1.02	0.17	0.67	0.11	0.72	0.12
02030105050040	08	823	8.90	DAR	8.50	0.95	5.57	0.63	4.70	0.53	3.57	0.40	0.86	0.10	2.71	0.30	5.54	0.62	5.52	0.62	5.24	0.59	5.29	0.59	4.67	0.52	4.65	0.52	4.37	0.49	4.42	0.50	2.68	0.30	2.66	0.30	2.38	0.27	2.43	0.27
02030105050050	08	824	4.92	REG	4.29	0.87	2.85	0.58	2.31	0.47	1.39	0.28	0.42	0.09	0.96	0.20	2.84	0.58	2.84	0.58	2.84	0.58	2.77	0.56	2.30	0.47	2.30	0.47	2.30	0.47	2.23	0.45	0.95	0.19	0.95	0.19	0.95	0.19	0.88	0.18
02030105050060	08	825	6.23	DAR	4.59	0.74	3.33	0.53	2.92	0.47	2.45	0.39	1.02	0.16	1.42	0.23	3.32	0.53	3.31	0.53	3.24	0.52	3.24	0.52	2.91	0.47	2.90	0.47	2.83	0.45	2.83	0.45	1.41	0.23	1.40	0.22	1.33	0.21	1.33	0.21
02030105050070	08	826	13.97	REG	11.25	0.80	7.37	0.53	6.03	0.43	4.77	0.34	1.51	0.11	3.27	0.23	7.34	0.53	7.31	0.52	7.30	0.52	7.19	0.51	6.00	0.43	5.97	0.43	5.97	0.43	5.85	0.42	3.23	0.23	3.20	0.23	3.20	0.23	3.08	0.22
02030105050080	08	827	16.93	DAR	13.98	0.83	9.41	0.56	8.08	0.48	5.60	0.33	1.64	0.10	3.96	0.23	9.38	0.55	9.38	0.55	9.29	0.55	9.16	0.54	8.05	0.48	8.05	0.48	7.96	0.47	7.83	0.46	3.92	0.23	3.92	0.23	3.83	0.23	3.71	0.22
02030105050090	08	828	5.09	REG	3.89	0.76	2.55	0.50	2.07	0.41	1.55	0.30	0.46	0.09	1.09	0.21	2.54	0.50	2.54	0.50	2.54	0.50	2.45	0.48	2.05	0.40	2.05	0.40	2.05	0.40	1.97	0.39	1.08	0.21	1.08	0.21	1.08	0.21	1.00	0.20
02030105050100	08	829	12.35	REG	9.54	0.77	6.23	0.50	5.11	0.41	3.43	0.28	0.99	0.08	2.44	0.20	6.10	0.49	6.10	0.49	6.08	0.49	5.27	0.43	4.98	0.40	4.98	0.40	4.97	0.40	4.16	0.34	2.32	0.19	2.32	0.19	2.30	0.19	1.49	0.12
02030105050110	08	830	7.55	REG	3.85	0.51	2.38	0.32	1.88	0.25	2.38	0.32	0.68	0.09	1.70	0.23	2.36	0.31	2.36	0.31	2.36	0.31	2.24	0.30	1.86	0.25	1.86	0.25	1.86	0.25	1.74	0.23	1.68	0.22	1.68	0.22	1.68	0.22	1.56	0.21
02030105060010	08	831	6.69	DAR	5.91	0.88	3.71	0.55	3.06	0.46	1.90	0.28	0.33	0.05	1.57	0.24	3.68	0.55	3.67	0.55	3.61	0.54	3.51	0.53	3.03	0.45	3.02	0.45	2.96	0.44	2.86	0.43	1.55	0.23	1.54	0.23	1.48	0.22	1.38	0.21
02030105060020	08	832	6.64	DAR	5.84	0.88	4.15	0.62	3.63	0.55	2.74	0.41	0.98	0.15	1.76	0.26	4.13	0.62	4.13	0.62	4.13	0.62	4.01	0.60	3.61	0.54	3.61	0.54	3.61	0.54	3.49	0.53	1.74	0.26	1.74	0.26	1.74	0.26	1.62	0.24
02030105060030	08	833	7.65	DAR	6.56	0.86	4.38	0.57	3.57	0.47	2.80	0.37	0.54	0.07	2.26	0.30	4.36	0.57	4.36	0.57	4.36	0.57	4.28	0.56	3.55	0.46	3.55	0.46	3.55	0.46	3.47	0.45	2.25	0.29	2.25	0.29	2.25	0.29	2.17	0.28
02030105060040	08	834	7.50	REG	6.37	0.85	4.21	0.56	3.42	0.46	1.83	0.24	0.54	0.07	1.29	0.17	4.20	0.56	4.20	0.56	4.20	0.56	4.12	0.55	3.41	0.45	3.41	0.45	3.41	0.45	3.33	0.44	1.28	0.17	1.28	0.17	1.28	0.17	1.20	0.16
02030105060050	08	835	6.60	DAR	4.67	0.71	2.91	0.44	2.45	0.37	1.68	0.26	0.44	0.07	1.25	0.19	2.89	0.44	2.89	0.44	2.89	0.44	2.76	0.42	2.43	0.37	2.43	0.37	2.43	0.37	2.30	0.35	1.23	0.19	1.23	0.19	1.23	0.19	1.10	0.17
02030105060060	08	836	5.07	DAR	3.82	0.75	2.48	0.49	2.16	0.43	1.50	0.30	0.48	0.10	1.02	0.20	2.47	0.49	2.47	0.49	2.47	0.49	2.44	0.48	2.15	0.42	2.15	0.42	2.15	0.42	2.12	0.42	1.02	0.20	1.02	0.20	1.02	0.20	0.98	0.19
02030105060070	08	837	8.40	DAR	6.23	0.74	3.97	0.47	3.30	0.39	2.57	0.31	0.75	0.09	1.82	0.22	3.95	0.47	3.94	0.47	3.93	0.47	3.83	0.46	3.28	0.39	3.27	0.39	3.26	0.39	3.16	0.38	1.80	0.21	1.79	0.21	1.78	0.21	1.68	0.20
02030105060080	08	838	6.68	REG	3.94	0.59	2.48	0.37	1.96	0.29	2.10	0.31	0.64	0.10	1.46	0.22	2.47	0.37	2.46	0.37	2.47	0.37	2.43	0.36	1.95	0.29	1.94	0.29	1.94	0.29	1.91	0.29	1.46	0.22	1.45	0.22	1.45	0.22	1.42	0.21
02030105060090	08	839	8.69	REG	5.80	0.67	3.73	0.43	3.03	0.35	2.50	0.29	0.70	0.08	1.80	0.21	3.72	0.43	3.72	0.43	3.71	0.43	3.67	0.42	3.02	0.35	3.02	0.35	3.01	0.35	2.97	0.34	1.79	0.21	1.79	0.21	1.78	0.21	1.74	0.20
02030105070010	08	840	9.32	REG	4.37	0.47	2.67	0.29	2.12	0.23	2.22	0.24	0.57	0.06	1.65	0.18	2.62	0.28	2.62	0.28	2.61	0.28	2.27	0.24	2.07	0.22	2.07	0.22	2.05	0.22	1.72	0.18	1.60	0.17	1.60	0.17	1.59	0.17	1.25	0.13
02030105120050	09	901	9.57	REG	5.66	0.59	3.58	0.37	2.92	0.30	1.80	0.19	0.43	0.04	1.38	0.14	3.55	0.37	3.51	0.37	3.52	0.37	3.34	0.35	2.89	0.30	2.85	0.30	2.85	0.30	2.68	0.28	1.34	0.14	1.31	0.14	1.31	0.14	1.13	0.12
02030105120060	09	902	6.54	REG	3.51	0.54	2.20	0.34	1.77	0.27	1.07	0.16	0.24	0.04	0.83	0.13	2.17	0.33	2.16	0.33	2.16	0.33	1.95	0.30	1.74	0.27	1.74	0.27	1.74	0.27	1.53	0.23	0.80	0.12	0.80	0.12	0.80	0.12	0.59	0.09
02040105170010	11	1101	6.03	REG	4.78	0.79	3.15	0.52	2.59	0.43	0.96	0.16	0.23	0.04	0.73	0.12	3.13	0.52	3.12	0.52	2.63	0.44	3.05	0.51	2.57	0.43	2.56	0.42	2.07	0.34	2.48	0.41	0.71	0.12	0.70	0.12	0.21	0.04	0.63	0.10
02040105170020	11	1102	17.54	REG	12.69	0.72	8.20	0.47	6.75	0.38	3.85	0.22	1.02	0.06	2.83	0.16	8.13	0.46	8.07	0.46	8.04	0.46	7.63	0.43	6.68	0.38	6.62	0.38	6.59	0.38	6.18	0.35	2.76	0.16	2.70	0.15	2.67	0.15	2.26	0.13
02040105170030	11	1103	11.83	DAR	5.30	0.45	3.06	0.26	2.45	0.21	1.49	0.13	0.36	0.03	1.14	0.10	2.98	0.25	2.89	0.24	2.84	0.24	2.31	0.20	2.37	0.20	2.28	0.19	2.24	0.19	1.70	0.14	1.05	0.09	0.97	0.08	0.92	0.08	0.39	0.03
02040105170040	11	1104	6.73	REG	4.13	0.61	2.62	0.39	2.11	0.31	1.72	0.26	0.46	0.07	1.25	0.19	2.61	0.39	2.61	0.39	2.61	0.39	2.52	0.37	2.10	0.31	2.10	0.31	2.10	0.31	2.01	0.30	1.24	0.18	1.24	0.18	1.24	0.18	1.16	0.17
02040105170050	11	1105	8.49	REG	5.88	0.69	3.80	0.45	3.12	0.37	1.65	0.19	0.41	0.05	1.25	0.15	3.77	0.44	3.77	0.44	3.75	0.44	3.60	0.42	3.09	0.36	3.09	0.36	3.07	0.36	2.91	0.34	1.22	0.14	1.22	0.14	1.20	0.14	1.04	0.12

Base and Low-Flow Statistics at Selected Continuous-Record Stream-Flow Gaging Stations, Low-Flow Partial-Record Stations, and Gaging Stations Analyzed as a Partial-Record Station in the New Jersey Highlands

Site number	Station Name	Mean Annual		Drought of Record Base flow		Base Flow Recurrence Interval: 2-year		5-year		10-year		25-year		Site number	Station Name	50-year		7-day, 10-year low-flow		September median flow		Low-flow margin	
		Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²			Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²
01367700	Wallkill River at Franklin, NJ	25.36	0.86	14.55	0.50	25.31	0.86	17.40	0.59	14.98	0.51	11.62	0.40	01367700	Wallkill River at Franklin, NJ	9.63	0.33	1.27	0.04	5.89	0.20	4.62	0.16
01367750	Beaver Run near Hamburg, NJ	4.01	0.72	2.14	0.38	3.85	0.69	2.80	0.50	2.33	0.42	1.85	0.33	01367750	Beaver Run near Hamburg, NJ	1.40	0.25	0.32	0.06	1.15	0.21	0.83	0.15
01367770	Wallkill River near Sussex, NJ	48.59	0.80	30.91	0.51	49.14	0.81	35.80	0.59	31.38	0.52	25.81	0.42	01367770	Wallkill River near Sussex, NJ	20.23	0.33	4.28	0.07	14.41	0.24	10.13	0.17
01367800	Papakating Creek at Pellettown, NJ	9.14	0.58	5.13	0.32	8.82	0.56	6.44	0.41	5.51	0.35	4.40	0.28	01367800	Papakating Creek at Pellettown, NJ	3.58	0.23	0.61	0.04	2.40	0.15	1.79	0.11
01367850	West Branch Papakating Creek at McCoys Corner, NJ	7.11	0.65	4.51	0.41	6.90	0.63	5.12	0.47	4.55	0.41	3.58	0.33	01367850	West Branch Papakating Creek at McCoys Corner, NJ	2.32	0.21	0.22	0.02	1.24	0.11	1.02	0.09
01367890	Clove Brook above Clove Acres Lake, at Sussex, NJ	9.89	0.51	5.70	0.30	9.62	0.50	7.00	0.36	5.93	0.31	4.83	0.25	01367890	Clove Brook above Clove Acres Lake, at Sussex, NJ	3.79	0.20	0.45	0.02	2.02	0.11	1.57	0.08
01367900	Clove Brook at Sussex, NJ	11.93	0.61	7.88	0.40	11.76	0.60	9.07	0.46	7.96	0.40	6.74	0.34	01367900	Clove Brook at Sussex, NJ	5.62	0.29	0.66	0.03	2.80	0.14	2.14	0.11
01367910	Papakating Creek at Sussex, NJ	31.41	0.53	16.27	0.27	30.24	0.51	20.88	0.35	17.60	0.30	13.46	0.23	01367910	Papakating Creek at Sussex, NJ	10.58	0.18	1.19	0.02	5.99	0.10	4.79	0.08
01368000	Wallkill River near Unionville, NY	98.01	0.70	62.78	0.45	103.05	0.74	68.79	0.49	60.31	0.43	47.50	0.34	01368000	Wallkill River near Unionville, NY	--	--	5.70	0.04	25.85	0.18	20.15	0.14
01368950	Black Creek near Vernon, NJ	16.67	0.96	10.39	0.60	16.24	0.94	12.24	0.71	10.80	0.62	8.79	0.51	01368950	Black Creek near Vernon, NJ	7.38	0.43	0.98	0.06	4.03	0.23	3.05	0.18
01378750	Great Brook at Green Village, NJ	4.56	0.58	2.47	0.31	4.33	0.55	3.29	0.42	2.81	0.35	2.36	0.30	01378750	Great Brook at Green Village, NJ	1.60	0.20	0.36	0.05	1.60	0.20	1.24	0.16
01378800	Primrose Brook near New Vernon, NJ	3.73	0.80	2.26	0.48	3.57	0.76	2.81	0.60	2.42	0.52	2.07	0.44	01378800	Primrose Brook near New Vernon, NJ	1.64	0.35	0.40	0.09	1.41	0.30	1.02	0.22
01378850	Great Brook near Basking Ridge, NJ	15.43	0.67	7.09	0.31	14.46	0.63	10.85	0.47	9.08	0.39	7.69	0.33	01378850	Great Brook near Basking Ridge, NJ	4.19	0.18	0.72	0.03	4.39	0.19	3.67	0.16
01379000	Passaic River near Millington, NJ	39.51	0.71	--	--	35.97	0.65	30.91	0.56	26.34	0.48	24.69	0.45	01379000	Passaic River near Millington, NJ	--	--	1.45	0.03	10.34	0.19	8.89	0.16
01379150	Harrisons Brook at Liberty Corner, NJ	2.10	0.56	1.08	0.29	1.97	0.53	1.45	0.39	1.20	0.32	1.00	0.27	01379150	Harrisons Brook at Liberty Corner, NJ	0.68	0.18	0.06	0.02	0.47	0.12	0.40	0.11
01379570	Passaic River at Hanover, NJ	84.76	0.66	43.78	0.34	79.48	0.62	60.29	0.47	49.52	0.39	41.77	0.33	01379570	Passaic River at Hanover, NJ	27.39	0.21	7.09	0.06	27.10	0.21	20.01	0.16
01379630	Russia Brook tributary at Milton NJ	1.61	0.98	0.98	0.60	1.57	0.95	1.14	0.70	0.98	0.60	0.82	0.50	01379630	Russia Brook tributary at Milton NJ	0.71	0.43	0.12	0.07	0.54	0.33	0.42	0.25
01379750	Rockaway River at Dover, NJ	34.48	1.12	20.55	0.67	33.45	1.09	25.21	0.82	21.54	0.70	17.81	0.58	01379750	Rockaway River at Dover, NJ	14.67	0.48	3.06	0.10	11.25	0.37	8.20	0.27
01379773	Green Pond Brook at Picatinny Arsenal, NJ	7.84	1.02	--	--	7.98	1.04	5.37	0.70	5.28	0.69	--	--	01379773	Green Pond Brook at Picatinny Arsenal, NJ	--	--	0.37	0.05	2.20	0.29	1.83	0.24
01380050	Hibernia Brook at outlet of Lake Telemark, NJ	1.74	0.69	0.83	0.33	1.67	0.66	1.08	0.43	0.89	0.35	0.66	0.26	01380050	Hibernia Brook at outlet of Lake Telemark, NJ	0.51	0.20	0.03	0.01	0.26	0.10	0.22	0.09
01380100	Beaver Brook at Rockaway, NJ	18.28	0.82	10.34	0.47	17.27	0.78	12.99	0.59	10.93	0.49	9.14	0.41	01380100	Beaver Brook at Rockaway, NJ	6.99	0.32	0.98	0.04	5.09	0.23	4.11	0.19
01380300	Stony Brook near Rockaway Valley, NJ	5.43	0.64	2.68	0.32	5.25	0.62	3.66	0.43	3.04	0.36	2.46	0.29	01380300	Stony Brook near Rockaway Valley, NJ	1.72	0.20	0.13	0.02	1.12	0.13	0.99	0.12
01380500	Rockaway River above Reservoir at Boonton, NJ	111.35	0.96	72.70	0.63	108.92	0.94	83.98	0.72	74.60	0.64	63.40	0.55	01380500	Rockaway River above Reservoir at Boonton, NJ	55.67	0.48	9.23	0.08	38.78	0.33	29.55	0.25
01381150	Crooked Brook near Boonton, NJ	7.57	0.96	4.09	0.52	6.01	0.76	4.86	0.62	4.33	0.55	3.73	0.48	01381150	Crooked Brook near Boonton, NJ	3.26	0.41	1.33	0.17	2.94	0.37	1.61	0.20
01381400	Whippany River near Morristown, NJ	12.67	0.90	10.77	0.77	12.48	0.89	10.90	0.78	10.16	0.73	9.17	0.65	01381400	Whippany River near Morristown, NJ	8.59	0.61	1.45	0.10	4.40	0.31	2.96	0.21
01381470	Jaquis Brook at Greystone Park State Hospital, NJ	1.79	1.28	1.13	0.81	1.53	1.10	1.30	0.93	1.19	0.86	1.05	0.76	01381470	Jaquis Brook at Greystone Park State Hospital, NJ	0.69	0.50	0.25	0.18	0.66	0.47	0.41	0.29
01381490	Watnong Brook at Morris Plains, NJ	7.62	0.98	4.74	0.61	6.28	0.81	5.49	0.71	5.12	0.66	4.67	0.60	01381490	Watnong Brook at Morris Plains, NJ	4.10	0.53	1.79	0.23	3.64	0.47	1.85	0.24
01381550	Malapardis Brook at Whippany, NJ	2.55	0.50	1.41	0.28	1.99	0.39	1.69	0.33	1.54	0.30	1.40	0.28	01381550	Malapardis Brook at Whippany, NJ	1.18	0.23	0.40	0.08	1.01	0.20	0.61	0.12
01381700	Troy Brook at Troy Hills, NJ	7.32	0.72	5.34	0.53	7.11	0.70	6.21	0.61	5.63	0.56	5.17	0.51	01381700	Troy Brook at Troy Hills, NJ	4.42	0.44	2.44	0.24	4.44	0.44	2.00	0.20
01382360	Kanouse Brook at Newfoundland, NJ	3.13	0.81	2.13	0.55	3.03	0.78	2.28	0.59	2.00	0.52	1.60	0.41	01382360	Kanouse Brook at Newfoundland, NJ	1.28	0.33	0.07	0.02	0.47	0.12	0.39	0.10
01382700	Stone House Brook at Kinnelon, NJ	2.07	0.60	1.61	0.47	2.01	0.58	1.64	0.48	1.47	0.43	1.26	0.37	01382700	Stone House Brook at Kinnelon, NJ	1.17	0.34	0.12	0.03	0.50	0.14	0.38	0.11
01382890	Belcher Creek at West Milford, NJ	5.04	0.69	3.67	0.50	4.96	0.68	4.01	0.55	3.63	0.50	3.17	0.44	01382890	Belcher Creek at West Milford, NJ	2.82	0.39	0.43	0.06	1.56	0.21	1.13	0.16
01382910	Morsetown Brook at West Milford, NJ	0.44	0.34	0.30	0.23	0.43	0.33	0.32	0.25	0.29	0.22	0.23	0.18	01382910	Morsetown Brook at West Milford, NJ	0.17	0.13	0.01	0.01	0.07	0.05	0.06	0.04
01384500	Ringwood Creek near Wanaque, NJ	16.88	0.88	12.36	0.65	16.85	0.88	13.15	0.69	11.84	0.62	9.97	0.52	01384500	Ringwood Creek near Wanaque, NJ	8.30	0.43	0.24	0.01	2.13	0.11	1.89	0.10
01385000	Cupsaw Brook near Wanaque, NJ	3.24	0.74	--	--	3.31	0.76	2.56	0.59	2.23	0.51	1.89	0.43	01385000	Cupsaw Brook near Wanaque, NJ	--	--	0.00	0.00	0.32	0.07	0.32	0.07
01385500	Erskine Brook near Wanaque, NJ	0.74	0.73	0.58	0.57	0.72	0.71	0.59	0.58	0.54	0.53	0.45	0.44	01385500	Erskine Brook near Wanaque, NJ	0.41	0.41	0.03	0.03	0.14	0.13	0.11	0.11
01386000	West Brook near Wanaque, NJ	10.69	0.91	8.56	0.73	10.32	0.87	8.57	0.73	8.06	0.68	6.42	0.54	01386000	West Brook near Wanaque, NJ	--	--	0.39	0.03	1.94	0.16	1.55	0.13
01386500	Blue Mine Brook near Wanaque, NJ	0.91	0.90	--	--	0.89	0.88	0.74	0.74	0.64	0.63	--	--	01386500	Blue Mine Brook near Wanaque, NJ	--	--	0.00	0.00	0.06	0.06	0.06	0.06
01387450	Mahwah River near Suffern, NY	10.99	0.89	9.43	0.77	10.62	0.86	8.42	0.68	7.99	0.65	7.11	0.58	01387450	Mahwah River near Suffern, NY	--	--	0.43	0.04	1.94	0.16	1.51	0.12
01387490	Masonicus Brook at West Mahwah, NJ	4.51	1.17	3.82	0.99	4.39	1.14	3.81	0.99	3.50	0.91	3.13	0.81	01387490	Masonicus Brook at West Mahwah, NJ	2.99	0.78	0.49	0.13	1.55	0.40	1.06	0.27
01387500	Ramapo River near Mahwah, NJ	101.66	0.85	82.99	0.69	97.53	0.81	81.70	0.68	73.02	0.61	63.00	0.52	01387500	Ramapo River near Mahwah, NJ	60.95	0.51	6.88	0.06	27.79	0.23	20.91	0.17
01387600	Darlington Brook near Darlington, NJ	1.87	0.55	1.39	0.41	1.83	0.54	1.48	0.44	1.34	0.40	1.15	0.34	01387600	Darlington Brook near Darlington, NJ	1.02	0.30	0.14	0.04	0.52	0.16	0.38	0.11
01387670	Ramapo River near Darlington, NJ	122.87	0.94	83.84	0.64	118.65	0.91	90.47	0.69	76.57	0.58	58.13	0.44	01387670	Ramapo River near Darlington, NJ	53.06	0.41	4.50	0.03	25.48	0.19	20.98	0.16
01387700	Bear Swamp Brook near Oakland, NJ	0.94	0.29	0.58	0.18	0.91	0.28	0.64	0.20	0.54	0.17	0.43	0.13	01387700	Bear Swamp Brook near Oakland, NJ	0.37	0.11	0.02	0.01	0.13	0.04	0.11	0.03
01387884	Pond Brook at US Route 202 at Oakland, NJ	6.15	0.82	4.78	0.63	6.02	0.80	5.02	0.67	4.58	0.61	4.03	0.54	01387884	Pond Brook at US Route 202 at Oakland, NJ	3.72	0.49	0.58	0.08	2.08	0.28	1.49	0.20
01387930	Ramapo River tributary No. 5 at Oakland, NJ	1.28	1.49	1.17	1.36	1.28	1.48	1.20	1.39	1.16	1.35	1.11	1.29	01387930	Ramapo River tributary No. 5 at Oakland, NJ	1.07	1.24	0.59	0.69	0.88	1.02	0.29	0.33
01388700	Beaver Dam Brook at Lincoln Park, NJ	9.47	0.77	5.50	0.45	9.24	0.75	6.50	0.53	5.56	0.45	4.45	0.36	01388700	Beaver Dam Brook at Lincoln Park, NJ	3.66	0.30	0.19	0.02	1.70	0.14	1.51	0.12
01388720	Beaver Dam Brook at Ryerson Road, at Lincoln Park, NJ	8.75	0.67	4.98	0.38	8.59	0.66	6.05	0.46	5.30	0.40	4.10	0.31	01388720	Beaver Dam Brook at Ryerson Road, at Lincoln Park, NJ	3.42	0.26	0.24	0.02	1.83	0.14	1.59	0.12
01389100	Singac Brook at Singac, NJ	11.52	1.04	9.78	0.88	11.35	1.02	10.31	0.93	9.78	0.88	9.23	0.83	01389100	Singac Brook at Singac, NJ	8.63	0.78	3.26	0.29	6.65	0.60	3.39	0.31
01389140	Deepavaal Brook at Two Bridges, NJ	3.40	0.45	2.12	0.28	3.28	0.43	2.62	0.34	2.29	0.30	2.02	0.27	01389140	Deepavaal Brook at Two Bridges, NJ	1.65	0.22	0.37	0.05	1.23	0.16	0.86	0.11
01390450	Saddle River at Upper Saddle River, NJ	7.50	0.69	6.33	0.58	7.32	0.67	6.38	0.59	5.80	0.53	5.31	0.49	01390450	Saddle River at Upper Saddle River, NJ	4.87	0.45	1.23	0.11	3.33	0.31	2.11	0.19
01390500	Saddle River at Ridgewood, NJ	14.35	0.66	13.37	0.62	13.43	0.62	10.89	0.50	8.34	0.39	7.44	0.34	01390500	Saddle River at Ridgewood, NJ	--	--	1.37	0.06	6.08	0.28	4.70	0.22
01390700	Hohokus Brook at Wyckoff, NJ	4.98	0.94	4.29	0.81	4.89	0.92	4.32	0.81	3.99	0.75	3.68	0.69	01390700	Hohokus Brook at Wyckoff, NJ	3.65	0.69	1.10	0.21	2.41	0.45	1.32	0.25
01390800	Valentine Brook at Allendale, NJ	2.33	0.94	1.93	0.78	2.27	0.92	1.93	0.78	1.75	0.71	1.55	0.63	01390800	Valentine Brook at Allendale, NJ	1.49	0.60	0.25	0.10	0.77	0.31	0.52	0.21
01390900	Ramsey Brook at Allendale, NJ	1.08	0.42	0.90	0.35	1.06	0.42	0.93	0.36	0.86	0.34	0.78	0.31	01390900	Ramsey Brook at Allendale, NJ	0.74	0.29	0.21	0.08	0.48	0.19	0.27	0.11
01396120	South Branch Raritan River at Bartley, NJ	11.14	0.89	6.90	0.55	10.69	0.86	8.72	0.70	7.61	0.61	6.65	0.53	01396120	South Branch Raritan River at Bartley, NJ	5.17	0.41	1.51	0.12	4.75	0.38	3.24	0.26
01396180	Drakes Brook at Bartley, NJ	12.40	0.75	8.55	0.52	11.97	0.72	9.87	0.59	8.72	0.53	7.59	0.46	01396180	Drakes Brook at Bartley, NJ	6.65	0.40	2.40	0.14	5.99	0.36	3.59	0.22
01396190	South Branch Raritan River at Four Bridges, NJ	21.89	0.71	13.98	0.45	20.91	0.67	16.80	0.54	14.48	0.47	12.35	0.40	01396190	South Branch Raritan River at Four Bridges, NJ	10.29	0.33	3.35	0.11	9.39	0.30	6.04	0.19
01396240	Electric Brook at Long Valley, NJ	2.11	0.66	1.03	0.32	1.99	0.63	1.38	0.44	1.11	0.35	0.86	0.27	01396240	Electric Brook at Long Valley, NJ	0.61	0.19	0.11	0.04	0.56	0.18	0.44	0.14

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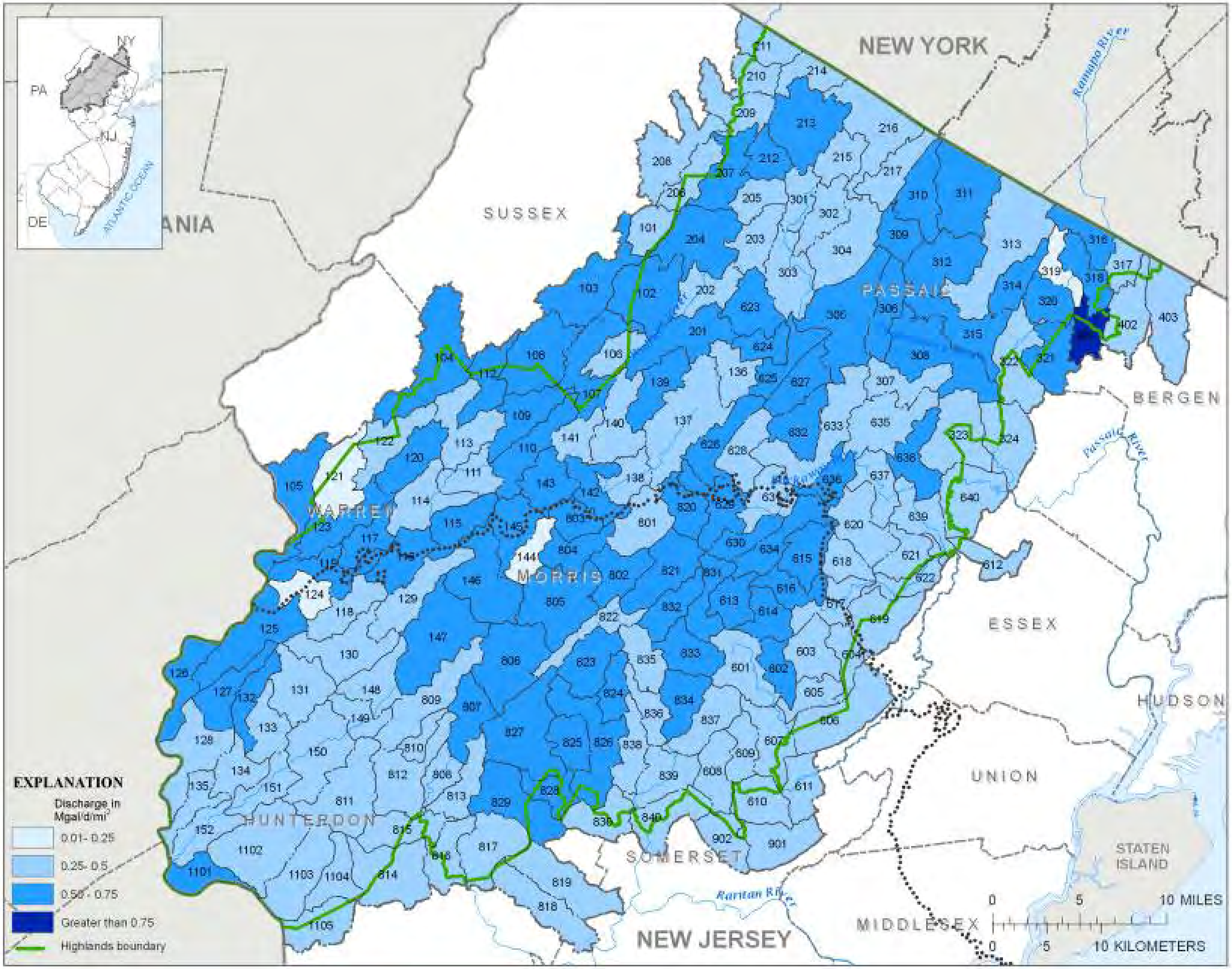
Site number	Station Name	Base Flow Recurrence Interval												Site number	Station Name			7-day, 10-year low-flow		September median flow		Low-flow margin	
		Mean Annual		Drought of Record Base flow		2-year		5-year		10-year		25-year				50-year							
		Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²			Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²	Mgal/d	Mgal/d/ mi²
01396280	South Branch Raritan River at Middle Valley, NJ	40.19	0.84	27.49	0.58	38.94	0.82	31.82	0.67	28.08	0.59	24.25	0.51	01396280	South Branch Raritan River at Middle Valley, NJ	21.19	0.44	7.68	0.16	19.92	0.42	12.24	0.26
01396350	South Branch Raritan River at Califon, NJ	49.43	0.84	32.49	0.56	47.87	0.82	38.47	0.66	33.81	0.58	28.78	0.49	01396350	South Branch Raritan River at Califon, NJ	23.97	0.41	9.09	0.16	22.91	0.39	13.83	0.24
01396500	South Branch Raritan River near High Bridge, NJ	59.15	0.91	40.31	0.62	56.24	0.86	47.00	0.72	40.97	0.63	35.48	0.54	01396500	South Branch Raritan River near High Bridge, NJ	30.29	0.46	13.95	0.21	29.73	0.46	15.78	0.24
01396550	Spruce Run at Newport, NJ	4.99	0.88	3.20	0.57	4.78	0.84	3.86	0.68	3.39	0.60	2.95	0.52	01396550	Spruce Run at Newport, NJ	2.43	0.43	0.49	0.09	1.83	0.32	1.34	0.24
01396590	Spruce Run near High Bridge, NJ	10.55	0.68	6.61	0.43	10.19	0.66	8.02	0.52	6.97	0.45	5.84	0.38	01396590	Spruce Run near High Bridge, NJ	4.69	0.30	1.63	0.11	4.30	0.28	2.67	0.17
01396600	Spruce Run near Clinton, NJ	11.94	0.66	7.15	0.39	11.37	0.63	8.68	0.48	7.33	0.40	5.99	0.33	01396600	Spruce Run near Clinton, NJ	4.91	0.27	1.42	0.08	4.65	0.26	3.23	0.18
01396660	Mulhockaway Creek at Van Syckel, NJ	8.43	0.71	--	--	7.75	0.66	6.11	0.52	5.68	0.48	4.82	0.41	01396660	Mulhockaway Creek at Van Syckel, NJ	--	--	1.20	0.10	3.17	0.27	1.97	0.17
01396670	Mulhockaway Creek tributary at Van Syckel, NJ	1.88	0.68	1.14	0.41	1.81	0.66	1.41	0.51	1.21	0.44	1.01	0.36	01396670	Mulhockaway Creek tributary at Van Syckel, NJ	0.80	0.29	0.28	0.10	0.76	0.27	0.47	0.17
01396700	Mulhockaway Creek near Clinton, NJ	12.93	0.63	8.03	0.39	12.34	0.60	9.54	0.47	8.02	0.39	6.79	0.33	01396700	Mulhockaway Creek near Clinton, NJ	5.75	0.28	1.89	0.09	5.39	0.26	3.50	0.17
01396865	Sidney Brook at Grandin, NJ	3.34	0.71	2.33	0.49	3.23	0.69	2.67	0.57	2.37	0.50	2.06	0.44	01396865	Sidney Brook at Grandin, NJ	1.81	0.38	0.51	0.11	1.46	0.31	0.95	0.20
01396900	Capoolong Creek at Lansdowne, NJ	9.19	0.65	5.73	0.41	8.88	0.63	6.92	0.49	5.95	0.42	5.01	0.36	01396900	Capoolong Creek at Lansdowne, NJ	4.14	0.29	1.08	0.08	3.26	0.23	2.17	0.15
01397100	Prescott Brook at Round Valley, NJ	2.44	0.53	1.70	0.37	2.36	0.51	1.92	0.42	1.70	0.37	1.48	0.32	01397100	Prescott Brook at Round Valley, NJ	1.31	0.28	0.31	0.07	0.97	0.21	0.66	0.14
01398107	Holland Brook at Readington, NJ	4.63	0.51	2.85	0.32	4.52	0.50	3.35	0.37	2.93	0.33	2.37	0.26	01398107	Holland Brook at Readington, NJ	1.99	0.22	0.20	0.02	1.19	0.13	0.99	0.11
01398220	India Brook near Mendham, NJ	3.86	0.88	2.40	0.55	3.80	0.87	2.78	0.64	2.42	0.56	2.00	0.46	01398220	India Brook near Mendham, NJ	1.73	0.40	0.22	0.05	1.24	0.29	1.03	0.24
01398300	Dawsons Brook near Ironia, NJ	1.00	0.96	0.69	0.66	0.98	0.94	0.78	0.75	0.68	0.65	0.60	0.57	01398300	Dawsons Brook near Ironia, NJ	0.54	0.52	0.15	0.14	0.46	0.44	0.31	0.30
01398360	Burnett Brook near Chester, NJ	5.84	0.88	4.13	0.62	5.68	0.86	4.65	0.70	4.15	0.63	3.63	0.55	01398360	Burnett Brook near Chester, NJ	3.23	0.49	0.98	0.15	2.74	0.41	1.76	0.26
01398500	Nb Raritan River near Far Hills, NJ	22.70	0.87	14.76	0.56	22.78	0.87	16.59	0.63	15.13	0.58	12.33	0.47	01398500	Nb Raritan River near Far Hills, NJ	10.42	0.40	1.87	0.07	9.69	0.37	7.83	0.30
01398700	Peapack Brook at Gladstone, NJ	3.00	0.71	1.88	0.44	2.89	0.68	2.19	0.52	1.87	0.44	1.57	0.37	01398700	Peapack Brook at Gladstone, NJ	1.36	0.32	0.28	0.07	1.08	0.26	0.80	0.19
01398850	Peapack Brook at Far Hills, NJ	8.80	0.75	5.82	0.50	8.44	0.72	6.66	0.57	5.71	0.49	4.97	0.42	01398850	Peapack Brook at Far Hills, NJ	4.41	0.38	1.11	0.09	3.46	0.30	2.35	0.20
01399194	Succasunna Brook near Succasunna, NJ	1.26	0.73	0.62	0.36	1.18	0.69	0.80	0.47	0.60	0.35	0.49	0.29	01399194	Succasunna Brook near Succasunna, NJ	0.39	0.23	0.04	0.03	0.33	0.19	0.29	0.17
01399295	Tanners Brook near Milltown, NJ	2.39	0.86	1.52	0.54	2.32	0.84	1.78	0.64	1.56	0.56	1.30	0.47	01399295	Tanners Brook near Milltown, NJ	1.12	0.40	0.23	0.08	0.90	0.32	0.67	0.24
01399300	Lamington River at Milltown, NJ	23.36	1.01	14.79	0.64	22.71	0.98	17.45	0.75	15.20	0.66	12.71	0.55	01399300	Lamington River at Milltown, NJ	10.99	0.47	1.99	0.09	8.45	0.36	6.46	0.28
01399500	Lamington (Black) River near Pottersville, NJ	30.74	0.94	19.46	0.59	30.28	0.92	23.37	0.71	20.16	0.61	17.00	0.52	01399500	Lamington (Black) River near Pottersville, NJ	15.15	0.46	3.11	0.09	12.93	0.39	9.81	0.30
01399510	Upper Cold Brook near Pottersville, NJ	1.84	0.84	--	--	1.87	0.86	1.46	0.67	1.11	0.51	--	--	01399510	Upper Cold Brook near Pottersville, NJ	--	--	0.16	0.07	0.78	0.36	0.62	0.28
01399525	Axle Brook near Pottersville, NJ	0.38	0.31	0.21	0.17	0.37	0.30	0.25	0.21	0.21	0.17	0.16	0.13	01399525	Axle Brook near Pottersville, NJ	0.13	0.11	0.01	0.01	0.08	0.06	0.07	0.06
01399540	Cold Brook at Oldwick, NJ	3.93	0.74	2.79	0.53	3.82	0.72	3.18	0.60	2.85	0.54	2.50	0.47	01399540	Cold Brook at Oldwick, NJ	2.21	0.42	0.88	0.16	2.09	0.39	1.22	0.23
01399570	Rockaway Creek at McCrea Mills, NJ	13.98	0.82	9.41	0.55	13.60	0.80	10.69	0.63	9.41	0.55	8.08	0.48	01399570	Rockaway Creek at McCrea Mills, NJ	7.08	0.42	1.64	0.10	5.60	0.33	3.96	0.23
01399670	South Branch Rockaway Creek at Whitehouse Station, NJ	12.12	0.99	--	--	10.62	0.86	7.75	0.63	5.83	0.47	5.27	0.43	01399670	South Branch Rockaway Creek at Whitehouse Station, NJ	--	--	1.29	0.11	4.46	0.36	3.17	0.26
01403150	West Branch Middle Brook near Martinsville, NJ	0.64	0.32	--	--	0.60	0.30	0.49	0.24	0.41	0.21	0.34	0.17	01403150	West Branch Middle Brook near Martinsville, NJ	--	--	0.02	0.01	0.15	0.07	0.12	0.06
01443275	East Branch Paulins Kill tributary 1 near Lafayette, NJ	0.32	0.18	0.14	0.08	0.30	0.17	0.19	0.11	0.15	0.08	0.11	0.06	01443275	East Branch Paulins Kill tributary 1 near Lafayette, NJ	0.08	0.04	0.01	0.00	0.05	0.03	0.05	0.03
01443300	Paulins Kill at Lafayette, NJ	26.18	0.79	17.83	0.54	25.66	0.78	20.67	0.63	18.54	0.56	15.95	0.48	01443300	Paulins Kill at Lafayette, NJ	13.59	0.41	4.59	0.14	11.39	0.35	6.80	0.21
01443500	Paulins Kill at Blairstown, NJ	98.57	0.78	63.88	0.51	94.77	0.75	73.71	0.59	67.24	0.53	53.86	0.43	01443500	Paulins Kill at Blairstown, NJ	49.43	0.39	10.40	0.08	34.90	0.28	24.50	0.19
01443510	Blair Creek at Blairstown, NJ	9.35	0.71	5.54	0.42	9.13	0.70	6.71	0.51	5.84	0.45	4.73	0.36	01443510	Blair Creek at Blairstown, NJ	3.92	0.30	0.53	0.04	2.17	0.17	1.63	0.12
01445000	Pequest River at Huntsville, NJ	26.79	0.86	--	--	26.17	0.84	19.83	0.64	17.49	0.56	--	--	01445000	Pequest River at Huntsville, NJ	--	--	1.36	0.04	7.76	0.25	6.39	0.21
01445100	Pequest River at Long Bridge, NJ	38.80	0.80	22.61	0.47	37.30	0.77	28.58	0.59	24.41	0.50	20.06	0.41	01445100	Pequest River at Long Bridge, NJ	15.88	0.33	5.17	0.11	14.58	0.30	9.41	0.19
01445430	Pequest River at Townsbury, NJ	65.99	0.71	38.29	0.41	63.86	0.69	47.75	0.52	41.03	0.44	33.30	0.36	01445430	Pequest River at Townsbury, NJ	26.47	0.29	5.77	0.06	19.11	0.21	13.34	0.14
01445490	Furnace Brook at Oxford, NJ	3.79	0.88	2.52	0.59	3.66	0.85	2.98	0.70	2.64	0.62	2.28	0.53	01445490	Furnace Brook at Oxford, NJ	1.94	0.45	0.73	0.17	1.70	0.40	0.97	0.23
01445500	Pequest River at Pequest, NJ	84.80	0.80	49.72	0.47	82.29	0.78	63.40	0.60	54.46	0.51	44.92	0.42	01445500	Pequest River at Pequest, NJ	34.06	0.32	12.49	0.12	32.32	0.30	19.83	0.19
01445800	Honey Run near Ramseyburg, NJ	1.54	0.70	0.81	0.37	1.49	0.67	1.02	0.46	0.86	0.39	0.66	0.30	01445800	Honey Run near Ramseyburg, NJ	0.51	0.23	0.04	0.02	0.24	0.11	0.20	0.09
01445900	Honey Run near Hope, NJ	5.40	0.53	2.36	0.23	5.07	0.50	3.08	0.30	2.48	0.24	1.65	0.16	01445900	Honey Run near Hope, NJ	0.89	0.09	0.04	0.00	0.46	0.04	0.42	0.04
01446000	Beaver Brook near Belvidere, NJ	27.74	0.76	--	--	28.27	0.77	20.31	0.55	18.52	0.50	16.82	0.46	01446000	Beaver Brook near Belvidere, NJ	--	--	1.29	0.04	8.21	0.22	6.92	0.19
01446400	Pequest River at Belvidere, NJ	126.78	0.81	76.44	0.49	122.25	0.78	94.40	0.60	81.60	0.52	67.23	0.43	01446400	Pequest River at Belvidere, NJ	53.96	0.34	16.03	0.10	45.30	0.29	29.27	0.19
01446520	Pophandusing Brook at Belvidere, NJ	1.07	0.20	0.63	0.12	1.03	0.19	0.78	0.15	0.67	0.12	0.55	0.10	01446520	Pophandusing Brook at Belvidere, NJ	0.44	0.08	0.11	0.02	0.35	0.06	0.23	0.04
01446568	Buckhorn Creek at Hutchinson Road, at Hutchinson, NJ	3.06	0.37	1.92	0.23	2.98	0.36	2.32	0.28	2.04	0.24	1.71	0.20	01446568	Buckhorn Creek at Hutchinson Road, at Hutchinson, NJ	1.41	0.17	0.38	0.05	1.06	0.13	0.68	0.08
01455100	Lopatcong Creek at Phillipsburg, NJ	8.61	0.59	7.08	0.49	8.45	0.58	7.66	0.53	7.23	0.50	6.68	0.46	01455100	Lopatcong Creek at Phillipsburg, NJ	6.19	0.43	3.93	0.27	5.90	0.41	1.98	0.14
01455160	Brass Castle Creek near Washington, NJ	1.03	0.44	0.47	0.20	0.97	0.42	0.66	0.28	0.53	0.23	0.40	0.17	01455160	Brass Castle Creek near Washington, NJ	0.30	0.13	0.06	0.02	0.26	0.11	0.21	0.09
01455230	Merrill Creek at Coopersville, NJ	3.55	0.92	2.47	0.64	3.49	0.91	2.86	0.74	2.59	0.67	2.25	0.58	01455230	Merrill Creek at Coopersville, NJ	1.94	0.51	0.63	0.16	1.45	0.38	0.82	0.21
01455300	Pohatcong Creek at Carpentersville, NJ	28.62	0.50	19.90	0.35	28.06	0.49	22.93	0.40	20.82	0.37	17.98	0.32	01455300	Pohatcong Creek at Carpentersville, NJ	15.58	0.27	4.87	0.09	11.60	0.20	6.74	0.12
01455350	Weldon Brook near Woodport, NJ	3.44	0.95	1.78	0.49	3.21	0.88	2.04	0.56	1.65	0.45	1.16	0.32	01455350	Weldon Brook near Woodport, NJ	0.64	0.18	0.02	0.01	0.33	0.09	0.31	0.08
01455360	Beaver Brook near Woodport, NJ	2.07	0.74	1.26	0.45	1.99	0.71	1.40	0.50	1.21	0.43	0.88	0.32	01455360	Beaver Brook near Woodport, NJ	0.49	0.18	0.02	0.01	0.17	0.06	0.16	0.06
01455370	Weldon Brook at Hurdtown, NJ	5.95	0.74	3.03	0.37	5.79	0.72	3.71	0.46	3.07	0.38	2.29	0.28	01455370	Weldon Brook at Hurdtown, NJ	1.75	0.22	0.04	0.00	0.51	0.06	0.47	0.06
01455780	Lubbers Run at Lockwood, NJ	18.88	1.16	10.62	0.65	18.25	1.12	12.79	0.78	10.68	0.66	8.45	0.52	01455780	Lubbers Run at Lockwood, NJ	6.49	0.40	0.31	0.02	2.36	0.14	2.05	0.13
01456000	Musconetcong River near Hackettstown, NJ	65.18	0.95	41.44	0.60	67.32	0.98	49.12	0.71	38.96	0.57	31.75	0.46	01456000	Musconetcong River near Hackettstown, NJ	24.97	0.36	7.74	0.11	33.61	0.49	25.86	0.38
01456080	Mine Brook near Hackettstown, NJ	1.42	0.29	0.53	0.11	1.34	0.27	0.77	0.16	0.60	0.12	0.41	0.08	01456080	Mine Brook near Hackettstown, NJ	0.29	0.06	0.01	0.00	0.13	0.03	0.12	0.02
01456100	Hatchery Brook at Hackettstown, NJ	1.24	0.68	0.70	0.38	1.18	0.65	0.90	0.49	0.75	0.41	0.62	0.34	01456100	Hatchery Brook at Hackettstown, NJ	0.49	0.27	0.15	0.08	0.46	0.25	0.31	0.17
01456210	Hances Brook near Beattystown, NJ	2.47	0.60	1.74	0.42	2.41	0.58	1.99	0.48	1.79	0.43	1.57	0.38	01456210	Hances Brook near Beattystown, NJ	1.34	0.32	0.43	0.10	1.01	0.24	0.58	0.14
01457000	Musconetcong River near Bloomsbury, NJ	130.55	0.93	79.50	0.56	125.48	0.89	100.55	0.71	86.02	0.61	75.00	0.53	01457000	Musconetcong River near Bloomsbury, NJ	62.66	0.44	29.18	0.21	67.86	0.48	38.69	0.27
01457400	Musconetcong River at Riegelsville, NJ	152.99	0.98	98.14	0.63	147.46	0.95	120.17	0.77	104.49	0.67	90.90	0.58	01457400	Musconetcong River at Riegelsville, NJ	75.84	0.49	35.60	0.23	78.16	0.50	42.57	0.27
01458100	Hakihokake Creek at Milford, NJ	11.72	0.68	8.27	0.48	11.36	0.66	9.49	0.55	8.48	0.49	7.44	0.43	01458100	Hakihokake Creek at Milford, NJ	6.55	0.38	2.23	0.13	5.58	0.32	3.34	0.19
01458400	Harihokake Creek near Frenchtown, NJ	4.39	0.45	2.42	0.25	4.13	0.42	3.06	0.31	2.53	0.26	2.03	0.21	01458400	Harihokake Creek near Frenchtown, NJ	1.61	0.17	0.30	0.03	1.24	0.13	0.94	0.10
01458700	Little Nishisakawick Creek at Frenchtown, NJ	0.97	0.28	0.47	0.13	0.91	0.26	0.62	0.18	0.50	0.14	0.38	0.11	01458700	Little Nishisakawick Creek at Frenchtown, NJ	0.29	0.08	0.02	0.01	0.16	0.05	0.14	0.04

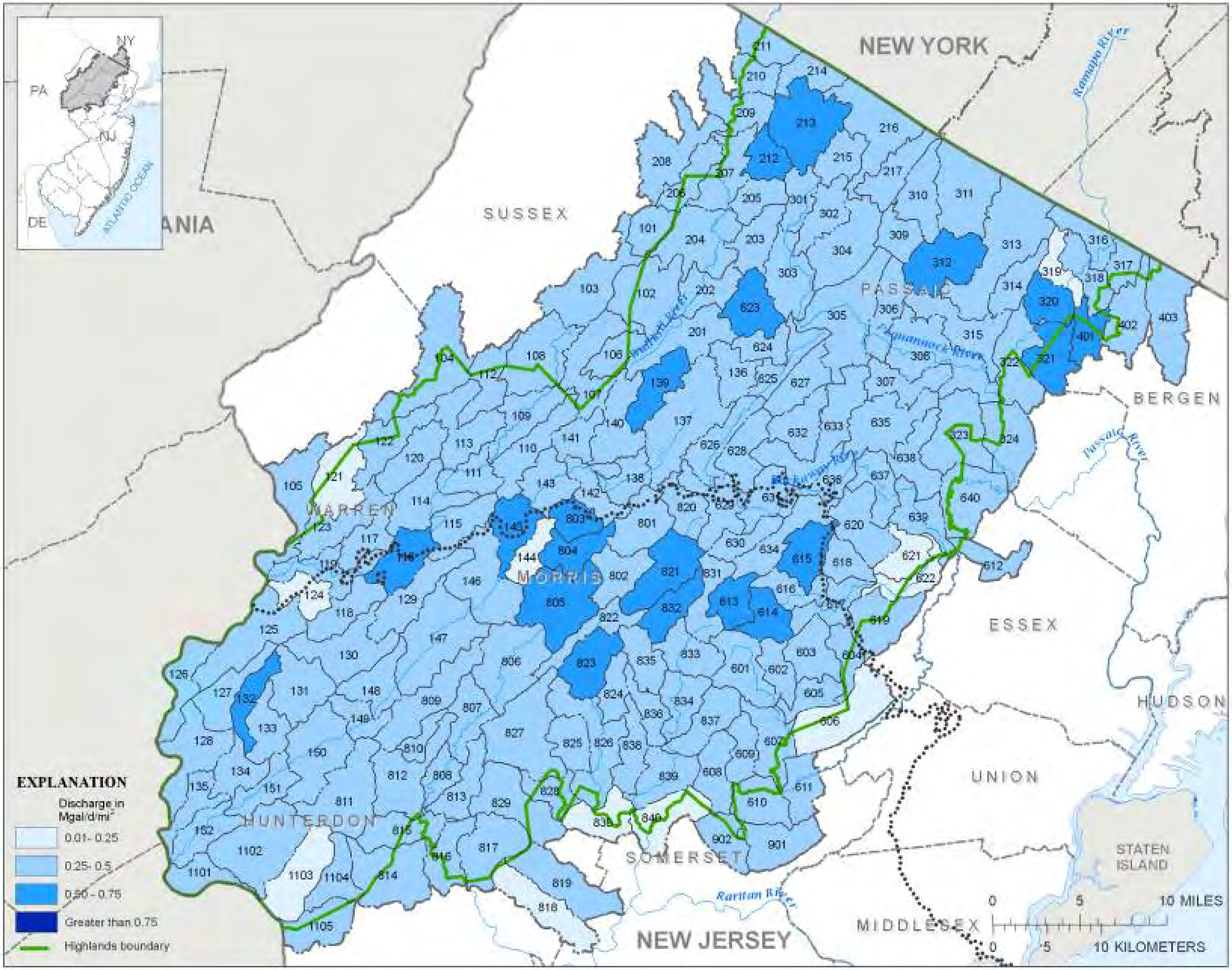
Notes:

Mgal/D = Million Gallons Per Day

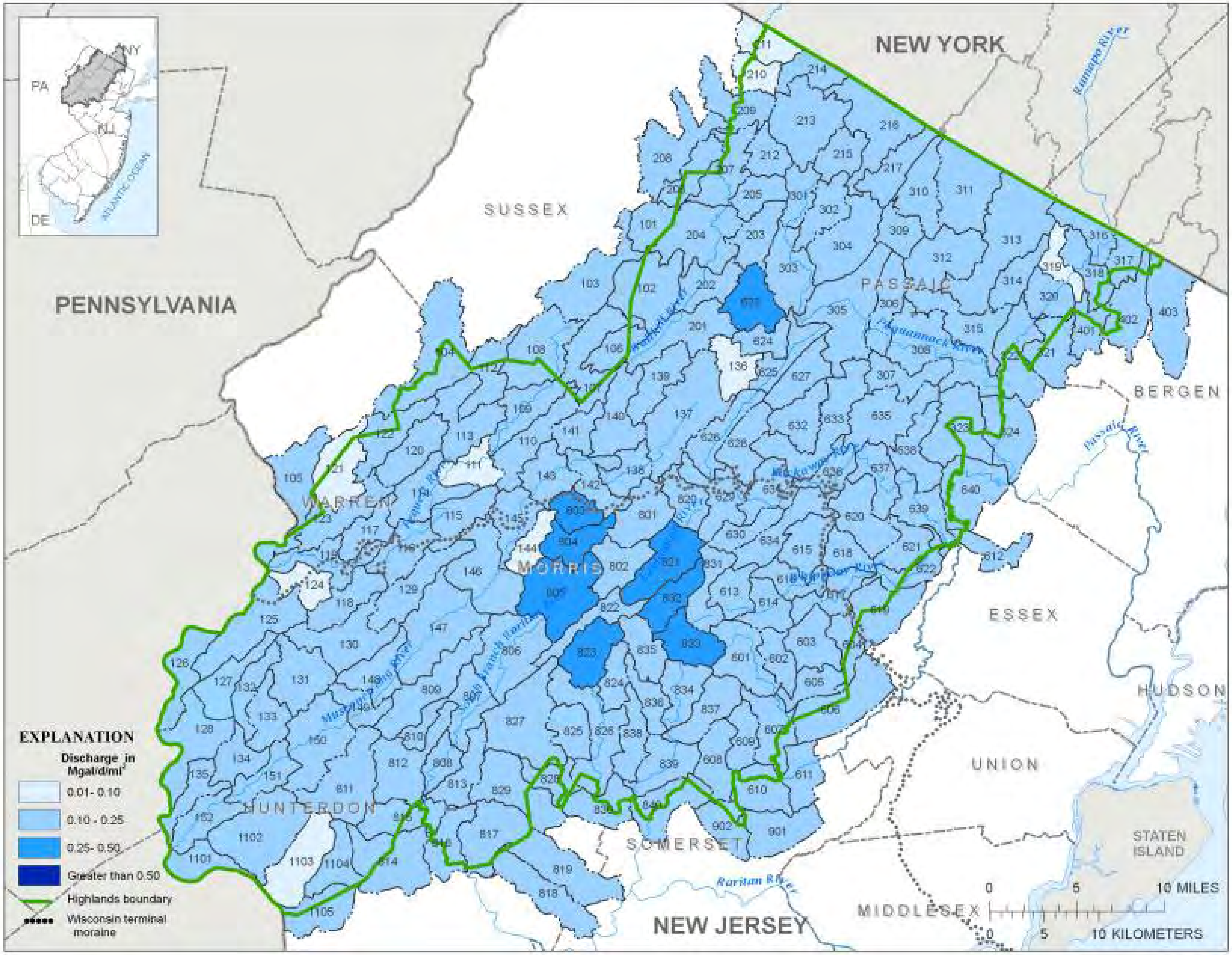
-- = No Determination



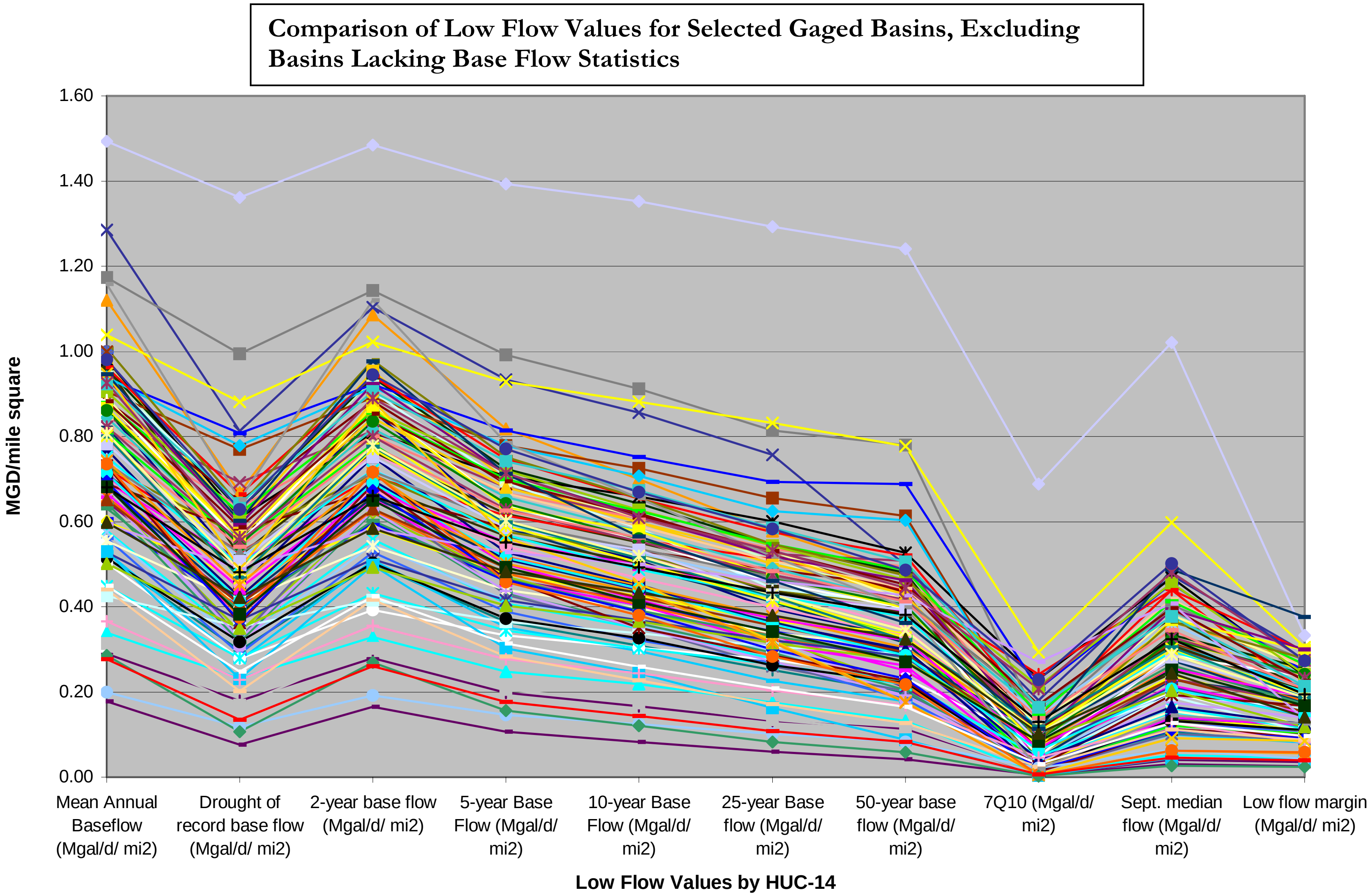
Mean Annual Base Flow for the 10=Year Recurrence Interval, New Jersey Highlands



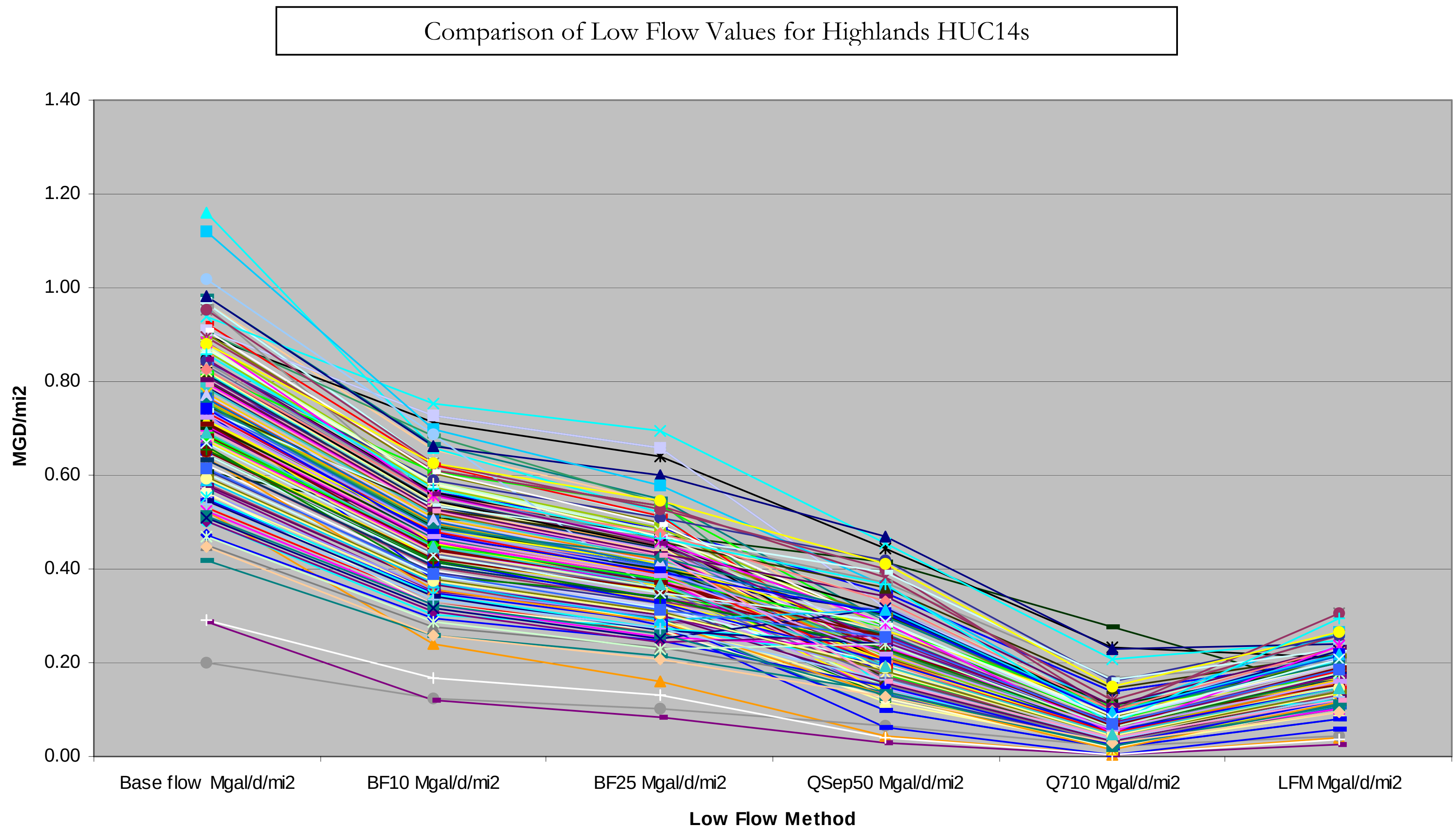
Mean Annual Base Flow for the 25-Year Recurrence Interval, New Jersey Highlands



Low-Flow Margin Defined as the September Median Minus the 7-Day 10-Year Low-Flow Discharge, New Jersey Highlands



This figure provides a graphical summary of actual base flow data from streams with long-term flow monitoring data (a total of 121 gaged stations; 25 with continuous records and another 96 with low flow partial records). The type of station and location are shown in the figure titled Location of Stream Flow Gaging Stations in the Highlands Study Area. The station site number, station name, drainage area size, latitude and longitude, period of record and station type for all stations are listed in the Site Information for Continuous Record Stream Flow Gaging Stations and Gaging Stations Analyzed as a Partial Record Station in the New Jersey Highlands table.



This figure provides a graphical summary of statistically-derived base flow data for each of the 183 HUC14s within the Highlands Region. The flow data was derived from long-term flow monitoring data of 121 gaged stations.

APPENDIX C

Total Water Use by Use Type- Maximum Month in MGD

		Potable Supply*			Industrial		Commercial		Recreation		Irrigation		Aquaculture		Agriculture		Power		Mining		Total Use		Total Consumptive & Depletive Use	
HUC_NAME	HUC14	GW	SW	Wastewater Returns	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW[1]	GW	SW[2]
Wallkill R/Lake Mohawk(above Sparta Sta)	02020007010010	0.88	1.21									0.11									0.88	1.32	0.72	0.10
Wallkill R (Ogdensburg to SpartaStation)	02020007010020	0.40																			0.40	0.00	0.32	0.00
Franklin Pond Creek	02020007010030	0.15																			0.15	0.00	0.09	0.00
Wallkill R(Hamburg SW Bdy to Ogdensburg)	02020007010040	0.98									0.09	0.02					0.02				1.09	0.02	0.85	0.02
Hardistonville tribs	02020007010050	0.07									0.11	0.17									0.18	0.17	0.11	0.15
Beaver Run	02020007010060	0.07							0.00	0.00			0.00	0.00					0.00	0.00	0.07	0.00	0.02	0.00
Wallkill R(Martins Rd to Hamburg SW Bdy)	02020007010070	1.27			0.17						0.56	0.09									2.00	0.09	0.80	0.08
Papakating Creek (below Pellettown)	02020007020070	0.15		1.80					0.00	0.00			0.00	0.00					0.00	0.00	0.15	0.00	0.04	0.00
Wallkill R(41d13m30s to Martins Road)	02020007030010	0.29							0.00	0.00			0.00	0.00					0.00	0.00	0.29	0.00	0.15	0.00
Wallkill River(Owens gage to 41d13m30s)	02020007030030	0.10							0.00	0.00			0.00	0.00					0.00	0.00	0.10	0.00	0.03	0.00
Wallkill River(stateline to Owens gage)	02020007030040	0.12							0.00	0.00			0.00	0.00					0.00	0.00	0.12	0.00	0.03	0.00
Black Ck(above/incl G.Gorge Resort trib)	02020007040010	0.64							0.00	0.00	0.00	0.05	0.00	0.00					0.00	0.00	0.64	0.05	0.50	0.04
Black Creek (below G. Gorge Resort trib)	02020007040020	0.51	0.01						0.34	2.64											0.84	2.65	0.23	0.08
Pochuck Ck/Glenwood Lk & northern trib	02020007040030	0.15																			0.15	0.00	0.04	0.00
Highland Lake/Wawayanda Lake	02020007040040	0.14																			0.14	0.00	0.04	0.00
Wawayanda Creek & tribs	02020007040050	0.35																			0.35	0.00	0.10	0.00
Long House Creek/Upper Greenwood Lake	02020007040060	0.19																			0.19	0.00	0.05	0.00
Passaic R Upr (above Osborn Mills)	02030103010010	0.69									0.05	0.13									0.74	0.13	0.57	0.11
Primrose Brook	02030103010020	0.12																			0.12	0.00	0.06	0.00
Great Brook (above Green Village Rd)	02030103010030	1.28			0.06							0.09									1.33	0.09	1.11	0.08
Loantaka Brook	02030103010040	2.48									0.09	0.13									2.57	0.13	1.13	0.12
Great Brook (below Green Village Rd)	02030103010050	0.07		1.16																	0.07	0.00	0.02	0.00
Black Brook (Great Swamp NWR)	02030103010060	0.06									0.13										0.19	0.00	0.12	0.00
Passaic R Upr (Dead R to Osborn Mills)	02030103010070	0.07										0.04								0.03	0.07	0.06	0.02	0.04
Dead River (above Harrisons Brook)	02030103010080	0.06									0.01										0.07	0.00	0.02	0.00
Harrisons Brook	02030103010090	0.04																			0.04	0.00	0.01	0.00
Dead River (below Harrisons Brook)	02030103010100	0.15																			0.15	0.00	0.04	0.00
Passaic R Upr (Plainfield Rd to Dead R)	02030103010110	0.11		1.82																	0.11	0.00	0.03	0.00
Passaic R Upr (Pine Bk br to Rockaway)	02030103010180	1.65																			1.65	0.00	1.47	0.00
Whippany R (above road at 74d 33m)	02030103020010	0.11																			0.11	0.00	0.03	0.00
Whippany R (Wash. Valley Rd to 74d 33m)	02030103020020	0.05																			0.05	0.00	0.01	0.00
Greystone / Watnong Mtn tribs	02030103020030	0.01			0.02																0.03	0.00	0.00	0.00
Whippany R(Lk Pocahontas to Wash Val Rd)	02030103020040	0.43																			0.43	0.00	0.11	0.00
Whippany R (Malapardis to Lk Pocahontas)	02030103020050	0.15		2.13	0.02																0.17	0.00	0.04	0.00
Malapardis Brook	02030103020060	6.58		3.16	0.00																6.58	0.00	5.92	0.00
Black Brook (Hanover)	02030103020070	4.48			1.08		0.05				0.28	0.02									5.89	0.02	4.29	0.01
Troy Brook (above Reynolds Ave)	02030103020080	8.28			0.16						0.01										8.45	0.00	7.47	0.00
Troy Brook (below Reynolds Ave)	02030103020090	2.06			0.11																2.17	0.00	1.86	0.00
Whippany R (Rockaway R to Malapardis Bk)	02030103020100	2.35									0.01										2.36	0.00	0.62	0.00
Russia Brook (above Milton)	02030103030010	0.44		2.13																	0.44	0.00	0.31	0.00
Russia Brook (below Milton)	02030103030020	0.14									0.01	0.08									0.15	0.08	0.04	0.08
Rockaway R (above Longwood Lake outlet)	02030103030030	0.26		0.12								0.28									0.26	0.28	0.12	0.25
Rockaway R (Stephens Bk to Longwood Lk)	02030103030040	0.22																			0.22	0.00	0.06	0.00
Green Pond Brook (above Burnt Meadow Bk)	02030103030050	0.10	0.02																		0.10	0.02	0.03	0.00
Green Pond Brook (below Burnt Meadow Bk)	02030103030060	0.87	3.78		0.19														0.22		1.28	3.78	0.76	0.00
Rockaway R (74d 33m 30s to Stephens Bk)	02030103030070	4.98																			4.98	0.00	4.38	0.00
Mill Brook (Morris Co)	02030103030080	0.10										0.01									0.10	0.01	0.03	0.01
Rockaway R (BM 534 brdg to 74d 33m 30s)	02030103030090	1.29			0.13	0.24													0.00		1.42	0.24	1.14	0.02
Hibernia Brook	02030103030100	0.10																			0.10	0.00	0.03	0.00
Beaver Brook (Morris County)	02030103030110	3.03																	0.10		3.13	0.00	2.62	0.00

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Total Water Use by Use Type- Maximum Month in MGD

		Potable Supply*			Industrial		Commercial		Recreation		Irrigation		Aquaculture		Agriculture		Power		Mining		Total Use		Total Consumptive & Depletive Use	
HUC_NAME	HUC14	GW	SW	Wastewater Returns	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW[1]	GW	SW[2]
Den Brook	02030103030120	0.11																			0.11	0.00	0.03	0.00
Stony Brook (Boonton)	02030103030130	0.51	0.56																		0.51	0.56	0.24	0.00
Rockaway R (Stony Brook to BM 534 brdg)	02030103030140	2.18									0.02	0.21				0.15					2.20	0.36	1.93	0.32
Rockaway R (Boonton dam to Stony Brook)	02030103030150	0.08	53.75																		0.08	53.75	0.02	0.00
Montville tribs.	02030103030160	0.25														0.02					0.25	0.02	0.06	0.02
Rockaway R (Passaic R to Boonton dam)	02030103030170	0.11																			0.11	0.00	0.03	0.00
Passaic R Upr (Pompton R to Pine Bk)	02030103040010	0.49		22.48																	0.49	0.00	0.21	0.00
Pequannock R (above Stockholm/Vernon Rd)	02030103050010	0.12																			0.12	0.00	0.03	0.00
Pacock Brook	02030103050020	0.16																			0.16	0.00	0.04	0.00
Pequannock R (above OakRidge Res outlet)	02030103050030	0.20																			0.20	0.00	0.05	0.00
Clinton Reservior/Mossmans Brook	02030103050040	0.31																			0.31	0.00	0.08	0.00
Pequannock R (Charlotteburg to OakRidge)	02030103050050	0.68																			0.68	0.00	0.36	0.00
Pequannock R(Macopin gage to Charl'brg)	02030103050060	0.22	46.28																		0.22	46.28	0.06	0.00
Stone House Brook	02030103050070	0.70	1.65	0.07																	0.70	1.65	0.52	0.00
Pequannock R (below Macopin gage)	02030103050080	2.16						0.07													2.16	0.07	1.75	0.03
Belcher Creek (above Pinecliff Lake)	02030103070010	0.47																			0.47	0.00	0.20	0.00
Belcher Creek (Pinecliff Lake & below)	02030103070020	0.37		0.14																	0.37	0.00	0.18	0.00
Wanaque R/Greenwood Lk(aboveMonks gage)	02030103070030	0.44		0.02																	0.44	0.00	0.12	0.00
West Brook/Burnt Meadow Brook	02030103070040	0.27		0.06																	0.27	0.00	0.09	0.00
Wanaque Reservior (below Monks gage)	02030103070050	0.58	336.11																		0.58	336.11	0.35	0.00
Meadow Brook/High Mountain Brook	02030103070060	0.80																			0.80	0.00	0.68	0.00
Wanaque R/Posts Bk (below reservior)	02030103070070	1.65																			1.65	0.00	0.44	0.00
Ramapo R (above 74d 11m 00s)	02030103100010	1.97		0.96																	1.97	0.00	1.74	0.00
Masonicus Brook	02030103100020	0.82																			0.82	0.00	0.72	0.00
Ramapo R (above Fyke Bk to 74d 11m 00s)	02030103100030	2.61									1.17										3.77	0.00	3.26	0.00
Ramapo R (Bear Swamp Bk thru Fyke Bk)	02030103100040	0.05																			0.05	0.00	0.01	0.00
Ramapo R (Crystal Lk br to BearSwamp Bk)	02030103100050	3.47																			3.47	0.00	3.10	0.00
Crystal Lake/Pond Brook	02030103100060	1.84					0.02				0.05										1.91	0.00	1.48	0.00
Ramapo R (below Crystal Lake bridge)	02030103100070	1.20			0.27																1.46	0.00	0.34	0.00
Lincoln Park tribs (Pompton River)	02030103110010	3.72		0.91							0.01	0.05				0.08					3.74	0.13	3.22	0.12
Pompton River	02030103110020	0.07			0.34						0.00	0.01				0.05					0.42	0.07	0.05	0.06
Hohokus Bk (above Godwin Ave)	02030103140010	0.44		5.57					0.09		0.00										0.53	0.00	0.25	0.00
Hohokus Bk(Pennington Ave to Godwin Ave)	02030103140020	3.05							0.02												3.08	0.00	2.72	0.00
Saddle River (above Rt 17)	02030103140040	5.52									0.05	0.03									5.57	0.03	4.32	0.03
Drakes Brook (above Eyland Ave)	02030105010010	0.92									0.01										0.93	0.00	0.61	0.00
Drakes Brook (below Eyland Ave)	02030105010020	4.25		0.04								0.23									4.25	0.23	3.33	0.21
Raritan River SB(above Rt 46)	02030105010030	0.56		0.37																	0.56	0.00	0.42	0.00
Raritan River SB(74d 44m 15s to Rt 46)	02030105010040	0.58									0.01										0.59	0.00	0.43	0.00
Raritan R SB(LongValley br to 74d44m15s)	02030105010050	1.08			0.27						0.01										1.35	0.00	0.38	0.00
Raritan R SB(Califon br to Long Valley)	02030105010060	0.34		0.44											0.00	0.01					0.34	0.01	0.15	0.01
Raritan R SB(StoneMill gage to Califon)	02030105010070	0.17																			0.17	0.00	0.08	0.00
Raritan R SB(Spruce Run-StoneMill gage)	02030105010080	0.32																			0.32	0.00	0.25	0.00
Spruce Run (above Glen Gardner)	02030105020010	0.35																			0.35	0.00	0.19	0.00
Spruce Run (Reservior to Glen Gardner)	02030105020020	0.12																			0.12	0.00	0.07	0.00
Mulhockaway Creek	02030105020030	0.21																			0.21	0.00	0.05	0.00
Spruce Run Reservior / Willoughby Brook	02030105020040	0.63	60.94								0.11	0.05									0.74	60.98	0.55	0.04
Beaver Brook (Clinton)	02030105020050	1.77			0.15							0.08									1.92	0.08	1.55	0.07
Cakepoulin Creek	02030105020060	0.18													0.20	0.03					0.38	0.03	0.21	0.03
Raritan R SB(River Rd to Spruce Run)	02030105020070	0.13	124.38																		0.13	124.38	0.03	0.00
Raritan R SB(Prescott Bk to River Rd)	02030105020080	0.19		1.25																	0.19	0.00	0.10	0.00

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Total Water Use by Use Type- Maximum Month in MGD

		Potable Supply*			Industrial		Commercial		Recreation		Irrigation		Aquaculture		Agriculture		Power		Mining		Total Use		Total Consumptive & Depletive Use	
HUC_NAME	HUC14	GW	SW	Wastewater Returns	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW[1]	GW	SW[2]
Prescott Brook / Round Valley Reservior	02030105020090	0.16																			0.16	0.00	0.04	0.00
Pleasant Run	02030105040020	0.26										0.07									0.26	0.07	0.07	0.06
Holland Brook	02030105040030	0.30									0.06	0.23									0.36	0.23	0.13	0.21
Lamington R (above Rt 10)	02030105050010	0.55				0.93															0.55	0.93	0.35	0.09
Lamington R (Hillside Rd to Rt 10)	02030105050020	4.26									0.02										4.28	0.00	2.02	0.00
Lamington R (Furnace Rd to Hillside Rd)	02030105050030	0.35		1.68	0.02										0.02						0.39	0.00	0.23	0.00
Lamington R(Pottersville gage-FurnaceRd)	02030105050040	0.27			0.13										0.00	0.02					0.40	0.02	0.15	0.01
Pottersville trib (Lamington River)	02030105050050	0.08																			0.08	0.00	0.02	0.00
Cold Brook	02030105050060	0.09													0.01						0.10	0.00	0.03	0.00
Lamington R(HallsBrRd-Pottersville gage)	02030105050070	0.17									0.05	0.48									0.22	0.48	0.08	0.43
Rockaway Ck (above McCrea Mills)	02030105050080	0.25		0.04											0.01					0.07	0.25	0.07	0.07	0.01
Rockaway Ck (RockawaySB to McCrea Mills)	02030105050090	0.10																			0.10	0.00	0.02	0.00
Rockaway Ck SB	02030105050100	0.98																			0.98	0.00	0.26	0.00
Lamington R (below Halls Bridge Rd)	02030105050110	0.14		0.69								0.19									0.14	0.19	0.04	0.17
Raritan R NB (above/incl India Bk)	02030105060010	0.30																			0.30	0.00	0.20	0.00
Burnett Brook (above Old Mill Rd)	02030105060020	0.14																			0.14	0.00	0.04	0.00
Raritan R NB(incl McVickers to India Bk)	02030105060030	0.09										0.11									0.09	0.11	0.02	0.10
Raritan R NB(Peapack Bk to McVickers Bk)	02030105060040	0.09		0.41				0.04													0.09	0.04	0.02	0.02
Peapack Brook (above/incl Gladstone Bk)	02030105060050	0.15																			0.15	0.00	0.04	0.00
Peapack Brook (below Gladstone Brook)	02030105060060	0.04										0.14									0.04	0.14	0.01	0.13
Raritan R NB(incl Mine Bk to Peapack Bk)	02030105060070	0.15									0.01	0.09									0.16	0.09	0.05	0.09
Middle Brook (NB Raritan River)	02030105060080	0.04		0.63							0.01										0.05	0.00	0.02	0.00
Raritan R NB (Lamington R to Mine Bk)	02030105060090	0.06									0.00										0.06	0.00	0.02	0.00
Raritan R NB (Rt 28 to Lamington R)	02030105070010	0.41		1.44																	0.41	0.00	0.24	0.00
Middle Brook EB	02030105120050	0.24									0.04										0.28	0.00	0.10	0.00
Middle Brook WB	02030105120060	0.25																			0.25	0.00	0.11	0.00
Lafayette Swamp tribs	02040105040040	0.05																			0.05	0.00	0.01	0.00
Sparta Junction tribs	02040105040050	0.66			0.00						0.06	0.01							0.19	5.79	0.91	5.80	0.57	0.70
Paulins Kill (above Rt 15)	02040105040060	0.21			0.09						0.01	0.07				0.05					0.31	0.12	0.11	0.11
Paulins Kill (Blairstown to Stillwater)	02040105050010	0.25																			0.25	0.00	0.13	0.03
Delawanna Creek (incl UDRV)	02040105060020	0.13			0.78																0.91	0.00	0.10	0.00
Lake Lenape trib	02040105070010	0.29																			0.29	0.00	0.22	0.00
New Wawayanda Lake/Andover Pond trib	02040105070020	0.41										0.03									0.41	0.03	0.26	0.03
Pequest River (above Brighton)	02040105070030	0.20																			0.20	0.00	0.06	0.00
Pequest River (Trout Brook to Brighton)	02040105070040	0.10																			0.10	0.00	0.03	0.00
Trout Brook/Lake Tranquility	02040105070050	0.08																			0.08	0.00	0.02	0.00
Pequest R (below Bear Swamp to Trout Bk)	02040105070060	0.69										0.07			0.12	0.17					0.81	0.24	0.39	0.22
Bear Brook (Sussex/Warren Co)	02040105080010	0.09		0.30							0.08										0.17	0.00	0.09	0.00
Bear Creek	02040105080020	0.07																			0.07	0.00	0.02	0.00
Pequest R (Drag Strip--below Bear Swamp)	02040105090010	0.15														0.43					0.15	0.43	0.04	0.38
Pequest R (Cemetary Road to Drag Strip)	02040105090020	0.10													0.13	0.06					0.23	0.06	0.13	0.06
Pequest R (Furnace Bk to Cemetary Road)	02040105090030	0.17											12.00								12.17	0.00	0.58	0.00
Mountain Lake Brook	02040105090040	0.11		0.31																	0.11	0.00	0.03	0.00
Furnace Brook	02040105090050	0.32				0.72															0.32	0.72	0.20	0.07
Pequest R (below Furnace Brook)	02040105090060	0.11			0.29		0.00														0.40	0.00	0.06	0.00
Union Church trib	02040105100010	0.07																			0.07	0.00	0.02	0.00
Honey Run	02040105100020	0.11													0.00	0.00					0.11	0.00	0.03	0.00
Beaver Brook (above Hope Village)	02040105100030	0.09																			0.09	0.00	0.02	0.00
Beaver Brook (below Hope Village)	02040105100040	0.10														0.01					0.10	0.01	0.03	0.01
Pophandusing Brook	02040105110010	0.52			0.02							0.01									0.53	0.01	0.43	0.01

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Total Water Use by Use Type- Maximum Month in MGD

HUC_NAME	HUC14	Potable Supply*			Industrial		Commercial		Recreation		Irrigation		Aquaculture		Agriculture		Power		Mining		Total Use		Total Consumptive & Depletive Use	
		GW	SW	Wastewater Returns	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW[1]	GW	SW[2]
Buckhorn Creek (incl UDRV)	02040105110020	0.22																	0.24		0.46	0.00	0.08	0.00
UDRV tribs (Rt 22 to Buckhorn Ck)	02040105110030	6.32		0.34	2.21																8.53	0.00	5.84	0.00
Lopatcong Creek (above Rt 57)	02040105120010	0.27									0.01	0.07									0.28	0.07	0.20	0.06
Lopatcong Creek (below Rt 57) incl UDRV	02040105120020	0.10			0.12						0.04								0.02		0.28	0.00	0.07	0.00
Pohatcong Creek (above Rt 31)	02040105140010	0.15		2.34											0.00						0.15	0.00	0.07	0.00
Pohatcong Ck (Brass Castle Ck to Rt 31)	02040105140020	0.86			0.61							0.03									1.47	0.03	0.28	0.03
Pohatcong Ck (Edison Rd-Brass Castle Ck)	02040105140030	0.09		0.80																	0.09	0.00	0.02	0.00
Merrill Creek	02040105140040	0.06																			0.06	0.00	0.02	0.00
Pohatcong Ck (Merrill Ck to Edison Rd)	02040105140050	0.06																			0.06	0.00	0.02	0.00
Pohatcong Ck (Springtown to Merrill Ck)	02040105140060	0.08																			0.08	0.00	0.02	0.00
Pohatcong Ck(below Springtown) incl UDRV	02040105140070	0.35																			0.35	0.00	0.29	0.00
Weldon Brook/Beaver Brook	02040105150010	0.16																			0.16	0.00	0.04	0.00
Lake Hopatcong	02040105150020	2.30																	0.07		2.37	0.00	1.53	0.00
Musconetcong R (Wills Bk to LkHopatcong)	02040105150030	1.76																			1.76	0.00	0.46	0.00
Lubbers Run (above/incl Dallis Pond)	02040105150040	0.74		2.06																	0.74	0.00	0.45	0.00
Lubbers Run (below Dallis Pond)	02040105150050	0.24																			0.24	0.00	0.06	0.00
Cranberry Lake / Jefferson Lake & tribs	02040105150060	0.08																			0.08	0.00	0.02	0.00
Musconetcong R(Waterloo to/incl WillsBk)	02040105150070	0.84					0.00														0.84	0.00	0.37	0.00
Musconetcong R (SaxtonFalls to Waterloo)	02040105150080	0.12																		0.14	0.12	0.14	0.03	0.02
Mine Brook (Morris Co)	02040105150090	0.14	0.97								0.00	0.00									0.15	0.97	0.07	0.00
Musconetcong R (Trout Bk to SaxtonFalls)	02040105150100	1.41														0.00					1.41	0.00	1.22	0.00
Musconetcong R (Hances Bk thru Trout Bk)	02040105160010	1.23			0.40																1.63	0.00	0.36	0.00
Musconetcong R (Changewater to HancesBk)	02040105160020	0.28		2.16	0.18										0.01						0.47	0.00	0.12	0.00
Musconetcong R (Rt 31 to Changewater)	02040105160030	0.74									0.12										0.86	0.00	0.70	0.00
Musconetcong R (75d 00m to Rt 31)	02040105160040	0.18																			0.18	0.00	0.12	0.00
Musconetcong R (I-78 to 75d 00m)	02040105160050	0.17						0.04													0.17	0.04	0.04	0.02
Musconetcong R (Warren Glen to I-78)	02040105160060	0.30																			0.30	0.00	0.21	0.00
Musconetcong R (below Warren Glen)	02040105160070	0.28			3.33													54.58			3.61	54.58	0.49	0.55
Holland Twp (Hakihokake to Musconetcong)	02040105170010	0.09			0.01										0.02						0.12	0.00	0.04	0.00
Hakihokake Creek	02040105170020	0.48			0.30						0.05	0.08									0.83	0.08	0.19	0.07
Harihokake Creek (and to Hakihokake Ck)	02040105170030	0.26		0.27	1.34																1.59	0.00	0.25	0.00
Nishisakawick Creek (above 40d 33m)	02040105170040	0.09							0.04												0.13	0.00	0.02	0.00
Nishisakawick Creek (below 40d 33m)	02040105170050	0.22																			0.22	0.00	0.14	0.00
	TOTALS:	**134.31**	**629.64**	**58.13**	**12.80**	**1.89**	**0.07**	**0.15**	**0.49**	**2.64**	**3.35**	**3.58**	**12.00**		**0.52**	**1.08**	**0.02**	**54.58**	**0.84**	**6.02**	**164.41**	**699.59**	**97.49**	**5.84**

[1] Reserviour withdrawals are included in Total Uses

[2] Reserviour withdrawals are not considered under C/D uses

* Includes domestic, institutional, public community and non-community systems

GROUND WATER AND SURFACE WATER BY TYPE
FULL ALLOCATION VOLUME IN MGD

SW_NAME	HUC14	Potable Supply				Bottling	Industrial	Commercial	Recreation	Irrigation	Aquaculture	Agriculture	Power	Mining	TOTAL USE
		Pub Sup - RES/Intakes	Public Supply - Other	Public Non-Community	Institutional										
Wallkill R/Lake Mohawk(above Sparta Sta)	02020007010010	1.274	1.254	0	0	0	0	0	0	0.115	0	0	0	0	2.643
Wallkill R (Ogdensburg to SpartaStation)	02020007010020	0	0.561	0	0	0	0	0	0	0	0	0	0	0	0.561
Franklin Pond Creek	02020007010030	0	0.102	0	0	0	0	0	0	0	0		0	0	0.102
Wallkill R(Hamburg SW Bdy to Ogdensburg)	02020007010040	0	1.107	0	0	0	0	0	0	0.204	0	0	0.102	0	1.413
Hardistonville tribs	02020007010050	0	0	0	0	0	0	0	0	0.292	0	0	0	0	0.292
Beaver Run	02020007010060	0	0	0	0	0	0	0	0	0.093	0	0	0	0	0.093
Wallkill R(Martins Rd to Hamburg SW Bdy)	02020007010070	0	1.063	0	0.102	0	0.263	0	0	0.111	0	0	0	0	1.539
Papakating Creek (below Pellettown)	02020007020070	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wallkill R(41d13m30s to Martins Road)	02020007030010	0	0.204	0.102	0	0	0	0	0	0.102	0	0	0	0	0.408
Wallkill River(Owens gage to 41d13m30s)	02020007030030	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wallkill River(stateline to Owens gage)	02020007030040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black Ck(above/incl G.Gorge Resort trib)	02020007040010	0	1.161	0	0	0	0	0	0	0.001	0	0	0	0	1.162
Black Creek (below G. Gorge Resort trib)	02020007040020	0	0.129	0.045	0	0	0	0	10.243	0	0	0	0	0	10.417
Pochuck Ck/Glenwood Lk & northern trib	02020007040030	0	0	0.057	0	0	0	0	0	0	0	0	0	0	0.057
Highland Lake/Wawayanda Lake	02020007040040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wawayanda Creek & tribs	02020007040050	0	0.102	0	0	0	0	0	0	0	0	0	0	0	0.102
Long House Creek/Upper Greenwood Lake	02020007040060	0	0	0.008	0	0	0	0	0	0	0	0	0	0	0.008
Passaic R Upr (above Osborn Mills)	02030103010010	0	1.288	0	0	0	0	0	0	0.251	0	0	0	0	1.539
Primrose Brook	02030103010020	0	0.102	0	0	0	0	0	0	0.135	0	0	0	0	0.237
Great Brook (above Green Village Rd)	02030103010030	0	1.306	0	0	0	0.102	0	0	0	0	0	0	0	1.408
Loantaka Brook	02030103010040	0	4.322	0	0	0	0	0	0	0.380	0	0	0	0	4.703
Great Brook (below Green Village Rd)	02030103010050	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black Brook (Great Swamp NWR)	02030103010060	0	0	0	0	0	0	0	0	0.204	0	0	0	0	0.204
Passaic R Upr (Dead R to Osborn Mills)	02030103010070	0	0	0	0	0	0	0	0	0.102	0	0	0	0.102	0.204
Dead River (above Harrisons Brook)	02030103010080	0	0	0	0	0	0	0	0	0.089	0	0	0	0	0.089
Harrisons Brook	02030103010090	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dead River (below Harrisons Brook)	02030103010100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Passaic R Upr (Plainfield Rd to Dead R)	02030103010110	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Passaic R Upr (Pine Bk br to Rockaway)	02030103010180	0	1.830	0	0	0	0	0	0	0	0	0	0	0	1.830
Whippany R (above road at 74d 33m)	02030103020010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Whippany R (Wash. Valley Rd to 74d 33m)	02030103020020	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Greystone / Watnong Mtn tribs	02030103020030	0	0	0	0	0	0.330	0	0	0	0	0	0	0	0.330
Whippany R(Lk Pocahontas to Wash Val Rd)	02030103020040	0	0.692	0	0	0	0	0	0	0	0	0	0	0	0.692
Whippany R (Malapardis to Lk Pocahontas)	02030103020050	0	0.294	0	0	0	0.102	0	0	0	0	0	0	0	0.396
Malapardis Brook	02030103020060	0	6.565	0	0	0	0.032	0	0	0	0	0	0	0	6.597
Black Brook (Hanover)	02030103020070	0	4.087	0	0.102	0	2.988	0.102	0	0.589	0	0	0	0	7.867
Troy Brook (above Reynolds Ave)	02030103020080	0	6.965	0	0	0	0.752	0	0	0.102	0	0	0	0	7.819
Troy Brook (below Reynolds Ave)	02030103020090	0	1.421	0	0	0	0.979	0	0	0	0	0	0	0	2.400
Whippany R (Rockaway R to Malapardis Bk)	02030103020100	0	2.377	0	0	0	0	0	0	0.102	0	0	0	0	2.479
Russia Brook (above Milton)	02030103030010	0	0.323	0	0	0	0	0	0	0	0	0	0	0	0.323
Russia Brook (below Milton)	02030103030020	0	0.003	0	0	0	0	0	0	0.263	0	0	0	0	0.266
Rockaway R (above Longwood Lake outlet)	02030103030030	0	0.065	0	0	0	0	0	0	0.424	0	0	0	0	0.489
Rockaway R (Stephens Bk to Longwood Lk)	02030103030040	0	0.017	0	0	0	0	0	0	0	0	0	0	0	0.017
Green Pond Brook (above Burnt Meadow Bk)	02030103030050	0	0.048	0	0	0	0	0	0	0	0	0	0	0	0.048
Green Pond Brook (below Burnt Meadow Bk)	02030103030060	0	4.850	0	0	0	0.213	0	0	0	0	0	0	0.721	5.784
Rockaway R (74d 33m 30s to Stephens Bk)	02030103030070	0	5.007	0	0	0	0	0	0	0	0	0	0	0	5.007
Mill Brook (Morris Co)	02030103030080	0	0	0	0	0	0	0	0	0.102	0	0	0	0	0.102
Rockaway R (BM 534 brdg to 74d 33m 30s)	02030103030090	0	0.864	0	0	0	1.019	0	0	0	0	0	0	0.002	1.885
Hibernia Brook	02030103030100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaver Brook (Morris County)	02030103030110	0	3.319	0	0	0	0	0	0	0	0	0	0	0.099	3.417
Den Brook	02030103030120	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Stony Brook (Boonton)	02030103030130	1.128	0.362	0	0	0	0	0	0	0	0	0	0	0	1.490
Rockaway R (Stony Brook to BM 534 brdg)	02030103030140	0	1.713	0.102	0	0	0	0	0	0.131	0	0.500	0	0	2.447
Rockaway R (Boonton dam to Stony Brook)	02030103030150	86.630	0	0	0	0	0	0	0	0	0	0	0	0	86.630
Montville tribs.	02030103030160	0	0	0	0	0	0	0	0	0	0	0.157	0	0	0.157
Rockaway R (Passaic R to Boonton dam)	02030103030170	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Passaic R Upr (Pompton R to Pine Bk)	02030103040010	0	0.204	0	0	0	0	0	0	0	0	0	0	0	0.204
Pequannock R (above Stockholm/Vernon Rd)	02030103050010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pacock Brook	02030103050020	0	0.017	0	0	0	0	0	0	0	0	0	0	0	0.017
Pequannock R (above OakRidge Res outlet)	02030103050030	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Clinton Reservior/Mossmans Brook	02030103050040	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Pequannock R (Charlotteburg to OakRidge)	02030103050050	0	0.609	0.008	0	0	0	0	0	0	0	0	0	0	0.616
Pequannock R(Macopin gage to Charl'brg)	02030103050060	58.093	0.024	0.035	0	0	0	0	0	0	0	0	0	0	58.152
Stone House Brook	02030103050070	4.077	0.284	0	0	0	0	0	0	0	0	0	0	0	4.361
Pequannock R (below Macopin gage)	02030103050080	0	3.026	0	0	0	0	0.102	0	0	0	0	0	0	3.128
Belcher Creek (above Pinecliff Lake)	02030103070010	0	0.478	0.004	0	0	0	0	0	0	0	0	0	0	0.482
Belcher Creek (Pinecliff Lake & below)	02030103070020	0	0.207	0.004	0	0	0	0	0	0	0	0	0	0	0.211
Wanaque R/Greenwood Lk(aboveMonks gage)	02030103070030	0	0.109	0	0	0	0	0	0	0	0	0	0	0	0.109
West Brook/Burnt Meadow Brook	02030103070040	0	0.102	0.044	0	0	0	0	0	0	0	0	0	0	0.146
Wanaque Reservior (below Monks gage)	02030103070050	1677.397	0.496	0	0	0	0	0	0	0	0	0	0	0	1677.894
Meadow Brook/High Mountain Brook	02030103070060	0	0.994	0	0	0	0	0	0	0	0	0	0	0	0.994
Wanaque R/Posts Bk (below reservior)	02030103070070	0	2.081	0	0	0	0	0	0	0	0	0	0	0	2.081
Ramapo R (above 74d 11m 00s)	02030103100010	0	2.006	0	0	0	0	0	0	0	0	0	0	0	2.006
Masonicus Brook	02030103100020	0	0.648	0	0	0	0	0	0	0	0	0	0	0	0.648
Ramapo R (above Fyke Bk to 74d 11m 00s)	02030103100030	0	3.079	0.010	0	0	0	0	0	1.004	0	0	0	0	4.093
Ramapo R (Bear Swamp Bk thru Fyke Bk)	02030103100040	0	0	0.002	0	0	0	0	0	0	0	0	0	0	0.002
Ramapo R (Crystal Lk br to BearSwamp Bk)	02030103100050	0	2.192	0	0	0	0	0	0	0	0	0	0	0	2.192
Crystal Lake/Pond Brook	02030103100060	0	2.495	0	0	0	0	0.102	0	0.096	0	0	0	0	2.693
Ramapo R (below Crystal Lake bridge)	02030103100070	0	1.146	0	0	0	0.405	0	0	0	0	0	0	0	1.551
Lincoln Park tribs (Pompton River)	02030103110010	0	4.966	0	0	0	0	0	0	0.296	0	0.465	0	0	5.726
Pompton River	02030103110020	0	0	0	0	0	0.102	0	0	0.204	0	0.257	0	0	0.563
Hohokus Bk (above Godwin Ave)	02030103140010	0	0.305	0.102	0	0	0	0	0.102	0.006	0	0	0	0	0.515
Hohokus Bk(Pennington Ave to Godwin Ave)	02030103140020	0	2.931	0	0	0	0	0	0.191	0	0	0	0	0	3.122
Saddle River (above Rt 17)	02030103140040	0	4.092	0	0	0	0	0	0	0.148	0	0	0	0	4.240
Drakes Brook (above Eyland Ave)	02030105010010	0	1.052	0.102	0	0	0	0	0	0.045	0	0	0	0	1.199
Drakes Brook (below Eyland Ave)	02030105010020	0	5.139	0	0	0	0	0	0	0.382	0	0	0	0	5.522
Raritan River SB(above Rt 46)	02030105010030	0	0.561	0	0	0	0	0	0	0	0	0	0	0	0.561
Raritan River SB(74d 44m 15s to Rt 46)	02030105010040	0	0.485	0	0	0	0	0	0	0.047	0	0	0	0	0.531
Raritan R SB(LongValley br to 74d44m15s)	02030105010050	0	0.821	0	0	0	0.940	0	0	0.102	0	0	0	0	1.863
Raritan R SB(Califon br to Long Valley)	02030105010060	0	0.187	0	0	0	0	0	0	0	0	2.120	0	0	2.307
Raritan R SB(StoneMill gage to Califon)	02030105010070	0	0.049	0	0	0	0	0	0	0	0	0	0	0	0.049
Raritan R SB(Spruce Run-StoneMill gage)	02030105010080	0	0.395	0	0	0	0	0	0	0	0	0	0	0	0.395
Spruce Run (above Glen Gardner)	02030105020010	0	0.204	0	0	0	0	0	0	0	0	0	0	0	0.204
Spruce Run (Reservior to Glen Gardner)	02030105020020	0	0.102	0	0	0	0	0	0	0	0	0	0	0	0.102
Mulhockaway Creek	02030105020030	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spruce Run Reservior / Willoughby Brook	02030105020040	60.935	0.810	0	0	0	0	0	0	0.102	0	0	0	0	61.847
Beaver Brook (Clinton)	02030105020050	0	2.339	0	0	0	0.214	0	0	0.164	0	0	0	0	2.717
Cakepoulin Creek	02030105020060	0	0	0	0	0	0	0	0	0	0	0.658	0	0	0.658
Raritan R SB(River Rd to Spruce Run)	02030105020070	433.151	0.077	0	0	0	0	0	0	0	0	0	0	0	433.228
Raritan R SB(Prescott Bk to River Rd)	02030105020080	0	0.078	0	0	0	0	0	0	0	0	0	0	0	0.078
Prescott Brook / Round Valley Reservior	02030105020090	0.814	0	0	0	0	0	0	0	0	0	0	0	0	0.814
Pleasant Run	02030105040020	0	0	0	0	0	0	0	0	0.064	0	0	0	0	0.064
Holland Brook	02030105040030	0	0	0	0	0	0	0	0	0.435	0	0	0	0	0.435
Lamington R (above Rt 10)	02030105050010	0	1.490	0	0	0	0	0	0	0	0	0	0	1.479	2.970
Lamington R (Hillside Rd to Rt 10)	02030105050020	0	3.703	0	0	0	0	0	0	0.102	0	0	0	0	3.805
Lamington R (Furnace Rd to Hillside Rd)	02030105050030	0	0.344	0	0	0	0.024	0	0	0	0	0.383	0	0	0.750
Lamington R(Pottersville gage-FurnaceRd)	02030105050040	0	0.127	0	0	0	0.157	0	0	0	0	0.689	0	0	0.973
Pottersville trib (Lamington River)	02030105050050	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cold Brook	02030105050060	0	0	0	0	0	0	0	0	0	0	0.086	0	0	0.086
Lamington R(HallsBrRd-Pottersville gage)	02030105050070	0	0	0	0	0	0	0	0	0.848	0	0	0	0	0.848
Rockaway Ck (above McCrea Mills)	02030105050080	0	0	0	0	0	0	0	0	0	0	0.100	0	0.102	0.202
Rockaway Ck (RockawaySB to McCrea Mills)	02030105050090	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rockaway Ck SB	02030105050100	0	0.896	0	0	0	0	0	0	0	0	0	0	0	0.896
Lamington R (below Halls Bridge Rd)	02030105050110	0	0	0	0	0	0	0	0	0.368	0	0	0	0	0.368
Raritan R NB (above/incl India Bk)	02030105060010	0	0.652	0	0	0	0	0	0	0	0	0	0	0	0.652
Burnett Brook (above Old Mill Rd)	02030105060020	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Raritan R NB(incl McVickers to India Bk)	02030105060030	0	0	0	0	0	0	0	0	0.211	0	0	0	0	0.211
Raritan R NB(Peapack Bk to McVickers Bk)	02030105060040	0	0	0	0	0	0	0.102	0	0	0	0	0	0	0.102
Peapack Brook (above/incl Gladstone Bk)	02030105060050	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Peapack Brook (below Gladstone Brook)	02030105060060	0	0	0	0	0	0	0	0	0.096	0	0	0	0	0.096
Raritan R NB(incl Mine Bk to Peapack Bk)	02030105060070	0	0.102	0	0	0	0	0	0	0.102	0	0	0	0	0.204
Middle Brook (NB Raritan River)	02030105060080	0	0	0	0	0	0	0	0	0.006	0	0	0	0	0.006
Raritan R NB (Lamington R to Mine Bk)	02030105060090	0	0	0	0	0	0	0	0	0.013	0	0	0	0	0.013
Raritan R NB (Rt 28 to Lamington R)	02030105070010	0	0.315	0	0	0	0	0	0	0	0	0	0	0	0.315
Middle Brook EB	02030105120050	0	0	0	0	0	0	0	0	0.039	0	0	0	0	0.039
Middle Brook WB	02030105120060	0	0.093	0	0	0	0	0	0	0	0	0	0	0	0.093

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Lafayette Swamp tribs	02040105040040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sparta Junction tribs	02040105040050	0	0.519	0.001	0	0	0.000	0	0	0.352	0	0	0	8.908	9.780
Paulins Kill (above Rt 15)	02040105040060	0	0.102	0.102	0	0	0.102	0	0	0.203	0	0.986	0	0	1.494
Paulins Kill (Blairstown to Stillwater)	02040105050010	0	0.102	0	0	0.102	0	0	0	0	0	0	0	0	0.203
Delawanna Creek (incl UDRV)	02040105060020	0	0	0	0	0	1.102	0	0	0	0	0	0	0	1.102
Lake Lenape trib	02040105070010	0	0.371	0	0	0	0	0	0	0	0	0	0	0	0.371
New Wawayanda Lake/Andover Pond trib	02040105070020	0	0.483	0.101	0	0	0	0	0	0.102	0	0	0	0	0.686
Pequest River (above Brighton)	02040105070030	0	0.102	0	0	0	0	0	0	0	0	0	0	0	0.102
Pequest River (Trout Brook to Brighton)	02040105070040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trout Brook/Lake Tranquility	02040105070050	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pequest R (below Bear Swamp to Trout Bk)	02040105070060	0	0.510	0	0	0	0	0	0	0.102	0	1.631	0	0	2.242
Bear Brook (Sussex/Warren Co)	02040105080010	0	0	0.102	0	0	0	0	0	0.102	0	0	0	0	0.204
Bear Creek	02040105080020	0	0	0.018	0	0	0	0	0	0	0	1.192	0	0	1.210
Pequest R (Drag Strip--below Bear Swamp)	02040105090010	0	0	0	0	0	0	0	0	0	0	2.869	0	0	2.869
Pequest R (Cemetary Road to Drag Strip)	02040105090020	0	0	0	0	0	0	0	0	0	0	0.502	0	0	0.502
Pequest R (Furnace Bk to Cemetary Road)	02040105090030	0	0.102	0	0	0	0	0	0	0	10.273	0	0	0	10.375
Mountain Lake Brook	02040105090040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furnace Brook	02040105090050	0	0.200	0	0	0	1.479	0	0	0	0	0	0	0	1.679
Pequest R (below Furnace Brook)	02040105090060	0	0	0.102	0	0	0.559	0.102	0	0	0	0	0	0	0.763
Union Church trib	02040105100010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Honey Run	02040105100020	0	0	0	0	0	0	0	0	0	0	0.487	0	0	0.487
Beaver Brook (above Hope Village)	02040105100030	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Beaver Brook (below Hope Village)	02040105100040	0	0	0	0	0	0	0	0	0	0	0.505	0	0	0.505
Pophandusing Brook	02040105110010	0	0.937	0	0	0	0.102	0	0	0.102	0	0	0	0	1.141
Buckhorn Creek (incl UDRV)	02040105110020	0	0.204	0	0	0	0	0	0	0	0	0	0	0.214	0.418
UDRV tribs (Rt 22 to Buckhorn Ck)	02040105110030	0	5.773	0	0	0	3.332	0	0	0	0	0	0	0	9.105
Lopatcong Creek (above Rt 57)	02040105120010	0	0.079	0	0	0	0	0	0	0.204	0	0	0	0	0.282
Lopatcong Creek (below Rt 57) incl UDRV	02040105120020	0	0	0	0	0	0.658	0	0	0.102	0	0	0	1.249	2.009
Pohatcong Creek (above Rt 31)	02040105140010	0	0.084	0.000	0	0	0	0	0	0	0	0.263	0	0	0.347
Pohatcong Ck (Brass Castle Ck to Rt 31)	02040105140020	0	0.926	0	0	0	0.664	0	0	0.102	0	0	0	0	1.692
Pohatcong Ck (Edison Rd-Brass Castle Ck)	02040105140030	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Merrill Creek	02040105140040	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pohatcong Ck (Merrill Ck to Edison Rd)	02040105140050	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pohatcong Ck (Springtown to Merrill Ck)	02040105140060	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pohatcong Ck(below Springtown) incl UDRV	02040105140070	0	0.427	0	0	0	0	0	0	0	0	0	0	0	0.427
Weldon Brook/Beaver Brook	02040105150010	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lake Hopatcong	02040105150020	0	1.644	0	0	0	0	0	0	0	0	0	0	0.102	1.745
Musconetcong R (Wills Bk to LkHopatcong)	02040105150030	0	2.149	0	0	0	0	0	0	0	0	0	0	0	2.149
Lubbers Run (above/incl Dallis Pond)	02040105150040	0	0.638	0	0	0	0	0	0	0	0	0	0	0	0.638
Lubbers Run (below Dallis Pond)	02040105150050	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cranberry Lake / Jefferson Lake & tribs	02040105150060	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Musconetcong R(Waterloo to/incl WillsBk)	02040105150070	0	0.357	0.395	0	0	0	0.102	0	0	0	0	0	0	0.853
Musconetcong R (SaxtonFalls to Waterloo)	02040105150080	0	0	0	0	0	0	0	0	0	0	0	0	8.416	8.416
Mine Brook (Morris Co)	02040105150090	0	0.063	0	0	0	0	0	0	0.112	0	0	0	0	0.175
Musconetcong R (Trout Bk to SaxtonFalls)	02040105150100	0	1.115	0	0	0	0	0	0	0	0	0.357	0	0	1.472
Musconetcong R (Hances Bk thru Trout Bk)	02040105160010	0	1.415	0	0	0	0.873	0	0	0	0	0	0	0	2.287
Musconetcong R (Changewater to HancesBk)	02040105160020	0	0.102	0	0	0	0.314	0	0	0	0	0.533	0	0	0.949
Musconetcong R (Rt 31 to Changewater)	02040105160030	0	0.777	0	0	0	0	0	0	0.362	0	0	0	0	1.138
Musconetcong R (75d 00m to Rt 31)	02040105160040	0	0.217	0	0	0	0	0	0	0	0	0	0	0	0.217
Musconetcong R (I-78 to 75d 00m)	02040105160050	0	0	0	0	0	0	0.102	0	0	0	0	0	0	0.102
Musconetcong R (Warren Glen to I-78)	02040105160060	0	0.153	0	0	0	0	0	0	0	0	0	0	0	0.153
Musconetcong R (below Warren Glen)	02040105160070	0	0.147	0	0	0	2.912	0	0	0	0	0	302.696	0	305.755
Holland Twp (Hakihokake to Musconetcong)	02040105170010	0	0	0	0	0	1.046	0	0	0	0	0.448	0	0	1.494
Hakihokake Creek	02040105170020	0	0.388	0	0	0	0.453	0	0	0.102	0	0	0	0	0.943
Harihokake Creek (and to Hakihokake Ck)	02040105170030	0	0.152	0	0	0	1.738	0	0	0	0	0	0	0	1.890
Nishisakawick Creek (above 40d 33m)	02040105170040	0	0	0	0	0	0	0	0.102	0	0	0	0	0	0.102
Nishisakawick Creek (below 40d 33m)	02040105170050	0	0.284	0	0	0	0	0	0	0	0	0	0	0	0.284

APPENDIX D

GROUND WATER CAPACITY
BY HUC14

HUC14	Subwatershed Name	Drainage area, mi2	Percent within Highlands Region	Ground Water Capacity			
				Median Sept Flow (MGD)	7Q10 (MGD)	LFM[1] (MGD)	Adjusted LFM[2] (MGD)
02020007010010	Wallkill R/Lake Mohawk(above Sparta Sta)	11.46	99.9%	2.27	0.49	1.78	1.81
02020007010020	Wallkill R (Ogdensburg to SpartaStation)	7.18	100.0%	0.96	0.21	0.76	0.77
02020007010030	Franklin Pond Creek	7.17	100.0%	0.99	0.22	0.78	0.79
02020007010040	Wallkill R(Hamburg SW Bdy to Ogdensburg)	14.11	99.6%	3.04	0.79	2.25	2.28
02020007010050	Hardistonville tribs	5.47	100.0%	0.71	0.15	0.56	0.57
02020007010060	Beaver Run	6.47	25.0%	1.33	0.37	0.96	0.25
02020007010070	Wallkill R(Martins Rd to Hamburg SW Bdy)	9.13	88.3%	1.80	0.46	1.34	1.21
02020007020070	Papakating Creek (below Pellettown)	13.27	0.0%	2.25	0.52	1.73	0.00
02020007030010	Wallkill R(41d13m30s to Martins Road)	9.15	47.3%	1.52	0.35	1.17	0.56
02020007030030	Wallkill River(Owens gage to 41d13m30s)	5.19	71.1%	0.51	0.09	0.42	0.31
02020007030040	Wallkill River(stateline to Owens gage)	6.41	59.0%	0.64	0.11	0.52	0.32
02020007040010	Black Ck(above/incl G.Gorge Resort trib)	5.41	100.0%	1.27	0.31	0.96	0.98
02020007040020	Black Creek (below G. Gorge Resort trib)	14.95	100.0%	3.50	0.85	2.64	2.70
02020007040030	Pochuck Ck/Glenwood Lk & northern trib	5.58	99.6%	0.82	0.18	0.64	0.65
02020007040040	Highland Lake/Wawayanda Lake	6.17	100.0%	0.85	0.18	0.68	0.69
02020007040050	Wawayanda Creek & tribs	14.34	99.9%	2.71	0.67	2.04	2.08
02020007040060	Long House Creek/Upper Greenwood Lake	7.85	100.0%	1.52	0.38	1.14	1.17
02030103010010	Passaic R Upr (above Osborn Mills)	10.13	100.0%	3.14	0.97	2.17	2.22
02030103010020	Primrose Brook	5.24	100.0%	1.57	0.44	1.13	1.15
02030103010030	Great Brook (above Green Village Rd)	7.92	100.0%	1.60	0.36	1.24	1.26
02030103010040	Loantaka Brook	5.06	60.8%	1.32	0.34	0.98	0.61
02030103010050	Great Brook (below Green Village Rd)	5.15	100.0%	0.93	0.19	0.74	0.76
02030103010060	Black Brook (Great Swamp NWR)	14.19	16.8%	2.17	0.39	1.77	0.30
02030103010070	Passaic R Upr (Dead R to Osborn Mills)	8.89	77.5%	1.63	0.35	1.28	1.01
02030103010080	Dead River (above Harrisons Brook)	7.60	99.8%	1.90	0.49	1.41	1.44
02030103010090	Harrisons Brook	5.44	100.0%	0.68	0.09	0.59	0.60
02030103010100	Dead River (below Harrisons Brook)	7.73	24.8%	1.51	0.34	1.17	0.29
02030103010110	Passaic R Upr (Plainfield Rd to Dead R)	6.68	0.0%	1.06	0.22	0.84	0.00
02030103010180	Passaic R Upr (Pine Bk br to Rockaway)	5.34	6.1%	1.06	0.25	0.82	0.05
02030103020010	Whippany R (above road at 74d 33m)	6.05	100.0%	1.91	0.63	1.28	1.31
02030103020020	Whippany R (Wash. Valley Rd to 74d 33m)	6.27	100.0%	1.98	0.65	1.3296	1.36
02030103020030	Greystone / Watnong Mtn tribs	7.77	100.0%	3.64	1.79	1.8504	1.89
02030103020040	Whippany R(Lk Pocahontas to Wash Val Rd)	5.61	100.0%	1.23	0.32	0.9079	0.93
02030103020050	Whippany R (Malapardis to Lk Pocahontas)	6.72	100.0%	1.36	0.32	1.0337	1.05
02030103020060	Malapardis Brook	5.09	100.0%	1.01	0.40	0.6148	0.63
02030103020070	Black Brook (Hanover)	10.38	33.6%	2.63	0.63	1.9974	0.68
02030103020080	Troy Brook (above Reynolds Ave)	10.06	100.0%	2.37	0.58	1.7927	1.83
02030103020090	Troy Brook (below Reynolds Ave)	6.04	96.9%	0.83	0.14	0.6894	0.68
02030103020100	Whippany R (Rockaway R to Malapardis Bk)	5.61	47.0%	0.83	0.15	0.6807	0.33
02030103030010	Russia Brook (above Milton)	8.56	100.0%	3.12	0.85	2.2755	2.32
02030103030020	Russia Brook (below Milton)	4.84	100.0%	1.00	0.26	0.7368	0.75
02030103030030	Rockaway R (above Longwood Lake outlet)	6.70	100.0%	1.38	0.37	1.0166	1.04
02030103030040	Rockaway R (Stephens Bk to Longwood Lk)	7.97	100.0%	1.41	0.35	1.0596	1.08
02030103030050	Green Pond Brook (above Burnt Meadow Bk)	7.37	100.0%	2.11	0.36	1.7571	1.79
02030103030060	Green Pond Brook (below Burnt Meadow Bk)	7.90	100.0%	1.30	0.29	1.0054	1.03
02030103030070	Rockaway R (74d 33m 30s to Stephens Bk)	9.10	100.0%	2.16	0.57	1.5831	1.61
02030103030080	Mill Brook (Morris Co)	4.89	100.0%	1.05	0.28	0.7769	0.79
02030103030090	Rockaway R (BM 534 brdg to 74d 33m 30s)	7.33	100.0%	1.39	0.33	1.0598	1.08
02030103030100	Hibernia Brook	7.92	100.0%	1.70	0.45	1.2472	1.27
02030103030110	Beaver Brook (Morris County)	14.76	100.0%	3.17	0.81	2.3557	2.40
02030103030120	Den Brook	9.01	100.0%	2.00	0.52	1.4782	1.51
02030103030130	Stony Brook (Boonton)	12.28	100.0%	1.62	0.19	1.4299	1.46

1 LFM = (Sept. Median Flow) - (7Q10)
2 Adjusted by 1.02 and % Highlands

GROUND WATER CAPACITY
BY HUC14

HUC14	Subwatershed Name	Drainage area, mi2	Percent within Highlands Region	Ground Water Capacity			
				Median Sept Flow (MGD)	7Q10 (MGD)	LFM[1] (MGD)	Adjusted LFM[2] (MGD)
02030103030140	Rockaway R (Stony Brook to BM 534 brdg)	5.28	100.0%	1.09	0.27	0.8192	0.84
02030103030150	Rockaway R (Boonton dam to Stony Brook)	6.90	100.0%	1.14	0.25	0.8896	0.91
02030103030160	Montville tribs.	7.91	100.0%	2.94	1.33	1.6080	1.64
02030103030170	Rockaway R (Passaic R to Boonton dam)	8.02	95.8%	1.81	0.42	1.3889	1.36
02030103040010	Passaic R Upr (Pompton R to Pine Bk)	11.87	22.1%	2.68	0.67	2.0180	0.45
02030103050010	Pequannock R (above Stockholm/Vernon Rd)	5.41	100.0%	0.79	0.18	0.6112	0.62
02030103050020	Pacock Brook	7.17	100.0%	1.23	0.29	0.9412	0.96
02030103050030	Pequannock R (above OakRidge Res outlet)	10.48	100.0%	2.08	0.53	1.5542	1.59
02030103050040	Clinton Reservior/Mossmans Brook	13.25	100.0%	2.85	0.76	2.0954	2.14
02030103050050	Pequannock R (Charlotteburg to OakRidge)	18.37	100.0%	5.09	1.50	3.5970	3.67
02030103050060	Pequannock R(Macopin gage to Charl'brg)	7.88	100.0%	1.48	0.37	1.1076	1.13
02030103050070	Stone House Brook	7.30	100.0%	1.34	0.33	1.0138	1.03
02030103050080	Pequannock R (below Macopin gage)	16.92	100.0%	3.51	0.91	2.6005	2.65
02030103070010	Belcher Creek (above Pinecliff Lake)	5.43	100.0%	1.00	0.25	0.7446	0.76
02030103070020	Belcher Creek (Pinecliff Lake & below)	9.03	100.0%	1.71	0.44	1.2728	1.30
02030103070030	Wanaque R/Greenwood Lk(aboveMonks gage)	14.62	100.0%	2.84	0.73	2.1018	2.14
02030103070040	West Brook/Burnt Meadow Brook	11.82	100.0%	1.94	0.39	1.5524	1.58
02030103070050	Wanaque Reservior (below Monks gage)	21.47	100.0%	4.22	1.07	3.1464	3.21
02030103070060	Meadow Brook/High Mountain Brook	5.99	100.0%	1.00	0.24	0.7565	0.77
02030103070070	Wanaque R/Posts Bk (below reservior)	10.80	100.0%	2.21	0.57	1.6399	1.67
02030103100010	Ramapo R (above 74d 11m 00s)	5.81	100.0%	1.00	0.25	0.7557	0.77
02030103100020	Masonicus Brook	4.35	72.6%	0.60	0.12	0.4809	0.36
02030103100030	Ramapo R (above Fyke Bk to 74d 11m 00s)	6.72	85.2%	1.31	0.33	0.9787	0.85
02030103100040	Ramapo R (Bear Swamp Bk thru Fyke Bk)	4.71	100.0%	0.19	0.02	0.1656	0.17
02030103100050	Ramapo R (Crystal Lk br to BearSwamp Bk)	6.31	97.6%	1.25	0.33	0.9183	0.91
02030103100060	Crystal Lake/Pond Brook	8.60	29.7%	2.38	0.67	1.7080	0.52
02030103100070	Ramapo R (below Crystal Lake bridge)	11.28	51.9%	2.02	0.47	1.5466	0.82
02030103110010	Lincoln Park tribs (Pompton River)	13.11	72.7%	1.82	0.21	1.6127	1.20
02030103110020	Pompton River	10.87	22.4%	2.77	0.69	2.0796	0.48
02030103140010	Hohokus Bk (above Godwin Ave)	5.30	32.4%	2.41	1.10	1.3152	0.43
02030103140020	Hohokus Bk(Pennington Ave to Godwin Ave)	9.37	16.0%	2.38	0.60	1.7746	0.29
02030103140040	Saddle River (above Rt 17)	13.63	3.6%	3.82	0.86	2.9538	0.11
02030105010010	Drakes Brook (above Eyland Ave)	9.27	100.0%	2.81	1.00	1.8090	1.85
02030105010020	Drakes Brook (below Eyland Ave)	7.31	100.0%	2.65	1.06	1.5853	1.62
02030105010030	Raritan River SB(above Rt 46)	5.03	100.0%	1.92	0.61	1.3054	1.33
02030105010040	Raritan River SB(74d 44m 15s to Rt 46)	6.66	100.0%	2.54	0.81	1.7297	1.76
02030105010050	Raritan R SB(LongValley br to 74d44m15s)	15.25	100.0%	6.37	2.46	3.9153	3.99
02030105010060	Raritan R SB(Califon br to Long Valley)	14.88	100.0%	4.68	1.47	3.2095	3.27
02030105010070	Raritan R SB(StoneMill gage to Califon)	7.89	100.0%	2.20	0.68	1.5139	1.54
02030105010080	Raritan R SB(Spruce Run-StoneMill gage)	4.62	100.0%	0.90	0.23	0.6672	0.68
02030105020010	Spruce Run (above Glen Gardner)	12.29	100.0%	3.41	1.29	2.1177	2.16
02030105020020	Spruce Run (Reservior to Glen Gardner)	3.21	100.0%	0.65	0.18	0.4705	0.48
02030105020030	Mulhockaway Creek	14.70	100.0%	3.96	1.50	2.4682	2.52
02030105020040	Spruce Run Reservior / Willoughby Brook	12.19	99.4%	2.85	0.76	2.0815	2.11
02030105020050	Beaver Brook (Clinton)	6.93	100.0%	1.66	0.45	1.2085	1.23
02030105020060	Cakepoulin Creek	14.22	32.3%	3.28	1.09	2.1899	0.72
02030105020070	Raritan R SB(River Rd to Spruce Run)	8.22	79.4%	1.89	0.50	1.3953	1.13
02030105020080	Raritan R SB(Prescott Bk to River Rd)	7.37	60.3%	1.76	0.48	1.2800	0.79
02030105020090	Prescott Brook / Round Valley Reservior	11.27	92.4%	2.05	0.48	1.5707	1.48
02030105040020	Pleasant Run	10.80	0.5%	2.78	0.75	2.0274	0.01
02030105040030	Holland Brook	12.44	0.1%	1.64	0.27	1.3701	0.00
02030105050010	Lamington R (above Rt 10)	6.27	100.0%	1.66	0.45	1.2034	1.23

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GROUND WATER CAPACITY
BY HUC14

HUC14	Subwatershed Name	Drainage area, mi2	Percent within Highlands Region	Ground Water Capacity			
				Median Sept Flow (MGD)	7Q10 (MGD)	LFM[1] (MGD)	Adjusted LFM[2] (MGD)
02030105050020	Lamington R (Hillside Rd to Rt 10)	11.03	100.0%	4.43	1.07	3.3611	3.43
02030105050030	Lamington R (Furnace Rd to Hillside Rd)	6.00	100.0%	1.48	0.40	1.0758	1.10
02030105050040	Lamington R(Pottersville gage-FurnaceRd)	8.90	100.0%	3.57	0.86	2.7126	2.77
02030105050050	Pottersville trib (Lamington River)	4.92	100.0%	1.39	0.42	0.9645	0.98
02030105050060	Cold Brook	6.23	100.0%	2.45	1.02	1.4211	1.45
02030105050070	Lamington R(HallsBrRd-Pottersville gage)	13.97	93.6%	4.77	1.51	3.2659	3.12
02030105050080	Rockaway Ck (above McCrea Mills)	16.93	98.6%	5.60	1.64	3.9557	3.98
02030105050090	Rockaway Ck (RockawaySB to McCrea Mills)	5.09	47.1%	1.55	0.46	1.0927	0.52
02030105050100	Rockaway Ck SB	12.35	66.6%	3.43	0.99	2.4415	1.66
02030105050110	Lamington R (below Halls Bridge Rd)	7.55	32.3%	2.38	0.68	1.7005	0.56
02030105060010	Raritan R NB (above/incl India Bk)	6.69	100.0%	1.90	0.33	1.5741	1.61
02030105060020	Burnett Brook (above Old Mill Rd)	6.64	100.0%	2.74	0.98	1.7562	1.79
02030105060030	Raritan R NB(incl McVickers to India Bk)	7.65	100.0%	2.80	0.54	2.2642	2.31
02030105060040	Raritan R NB(Peapack Bk to McVickers Bk)	7.50	100.0%	1.83	0.54	1.2925	1.32
02030105060050	Peapack Brook (above/incl Gladstone Bk)	6.60	100.0%	1.68	0.44	1.2482	1.27
02030105060060	Peapack Brook (below Gladstone Brook)	5.07	100.0%	1.50	0.48	1.0226	1.04
02030105060070	Raritan R NB(incl Mine Bk to Peapack Bk)	8.40	100.0%	2.57	0.75	1.8229	1.86
02030105060080	Middle Brook (NB Raritan River)	6.68	100.0%	2.10	0.64	1.4629	1.49
02030105060090	Raritan R NB (Lamington R to Mine Bk)	8.69	100.0%	2.50	0.70	1.8014	1.84
02030105070010	Raritan R NB (Rt 28 to Lamington R)	9.32	38.3%	2.22	0.57	1.6537	0.65
02030105120050	Middle Brook EB	9.57	2.4%	1.80	0.43	1.3760	0.03
02030105120060	Middle Brook WB	6.54	15.6%	1.07	0.24	0.8328	0.13
02040105040040	Lafayette Swamp tribs	5.51	2.0%	0.96	0.22	0.7403	0.01
02040105040050	Sparta Junction tribs	13.46	70.8%	4.68	1.88	2.7920	2.02
02040105040060	Paulins Kill (above Rt 15)	13.82	0.2%	4.80	1.93	2.8665	0.01
02040105050010	Paulins Kill (Blairstown to Stillwater)	18.95	33.0%	4.37	1.18	3.1927	1.08
02040105060020	Delawanna Creek (incl UDRV)	12.28	19.2%	2.46	0.62	1.8410	0.36
02040105070010	Lake Lenape trib	5.37	24.1%	0.81	0.18	0.6320	0.16
02040105070020	New Wawayanda Lake/Andover Pond trib	11.47	22.6%	2.88	0.51	2.3693	0.55
02040105070030	Pequest River (above Brighton)	13.45	28.3%	3.37	0.59	2.7768	0.80
02040105070040	Pequest River (Trout Brook to Brighton)	8.63	97.8%	2.87	0.87	2.0019	2.00
02040105070050	Trout Brook/Lake Tranquility	9.42	98.3%	1.94	0.50	1.4365	1.44
02040105070060	Pequest R (below Bear Swamp to Trout Bk)	6.30	100.0%	0.73	0.13	0.5964	0.61
02040105080010	Bear Brook (Sussex/Warren Co)	7.52	61.6%	1.65	0.43	1.2174	0.76
02040105080020	Bear Creek	10.79	100.0%	2.32	0.58	1.7402	1.78
02040105090010	Pequest R (Drag Strip--below Bear Swamp)	9.49	100.0%	1.46	0.32	1.1363	1.16
02040105090020	Pequest R (Cemetary Road to Drag Strip)	7.64	100.0%	1.73	0.47	1.2589	1.28
02040105090030	Pequest R (Furnace Bk to Cemetary Road)	8.23	100.0%	2.07	0.60	1.4689	1.50
02040105090040	Mountain Lake Brook	6.05	100.0%	1.09	0.27	0.8166	0.83
02040105090050	Furnace Brook	7.71	100.0%	1.41	0.34	1.0656	1.09
02040105090060	Pequest R (below Furnace Brook)	8.27	100.0%	1.96	0.53	1.4242	1.45
02040105100010	Union Church trib	8.32	100.0%	1.68	0.43	1.2452	1.27
02040105100020	Honey Run	10.31	65.2%	0.46	0.04	0.4180	0.28
02040105100030	Beaver Brook (above Hope Village)	8.98	79.8%	1.98	0.51	1.4666	1.19
02040105100040	Beaver Brook (below Hope Village)	9.06	93.2%	1.79	0.46	1.3311	1.27
02040105110010	Pophandusing Brook	5.62	100.0%	0.37	0.12	0.2461	0.25
02040105110020	Buckhorn Creek (incl UDRV)	14.72	99.8%	3.41	0.93	2.4844	2.53
02040105110030	UDRV tribs (Rt 22 to Buckhorn Ck)	7.87	99.4%	1.63	0.42	1.2144	1.23
02040105120010	Lopatcong Creek (above Rt 57)	7.75	100.0%	3.22	2.14	1.0794	1.10
02040105120020	Lopatcong Creek (below Rt 57) incl UDRV	11.99	99.7%	3.11	0.83	2.2789	2.32
02040105140010	Pohatcong Creek (above Rt 31)	10.08	100.0%	2.13	0.56	1.5675	1.60
02040105140020	Pohatcong Ck (Brass Castle Ck to Rt 31)	12.49	100.0%	2.80	0.75	2.0560	2.10

1 LFM = (Sept. Median Flow) - (7Q10)
2 Adjusted by 1.02 and % Highlands

GROUND WATER CAPACITY
BY HUC14

HUC14	Subwatershed Name	Drainage area, mi2	Percent within Highlands Region	Ground Water Capacity			
				Median Sept Flow (MGD)	7Q10 (MGD)	LFM[1] (MGD)	Adjusted LFM[2] (MGD)
02040105140030	Pohatcong Ck (Edison Rd-Brass Castle Ck)	10.76	100.0%	2.24	0.58	1.6556	1.69
02040105140040	Merrill Creek	5.63	100.0%	2.49	1.30	1.1920	1.22
02040105140050	Pohatcong Ck (Merrill Ck to Edison Rd)	6.95	100.0%	1.28	0.32	0.9659	0.99
02040105140060	Pohatcong Ck (Springtown to Merrill Ck)	6.33	100.0%	1.60	0.43	1.1619	1.19
02040105140070	Pohatcong Ck(below Springtown) incl UDRV	5.86	99.9%	1.02	0.24	0.7773	0.79
02040105150010	Weldon Brook/Beaver Brook	6.44	100.0%	0.40	0.03	0.3719	0.38
02040105150020	Lake Hopatcong	18.88	100.0%	3.46	0.81	2.6529	2.71
02040105150030	Musconetcong R (Wills Bk to LkHopatcong)	5.60	100.0%	0.92	0.20	0.7115	0.73
02040105150040	Lubbers Run (above/incl Dallis Pond)	8.00	100.0%	1.16	0.15	1.0068	1.03
02040105150050	Lubbers Run (below Dallis Pond)	10.07	100.0%	1.66	0.39	1.2703	1.30
02040105150060	Cranberry Lake / Jefferson Lake & tribs	5.24	100.0%	0.67	0.14	0.5288	0.54
02040105150070	Musconetcong R(Waterloo to/incl WillsBk)	6.95	100.0%	1.38	0.34	1.0381	1.06
02040105150080	Musconetcong R (SaxtonFalls to Waterloo)	7.74	100.0%	1.66	0.45	1.2112	1.24
02040105150090	Mine Brook (Morris Co)	4.95	100.0%	0.14	0.01	0.1206	0.12
02040105150100	Musconetcong R (Trout Bk to SaxtonFalls)	7.72	100.0%	2.21	0.67	1.5360	1.57
02040105160010	Musconetcong R (Hances Bk thru Trout Bk)	14.50	100.0%	4.15	1.25	2.8955	2.95
02040105160020	Musconetcong R (Changewater to HancesBk)	17.77	100.0%	5.56	1.76	3.8051	3.88
02040105160030	Musconetcong R (Rt 31 to Changewater)	7.77	100.0%	2.47	0.76	1.7162	1.75
02040105160040	Musconetcong R (75d 00m to Rt 31)	5.10	100.0%	1.37	0.39	0.9760	1.00
02040105160050	Musconetcong R (I-78 to 75d 00m)	14.49	100.0%	3.80	1.09	2.7120	2.77
02040105160060	Musconetcong R (Warren Glen to I-78)	6.76	100.0%	1.27	0.32	0.9483	0.97
02040105160070	Musconetcong R (below Warren Glen)	7.48	100.0%	1.27	0.31	0.9641	0.98
02040105170010	Holland Twp (Hakihokake to Musconetcong)	6.03	99.6%	0.96	0.23	0.7317	0.74
02040105170020	Hakihokake Creek	17.54	100.0%	3.85	1.02	2.8340	2.89
02040105170030	Harihokake Creek (and to Hakihokake Ck)	11.83	100.0%	1.49	0.36	1.1352	1.16
02040105170040	Nishisakawick Creek (above 40d 33m)	6.73	99.2%	1.72	0.46	1.2549	1.27
02040105170050	Nishisakawick Creek (below 40d 33m)	8.49	27.2%	1.65	0.41	1.2455	0.35

1 LFM = (Sept. Median Flow) - (7Q10)
2 Adjusted by 1.02 and % Highlands

Ground Water Availability by HUC14

			Availability Threshold							Ground Water Availability	
Subwatershed Name	**HUC14**	**Ground Water Capacity[1]**	**P**	**C**	**ECZ**	**Watershed Resource Value**	**Zone Designation**	**Ground Water Availability Threshold**	**Ag Ground Availability Threshold**	**Non-Ag Ground Water Availability[1] (MGD)**	**AG GW Availability[1] (MGD)**
Wallkill R/Lake Mohawk(above Sparta Sta)	02020007010010	**1.811**	73.3%	0.0%	26.7%	HIGH	P	5%	--	**0.091**	**0.000**
Wallkill R (Ogdensburg to SpartaStation)	02020007010020	**0.773**	94.8%	0.0%	5.2%	HIGH	P	5%	--	**0.039**	**0.000**
Franklin Pond Creek	02020007010030	**0.794**	92.5%	0.0%	7.5%	HIGH	P	5%	--	**0.040**	**0.000**
Wallkill R(Hamburg SW Bdy to Ogdensburg)	02020007010040	**2.285**	47.8%	32.3%	19.9%	HIGH	P	5%	--	**0.114**	**0.000**
Hardistonville tribs	02020007010050	**0.568**	76.6%	8.5%	14.9%	HIGH	P	5%	--	**0.028**	**0.000**
Beaver Run	02020007010060	**0.246**	39.7%	60.3%	0.0%	HIGH	P	5%	--	**0.012**	**0.000**
Wallkill R(Martins Rd to Hamburg SW Bdy)	02020007010070	**1.209**	44.6%	23.6%	31.8%	HIGH	P	5%	--	**0.060**	**0.000**
Papakating Creek (below Pellettown)	02020007020070	**0.000**	0.0%	100.0%	0.0%	HIGH	C	5%	10%	**0.000**	**0.000**
Wallkill R(41d13m30s to Martins Road)	02020007030010	**0.564**	78.5%	7.7%	13.8%	HIGH	P	5%	--	**0.028**	**0.000**
Wallkill River(Owens gage to 41d13m30s)	02020007030030	**0.306**	80.2%	14.3%	5.5%	HIGH	P	5%	--	**0.015**	**0.000**
Wallkill River(stateline to Owens gage)	02020007030040	**0.315**	51.6%	48.4%	0.0%	HIGH	P	5%	--	**0.016**	**0.000**
Black Ck(above/incl G.Gorge Resort trib)	02020007040010	**0.976**	59.5%	9.7%	30.8%	HIGH	P	5%	--	**0.049**	**0.000**
Black Creek (below G. Gorge Resort trib)	02020007040020	**2.697**	64.1%	18.4%	17.5%	HIGH	P	5%	--	**0.135**	**0.000**
Pochuck Ck/Glenwood Lk & northern trib	02020007040030	**0.653**	65.2%	30.6%	4.2%	HIGH	P	5%	--	**0.033**	**0.000**
Highland Lake/Wawayanda Lake	02020007040040	**0.689**	75.9%	0.0%	24.1%	HIGH	P	5%	--	**0.034**	**0.000**
Wawayanda Creek & tribs	02020007040050	**2.077**	81.9%	13.0%	5.1%	HIGH	P	5%	--	**0.104**	**0.000**
Long House Creek/Upper Greenwood Lake	02020007040060	**1.166**	83.9%	0.0%	16.1%	HIGH	P	5%	--	**0.058**	**0.000**
Passaic R Upr (above Osborn Mills)	02030103010010	**2.218**	52.0%	10.0%	38.0%	HIGH	P	5%	--	**0.111**	**0.000**
Primrose Brook	02030103010020	**1.152**	88.2%	7.3%	4.5%	HIGH	P	5%	--	**0.058**	**0.000**
Great Brook (above Green Village Rd)	02030103010030	**1.262**	25.8%	29.8%	44.4%	LOW	ECZ	20%	--	**0.252**	**0.000**
Loantaka Brook	02030103010040	**0.610**	19.3%	13.1%	67.6%	LOW	ECZ	20%	--	**0.122**	**0.000**
Great Brook (below Green Village Rd)	02030103010050	**0.757**	79.9%	19.6%	0.5%	HIGH	P	5%	--	**0.038**	**0.000**
Black Brook (Great Swamp NWR)	02030103010060	**0.305**	55.9%	44.1%	0.0%	HIGH	P	5%	--	**0.015**	**0.000**
Passaic R Upr (Dead R to Osborn Mills)	02030103010070	**1.014**	26.5%	4.6%	68.9%	LOW	ECZ	20%	--	**0.203**	**0.000**
Dead River (above Harrisons Brook)	02030103010080	**1.436**	56.9%	1.7%	41.5%	LOW	ECZ	20%	--	**0.287**	**0.000**
Harrisons Brook	02030103010090	**0.600**	2.9%	0.0%	97.1%	LOW	ECZ	20%	--	**0.120**	**0.000**
Dead River (below Harrisons Brook)	02030103010100	**0.295**	61.7%	0.0%	38.3%	HIGH	P	5%	--	**0.015**	**0.000**
Passaic R Upr (Plainfield Rd to Dead R)	02030103010110	**0.000**	100.0%	0.0%	0.0%	HIGH	P	5%	--	**0.000**	**0.000**
Passaic R Upr (Pine Bk br to Rockaway)	02030103010180	**0.051**	38.7%	0.0%	61.3%	LOW	ECZ	20%	--	**0.010**	**0.000**
Whippany R (above road at 74d 33m)	02030103020010	**1.309**	56.5%	0.0%	43.5%	HIGH	P	5%	--	**0.065**	**0.000**
Whippany R (Wash. Valley Rd to 74d 33m)	02030103020020	**1.356**	76.1%	0.0%	23.9%	HIGH	P	5%	--	**0.068**	**0.000**
Greystone / Watnong Mtn tribs	02030103020030	**1.887**	0.1%	0.0%	99.9%	LOW	ECZ	20%	--	**0.377**	**0.000**
Whippany R(Lk Pocahontas to Wash Val Rd)	02030103020040	**0.926**	14.4%	0.0%	85.6%	LOW	ECZ	20%	--	**0.185**	**0.000**
Whippany R (Malapardis to Lk Pocahontas)	02030103020050	**1.054**	5.3%	0.0%	94.7%	LOW	ECZ	20%	--	**0.211**	**0.000**
Malapardis Brook	02030103020060	**0.627**	0.0%	0.0%	100.0%	LOW	ECZ	20%	--	**0.125**	**0.000**
Black Brook (Hanover)	02030103020070	**0.684**	31.6%	0.0%	68.4%	LOW	ECZ	20%	--	**0.137**	**0.000**
Troy Brook (above Reynolds Ave)	02030103020080	**1.829**	5.6%	0.0%	94.4%	LOW	ECZ	20%	--	**0.366**	**0.000**
Troy Brook (below Reynolds Ave)	02030103020090	**0.681**	55.4%	0.0%	44.6%	MOD	C	5%	10%	**0.034**	**0.068**
Whippany R (Rockaway R to Malapardis Bk)	02030103020100	**0.326**	22.0%	0.0%	78.0%	LOW	ECZ	20%	--	**0.065**	**0.000**
Russia Brook (above Milton)	02030103030010	**2.321**	85.4%	0.0%	14.6%	HIGH	P	5%	--	**0.116**	**0.000**
Russia Brook (below Milton)	02030103030020	**0.752**	64.9%	0.0%	35.1%	HIGH	P	5%	--	**0.038**	**0.000**
Rockaway R (above Longwood Lake outlet)	02030103030030	**1.037**	67.1%	0.0%	32.9%	HIGH	P	5%	--	**0.052**	**0.000**
Rockaway R (Stephens Bk to Longwood Lk)	02030103030040	**1.081**	93.3%	0.0%	6.7%	HIGH	P	5%	--	**0.054**	**0.000**
Green Pond Brook (above Burnt Meadow Bk)	02030103030050	**1.792**	98.4%	0.0%	1.6%	HIGH	P	5%	--	**0.090**	**0.000**
Green Pond Brook (below Burnt Meadow Bk)	02030103030060	**1.026**	68.5%	0.0%	31.5%	HIGH	P	5%	--	**0.051**	**0.000**
Rockaway R (74d 33m 30s to Stephens Bk)	02030103030070	**1.615**	35.3%	0.0%	64.7%	LOW	ECZ	20%	--	**0.323**	**0.000**
Mill Brook (Morris Co)	02030103030080	**0.792**	0.1%	0.0%	99.9%	LOW	ECZ	20%	--	**0.158**	**0.000**
Rockaway R (BM 534 brdg to 74d 33m 30s)	02030103030090	**1.081**	0.8%	0.0%	99.2%	LOW	ECZ	20%	--	**0.216**	**0.000**
Hibernia Brook	02030103030100	**1.272**	89.5%	0.0%	10.5%	HIGH	P	5%	--	**0.064**	**0.000**

[1] Indicates value is adjusted to % area within Highlands Region

Ground Water Availability by HUC14

Subwatershed Name	HUC14	Ground Water Capacity[1]	P	C	ECZ	Watershed Resource Value	Zone Designation	Ground Water Availability Threshold	Ag Ground Availability Threshold	Non-Ag Ground Water Availability[1] (MGD)	AG GW Availability[1] (MGD)
			Availability Threshold							Ground Water Availability	
Beaver Brook (Morris County)	02030103030110	**2.403**	79.6%	0.0%	20.4%	HIGH	P	5%	--	**0.120**	**0.000**
Den Brook	02030103030120	**1.508**	0.0%	0.0%	100.0%	LOW	ECZ	20%	--	**0.302**	**0.000**
Stony Brook (Boonton)	02030103030130	**1.458**	88.7%	0.0%	11.3%	HIGH	P	5%	--	**0.073**	**0.000**
Rockaway R (Stony Brook to BM 534 brdg)	02030103030140	**0.836**	24.1%	0.0%	75.9%	MOD	ECZ	20%	--	**0.167**	**0.000**
Rockaway R (Boonton dam to Stony Brook)	02030103030150	**0.907**	26.6%	0.0%	73.4%	LOW	ECZ	20%	--	**0.181**	**0.000**
Montville tribs.	02030103030160	**1.640**	42.7%	0.0%	57.3%	HIGH	P	5%	--	**0.082**	**0.000**
Rockaway R (Passaic R to Boonton dam)	02030103030170	**1.357**	2.7%	0.0%	97.3%	LOW	ECZ	20%	--	**0.271**	**0.000**
Passaic R Upr (Pompton R to Pine Bk)	02030103040010	**0.455**	36.2%	0.0%	63.8%	HIGH	P	5%	--	**0.023**	**0.000**
Pequannock R (above Stockholm/Vernon Rd)	02030103050010	**0.623**	100.0%	0.0%	0.0%	HIGH	P	5%	--	**0.031**	**0.000**
Pacock Brook	02030103050020	**0.960**	99.8%	0.0%	0.2%	HIGH	P	5%	--	**0.048**	**0.000**
Pequannock R (above OakRidge Res outlet)	02030103050030	**1.585**	97.2%	0.0%	2.8%	HIGH	P	5%	--	**0.079**	**0.000**
Clinton Reservior/Mossmans Brook	02030103050040	**2.137**	99.2%	0.0%	0.8%	HIGH	P	5%	--	**0.107**	**0.000**
Pequannock R (Charlotteburg to OakRidge)	02030103050050	**3.669**	94.8%	0.0%	5.2%	HIGH	P	5%	--	**0.183**	**0.000**
Pequannock R(Macopin gage to Charl'brg)	02030103050060	**1.130**	94.8%	0.0%	5.2%	HIGH	P	5%	--	**0.056**	**0.000**
Stone House Brook	02030103050070	**1.034**	75.8%	0.0%	24.2%	HIGH	P	5%	--	**0.052**	**0.000**
Pequannock R (below Macopin gage)	02030103050080	**2.652**	59.4%	0.0%	40.6%	HIGH	P	5%	--	**0.133**	**0.000**
Belcher Creek (above Pinecliff Lake)	02030103070010	**0.759**	78.2%	0.0%	21.8%	HIGH	P	5%	--	**0.038**	**0.000**
Belcher Creek (Pinecliff Lake & below)	02030103070020	**1.298**	85.2%	0.0%	14.8%	HIGH	P	5%	--	**0.065**	**0.000**
Wanaque R/Greenwood Lk(aboveMonks gage)	02030103070030	**2.143**	95.1%	0.0%	4.9%	HIGH	P	5%	--	**0.107**	**0.000**
West Brook/Burnt Meadow Brook	02030103070040	**1.583**	93.8%	0.0%	6.2%	HIGH	P	5%	--	**0.079**	**0.000**
Wanaque Reservior (below Monks gage)	02030103070050	**3.208**	91.8%	0.0%	8.2%	HIGH	P	5%	--	**0.160**	**0.000**
Meadow Brook/High Mountain Brook	02030103070060	**0.772**	60.1%	0.0%	39.9%	HIGH	P	5%	--	**0.039**	**0.000**
Wanaque R/Posts Bk (below reservior)	02030103070070	**1.673**	78.2%	0.0%	21.8%	HIGH	P	5%	--	**0.084**	**0.000**
Ramapo R (above 74d 11m 00s)	02030103100010	**0.771**	72.1%	0.0%	27.9%	HIGH	P	5%	--	**0.039**	**0.000**
Masonicus Brook	02030103100020	**0.356**	0.0%	0.0%	100.0%	LOW	ECZ	20%	--	**0.071**	**0.000**
Ramapo R (above Fyke Bk to 74d 11m 00s)	02030103100030	**0.850**	62.8%	0.0%	37.2%	HIGH	P	5%	--	**0.043**	**0.000**
Ramapo R (Bear Swamp Bk thru Fyke Bk)	02030103100040	**0.169**	91.5%	0.0%	8.5%	HIGH	P	5%	--	**0.008**	**0.000**
Ramapo R (Crystal Lk br to BearSwamp Bk)	02030103100050	**0.914**	81.5%	0.0%	18.5%	HIGH	P	5%	--	**0.046**	**0.000**
Crystal Lake/Pond Brook	02030103100060	**0.517**	11.0%	0.0%	89.0%	LOW	ECZ	20%	--	**0.103**	**0.000**
Ramapo R (below Crystal Lake bridge)	02030103100070	**0.819**	56.2%	0.0%	43.8%	HIGH	P	5%	--	**0.041**	**0.000**
Lincoln Park tribs (Pompton River)	02030103110010	**1.197**	42.9%	0.0%	57.1%	HIGH	P	5%	--	**0.060**	**0.000**
Pompton River	02030103110020	**0.475**	10.1%	0.0%	89.9%	LOW	ECZ	20%	--	**0.095**	**0.000**
Hohokus Bk (above Godwin Ave)	02030103140010	**0.435**	22.1%	0.0%	77.9%	LOW	ECZ	20%	--	**0.087**	**0.000**
Hohokus Bk(Pennington Ave to Godwin Ave)	02030103140020	**0.290**	0.0%	0.0%	100.0%	LOW	ECZ	20%	--	**0.058**	**0.000**
Saddle River (above Rt 17)	02030103140040	**0.108**	0.0%	0.0%	100.0%	LOW	ECZ	20%	--	**0.022**	**0.000**
Drakes Brook (above Eyland Ave)	02030105010010	**1.845**	55.8%	0.0%	44.2%	HIGH	P	5%	--	**0.092**	**0.000**
Drakes Brook (below Eyland Ave)	02030105010020	**1.617**	43.1%	0.0%	56.9%	LOW	ECZ	20%	--	**0.323**	**0.000**
Raritan River SB(above Rt 46)	02030105010030	**1.331**	51.3%	1.1%	47.6%	HIGH	P	5%	--	**0.067**	**0.000**
Raritan River SB(74d 44m 15s to Rt 46)	02030105010040	**1.764**	52.8%	22.3%	24.9%	HIGH	P	5%	--	**0.088**	**0.000**
Raritan R SB(LongValley br to 74d44m15s)	02030105010050	**3.994**	57.7%	19.4%	22.9%	HIGH	P	5%	--	**0.200**	**0.000**
Raritan R SB(Califon br to Long Valley)	02030105010060	**3.274**	57.0%	41.0%	2.1%	HIGH	P	5%	--	**0.164**	**0.000**
Raritan R SB(StoneMill gage to Califon)	02030105010070	**1.544**	70.6%	15.2%	14.1%	HIGH	P	5%	--	**0.077**	**0.000**
Raritan R SB(Spruce Run-StoneMill gage)	02030105010080	**0.681**	15.7%	0.0%	84.3%	LOW	ECZ	20%	--	**0.136**	**0.000**
Spruce Run (above Glen Gardner)	02030105020010	**2.160**	60.7%	33.1%	6.3%	HIGH	P	5%	--	**0.108**	**0.000**
Spruce Run (Reservior to Glen Gardner)	02030105020020	**0.480**	70.0%	27.0%	3.0%	HIGH	P	5%	--	**0.024**	**0.000**
Mulhockaway Creek	02030105020030	**2.518**	55.9%	43.8%	0.3%	HIGH	P	5%	--	**0.126**	**0.000**
Spruce Run Reservior / Willoughby Brook	02030105020040	**2.111**	75.9%	12.2%	11.9%	HIGH	P	5%	--	**0.106**	**0.000**
Beaver Brook (Clinton)	02030105020050	**1.233**	25.5%	46.6%	28.0%	MOD	C	5%	10%	**0.062**	**0.123**

[1] Indicates value is adjusted to % area within Highlands Region

Ground Water Availability by HUC14

			Availability Threshold							Ground Water Availability	
Subwatershed Name	**HUC14**	**Ground Water Capacity[1]**	**P**	**C**	**ECZ**	**Watershed Resource Value**	**Zone Designation**	**Ground Water Availability Threshold**	**Ag Ground Availability Threshold**	**Non-Ag Ground Water Availability[1] (MGD)**	**AG GW Availability[1] (MGD)**
Cakepoulin Creek	02030105020060	**0.721**	0.0%	100.0%	0.0%	MOD	C	5%	10%	**0.036**	**0.072**
Raritan R SB(River Rd to Spruce Run)	02030105020070	**1.130**	26.0%	50.6%	23.5%	LOW	ECZ	20%	--	**0.226**	**0.000**
Raritan R SB(Prescott Bk to River Rd)	02030105020080	**0.788**	25.2%	42.7%	32.1%	LOW	ECZ	20%	--	**0.158**	**0.000**
Prescott Brook / Round Valley Reservior	02030105020090	**1.480**	80.4%	18.1%	1.5%	MOD	P	5%	--	**0.074**	**0.000**
Pleasant Run	02030105040020	**0.010**	30.5%	69.5%	0.0%	MOD	C	5%	10%	**0.001**	**0.001**
Holland Brook	02030105040030	**0.002**	100.0%	0.0%	0.0%	HIGH	P	5%	--	**0.000**	**0.000**
Lamington R (above Rt 10)	02030105050010	**1.227**	43.0%	0.0%	57.0%	LOW	ECZ	20%	--	**0.245**	**0.000**
Lamington R (Hillside Rd to Rt 10)	02030105050020	**3.428**	61.8%	0.0%	38.2%	HIGH	P	5%	--	**0.171**	**0.000**
Lamington R (Furnace Rd to Hillside Rd)	02030105050030	**1.097**	68.7%	10.8%	20.5%	MOD	C	5%	10%	**0.055**	**0.110**
Lamington R(Pottersville gage-FurnaceRd)	02030105050040	**2.767**	52.9%	34.7%	12.4%	HIGH	P	5%	--	**0.138**	**0.000**
Pottersville trib (Lamington River)	02030105050050	**0.984**	73.9%	25.0%	1.1%	HIGH	P	5%	--	**0.049**	**0.000**
Cold Brook	02030105050060	**1.450**	18.5%	79.2%	2.3%	MOD	C	5%	10%	**0.072**	**0.145**
Lamington R(HallsBrRd-Pottersville gage)	02030105050070	**3.117**	19.7%	77.6%	2.7%	HIGH	C	5%	10%	**0.156**	**0.312**
Rockaway Ck (above McCrea Mills)	02030105050080	**3.979**	42.8%	56.6%	0.6%	MOD	C	5%	10%	**0.199**	**0.398**
Rockaway Ck (RockawaySB to McCrea Mills)	02030105050090	**0.524**	60.7%	25.8%	13.5%	HIGH	P	5%	--	**0.026**	**0.000**
Rockaway Ck SB	02030105050100	**1.658**	31.7%	42.5%	25.8%	LOW	ECZ	20%	--	**0.332**	**0.000**
Lamington R (below Halls Bridge Rd)	02030105050110	**0.560**	47.2%	52.8%	0.0%	HIGH	P	5%	--	**0.028**	**0.000**
Raritan R NB (above/incl India Bk)	02030105060010	**1.606**	46.2%	0.0%	53.8%	MOD	C	5%	10%	**0.080**	**0.161**
Burnett Brook (above Old Mill Rd)	02030105060020	**1.791**	67.3%	0.0%	32.7%	MOD	C	5%	10%	**0.090**	**0.179**
Raritan R NB(incl McVickers to India Bk)	02030105060030	**2.309**	63.7%	13.9%	22.3%	HIGH	P	5%	--	**0.115**	**0.000**
Raritan R NB(Peapack Bk to McVickers Bk)	02030105060040	**1.318**	56.8%	40.9%	2.3%	HIGH	P	5%	--	**0.066**	**0.000**
Peapack Brook (above/incl Gladstone Bk)	02030105060050	**1.273**	56.6%	24.2%	19.2%	HIGH	P	5%	--	**0.064**	**0.000**
Peapack Brook (below Gladstone Brook)	02030105060060	**1.043**	28.0%	31.0%	40.9%	MOD	C	5%	10%	**0.052**	**0.104**
Raritan R NB(incl Mine Bk to Peapack Bk)	02030105060070	**1.859**	52.7%	15.0%	32.3%	LOW	ECZ	20%	--	**0.372**	**0.000**
Middle Brook (NB Raritan River)	02030105060080	**1.492**	6.8%	93.2%	0.0%	MOD	C	5%	10%	**0.075**	**0.149**
Raritan R NB (Lamington R to Mine Bk)	02030105060090	**1.837**	22.0%	56.3%	21.6%	MOD	C	5%	10%	**0.092**	**0.184**
Raritan R NB (Rt 28 to Lamington R)	02030105070010	**0.646**	43.3%	37.2%	19.5%	MOD	C	5%	10%	**0.032**	**0.065**
Middle Brook EB	02030105120050	**0.034**	54.9%	0.0%	45.1%	LOW	ECZ	20%	--	**0.007**	**0.000**
Middle Brook WB	02030105120060	**0.133**	94.8%	0.0%	5.2%	HIGH	P	5%	--	**0.007**	**0.000**
Lafayette Swamp tribs	02040105040040	**0.015**	39.0%	61.0%	0.0%	HIGH	P	5%	--	**0.001**	**0.000**
Sparta Junction tribs	02040105040050	**2.015**	77.4%	16.8%	5.8%	HIGH	P	5%	--	**0.101**	**0.000**
Paulins Kill (above Rt 15)	02040105040060	**0.006**	0.0%	100.0%	0.0%	MOD	C	5%	10%	**0.000**	**0.001**
Paulins Kill (Blairstown to Stillwater)	02040105050010	**1.076**	40.6%	59.4%	0.0%	HIGH	P	5%	--	**0.054**	**0.000**
Delawanna Creek (incl UDRV)	02040105060020	**0.361**	73.9%	23.4%	2.7%	HIGH	P	5%	--	**0.018**	**0.000**
Lake Lenape trib	02040105070010	**0.155**	61.2%	0.0%	38.8%	HIGH	P	5%	--	**0.008**	**0.000**
New Wawayanda Lake/Andover Pond trib	02040105070020	**0.545**	81.7%	1.3%	17.0%	HIGH	P	5%	--	**0.027**	**0.000**
Pequest River (above Brighton)	02040105070030	**0.802**	58.7%	41.3%	0.0%	HIGH	P	5%	--	**0.040**	**0.000**
Pequest River (Trout Brook to Brighton)	02040105070040	**1.996**	27.1%	66.6%	6.3%	MOD	C	5%	10%	**0.100**	**0.200**
Trout Brook/Lake Tranquility	02040105070050	**1.440**	58.4%	35.4%	6.2%	HIGH	P	5%	--	**0.072**	**0.000**
Pequest R (below Bear Swamp to Trout Bk)	02040105070060	**0.608**	52.2%	35.1%	12.8%	HIGH	P	5%	--	**0.030**	**0.000**
Bear Brook (Sussex/Warren Co)	02040105080010	**0.764**	15.9%	84.1%	0.0%	HIGH	C	5%	10%	**0.038**	**0.076**
Bear Creek	02040105080020	**1.775**	41.7%	58.3%	0.0%	HIGH	P	5%	--	**0.089**	**0.000**
Pequest R (Drag Strip--below Bear Swamp)	02040105090010	**1.159**	57.7%	42.3%	0.0%	HIGH	P	5%	--	**0.058**	**0.000**
Pequest R (Cemetary Road to Drag Strip)	02040105090020	**1.284**	51.9%	48.1%	0.0%	HIGH	P	5%	--	**0.064**	**0.000**
Pequest R (Furnace Bk to Cemetary Road)	02040105090030	**1.498**	81.3%	18.4%	0.3%	HIGH	P	5%	--	**0.075**	**0.000**
Mountain Lake Brook	02040105090040	**0.833**	89.8%	7.7%	2.5%	HIGH	P	5%	--	**0.042**	**0.000**
Furnace Brook	02040105090050	**1.087**	68.6%	19.1%	12.3%	HIGH	P	5%	--	**0.054**	**0.000**
Pequest R (below Furnace Brook)	02040105090060	**1.452**	39.7%	44.1%	16.1%	HIGH	P	5%	--	**0.073**	**0.000**

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Ground Water Availability by HUC14

			Availability Threshold							Ground Water Availability	
Subwatershed Name	**HUC14**	**Ground Water Capacity[1]**	**P**	**C**	**ECZ**	**Watershed Resource Value**	**Zone Designation**	**Ground Water Availability Threshold**	**Ag Ground Availability Threshold**	**Non-Ag Ground Water Availability[1] (MGD)**	**AG GW Availability[1] (MGD)**
Union Church trib	02040105100010	**1.270**	53.9%	46.1%	0.0%	HIGH	P	5%	--	**0.064**	**0.000**
Honey Run	02040105100020	**0.278**	33.8%	66.2%	0.0%	HIGH	P	5%	--	**0.014**	**0.000**
Beaver Brook (above Hope Village)	02040105100030	**1.193**	42.7%	57.3%	0.0%	HIGH	P	5%	--	**0.060**	**0.000**
Beaver Brook (below Hope Village)	02040105100040	**1.265**	30.5%	69.5%	0.0%	HIGH	P	5%	--	**0.063**	**0.000**
Pophandusing Brook	02040105110010	**0.251**	28.2%	53.2%	18.7%	MOD	C	5%	10%	**0.013**	**0.025**
Buckhorn Creek (incl UDRV)	02040105110020	**2.529**	37.8%	58.3%	3.9%	MOD	C	5%	10%	**0.126**	**0.253**
UDRV tribs (Rt 22 to Buckhorn Ck)	02040105110030	**1.231**	21.8%	62.8%	15.4%	MOD	C	5%	10%	**0.062**	**0.123**
Lopatcong Creek (above Rt 57)	02040105120010	**1.101**	44.9%	35.6%	19.6%	HIGH	P	5%	--	**0.055**	**0.000**
Lopatcong Creek (below Rt 57) incl UDRV	02040105120020	**2.318**	6.8%	45.3%	47.9%	LOW	ECZ	20%	--	**0.464**	**0.000**
Pohatcong Creek (above Rt 31)	02040105140010	**1.599**	77.5%	21.3%	1.2%	HIGH	P	5%	--	**0.080**	**0.000**
Pohatcong Ck (Brass Castle Ck to Rt 31)	02040105140020	**2.097**	48.7%	19.5%	31.8%	HIGH	P	5%	--	**0.105**	**0.000**
Pohatcong Ck (Edison Rd-Brass Castle Ck)	02040105140030	**1.689**	26.3%	68.3%	5.4%	MOD	C	5%	10%	**0.084**	**0.169**
Merrill Creek	02040105140040	**1.216**	63.3%	30.2%	6.5%	HIGH	P	5%	--	**0.061**	**0.000**
Pohatcong Ck (Merrill Ck to Edison Rd)	02040105140050	**0.985**	21.5%	75.7%	2.8%	MOD	C	5%	10%	**0.049**	**0.099**
Pohatcong Ck (Springtown to Merrill Ck)	02040105140060	**1.185**	5.4%	80.8%	13.8%	MOD	C	5%	10%	**0.059**	**0.119**
Pohatcong Ck(below Springtown) incl UDRV	02040105140070	**0.792**	21.2%	66.3%	12.5%	MOD	C	5%	10%	**0.040**	**0.079**
Weldon Brook/Beaver Brook	02040105150010	**0.379**	99.4%	0.0%	0.6%	HIGH	P	5%	--	**0.019**	**0.000**
Lake Hopatcong	02040105150020	**2.706**	39.1%	0.0%	60.9%	LOW	ECZ	20%	--	**0.541**	**0.000**
Musconetcong R (Wills Bk to LkHopatcong)	02040105150030	**0.726**	35.3%	0.0%	64.7%	LOW	ECZ	20%	--	**0.145**	**0.000**
Lubbers Run (above/incl Dallis Pond)	02040105150040	**1.027**	85.8%	0.0%	14.2%	HIGH	P	5%	--	**0.051**	**0.000**
Lubbers Run (below Dallis Pond)	02040105150050	**1.296**	88.0%	0.0%	12.0%	HIGH	P	5%	--	**0.065**	**0.000**
Cranberry Lake / Jefferson Lake & tribs	02040105150060	**0.539**	97.1%	0.0%	2.9%	HIGH	P	5%	--	**0.027**	**0.000**
Musconetcong R(Waterloo to/incl WillsBk)	02040105150070	**1.059**	55.5%	0.0%	44.5%	HIGH	P	5%	--	**0.053**	**0.000**
Musconetcong R (SaxtonFalls to Waterloo)	02040105150080	**1.235**	99.7%	0.0%	0.3%	HIGH	P	5%	--	**0.062**	**0.000**
Mine Brook (Morris Co)	02040105150090	**0.123**	51.3%	14.3%	34.5%	HIGH	P	5%	--	**0.006**	**0.000**
Musconetcong R (Trout Bk to SaxtonFalls)	02040105150100	**1.567**	68.5%	0.0%	31.5%	HIGH	P	5%	--	**0.078**	**0.000**
Musconetcong R (Hances Bk thru Trout Bk)	02040105160010	**2.953**	51.3%	26.1%	22.6%	HIGH	P	5%	--	**0.148**	**0.000**
Musconetcong R (Changewater to HancesBk)	02040105160020	**3.881**	58.8%	39.8%	1.4%	HIGH	P	5%	--	**0.194**	**0.000**
Musconetcong R (Rt 31 to Changewater)	02040105160030	**1.751**	25.7%	52.4%	21.9%	MOD	C	5%	10%	**0.088**	**0.175**
Musconetcong R (75d 00m to Rt 31)	02040105160040	**0.995**	30.0%	55.1%	14.9%	MOD	C	5%	10%	**0.050**	**0.100**
Musconetcong R (I-78 to 75d 00m)	02040105160050	**2.766**	38.4%	61.6%	0.0%	MOD	C	5%	10%	**0.138**	**0.277**
Musconetcong R (Warren Glen to I-78)	02040105160060	**0.967**	50.2%	40.6%	9.2%	HIGH	P	5%	--	**0.048**	**0.000**
Musconetcong R (below Warren Glen)	02040105160070	**0.983**	40.5%	58.4%	1.0%	HIGH	P	5%	--	**0.049**	**0.000**
Holland Twp (Hakihokake to Musconetcong)	02040105170010	**0.744**	63.8%	33.6%	2.7%	HIGH	P	5%	--	**0.037**	**0.000**
Hakihokake Creek	02040105170020	**2.891**	36.4%	54.0%	9.6%	HIGH	P	5%	--	**0.145**	**0.000**
Harihokake Creek (and to Hakihokake Ck)	02040105170030	**1.158**	17.4%	80.4%	2.2%	MOD	C	5%	10%	**0.058**	**0.116**
Nishisakawick Creek (above 40d 33m)	02040105170040	**1.269**	3.9%	96.1%	0.0%	MOD	C	5%	10%	**0.063**	**0.127**
Nishisakawick Creek (below 40d 33m)	02040105170050	**0.345**	4.0%	96.0%	0.0%	MOD	C	5%	10%	**0.017**	**0.035**

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Net Water Availability by HUC14

Subwatershed Name	HUC14	Ground Water Capacity[1] (MGD)	Ag Net Water Availability			Net Water Availability (non-ag)			Water Availability Constraints	
			AG GW Availability[1] (MGD)	AG Cons. Use - (MGD)	AG Net Availability[1] (MGD)	Non-Ag Ground Water Avail.[1] (MGD)	Total Max Month C/D Use[1]- (MGD)	Net Water Availability[1] (MGD)	Current Deficit Area	Existing Constrained Area[2]
Wallkill R/Lake Mohawk(above Sparta Sta)	02020007010010	1.8112	-	-		0.091	0.8176	(0.7270)	Y	--
Wallkill R (Ogdensburg to SpartaStation)	02020007010020	0.7733	-	-		0.039	0.3243	(0.2857)	Y	--
Franklin Pond Creek	02020007010030	0.7942	-	-		0.040	0.0890	(0.0493)	Y	--
Wallkill R(Hamburg SW Bdy to Ogdensburg)	02020007010040	2.2850	-	-		0.114	0.8683	(0.7540)	Y	--
Hardistonville tribs	02020007010050	0.5678	-	-		0.028	0.2563	(0.2279)	Y	--
Beaver Run	02020007010060	0.2457	-	-		0.012	0.0045	0.0078	--	Y
Wallkill R(Martins Rd to Hamburg SW Bdy)	02020007010070	1.2091	-	-		0.060	0.7800	(0.7195)	Y	--
Papakating Creek (below Pellettown)	02020007020070	0.0000	0.000	0.0000	0.0000	0.000	0.0000	0.0000	--	Y
Wallkill R(41d13m30s to Martins Road)	02020007030010	0.5639	-	-		0.028	0.0687	(0.0405)	Y	--
Wallkill River(Owens gage to 41d13m30s)	02020007030030	0.3063	-	-		0.015	0.0190	(0.0037)	Y	--
Wallkill River(stateline to Owens gage)	02020007030040	0.3155	-	-		0.016	0.0181	(0.0023)	Y	--
Black Ck(above/incl G.Gorge Resort trib)	02020007040010	0.9765	-	-		0.049	0.5455	(0.4967)	Y	--
Black Creek (below G. Gorge Resort trib)	02020007040020	2.6968	-	-		0.135	0.3110	(0.1762)	Y	--
Pochuck Ck/Glenwood Lk & northern trib	02020007040030	0.6533	-	-		0.033	0.0382	(0.0055)	Y	--
Highland Lake/Wawayanda Lake	02020007040040	0.6889	-	-		0.034	0.0376	(0.0031)	Y	--
Wawayanda Creek & tribs	02020007040050	2.0770	-	-		0.104	0.0978	0.0061	--	Y
Long House Creek/Upper Greenwood Lake	02020007040060	1.1663	-	-		0.058	0.0488	0.0095	--	Y
Passaic R Upr (above Osborn Mills)	02030103010010	2.2177	-	-		0.111	0.6888	(0.5779)	Y	--
Primrose Brook	02030103010020	1.1520	-	-		0.058	0.0631	(0.0055)	Y	--
Great Brook (above Green Village Rd)	02030103010030	1.2621	-	-		0.252	1.1941	(0.9417)	Y	--
Loantaka Brook	02030103010040	0.6098	-	-		0.122	0.7564	(0.6345)	Y	--
Great Brook (below Green Village Rd)	02030103010050	0.7572	-	-		0.038	0.0194	0.0185	--	--
Black Brook (Great Swamp NWR)	02030103010060	0.3049	-	-		0.015	0.0204	(0.0052)	Y	--
Passaic R Upr (Dead R to Osborn Mills)	02030103010070	1.0137	-	-		0.203	0.0431	0.1597	--	--
Dead River (above Harrisons Brook)	02030103010080	1.4357	-	-		0.287	0.0226	0.2645	--	--
Harrisons Brook	02030103010090	0.5997	-	-		0.120	0.0112	0.1088	--	--
Dead River (below Harrisons Brook)	02030103010100	0.2950	-	-		0.015	0.0099	0.0048	--	--
Passaic R Upr (Plainfield Rd to Dead R)	02030103010110	0.0000	-	-		0.000	0.0000	0.0000	--	--
Passaic R Upr (Pine Bk br to Rockaway)	02030103010180	0.0513	-	-		0.010	0.0906	(0.0803)	Y	--
Whippany R (above road at 74d 33m)	02030103020010	1.3090	-	-		0.065	0.0279	0.0376	--	Y
Whippany R (Wash. Valley Rd to 74d 33m)	02030103020020	1.3562	-	-		0.068	0.0131	0.0547	--	Y
Greystone / Watnong Mtn tribs	02030103020030	1.8874	-	-		0.377	0.0036	0.0944	--	Y
Whippany R(Lk Pocahontas to Wash Val Rd)	02030103020040	0.9261	-	-		0.185	0.1110	0.0463	--	Y
Whippany R (Malapardis to Lk Pocahontas)	02030103020050	1.0544	-	-		0.211	0.0419	0.0527	--	Y
Malapardis Brook	02030103020060	0.6271	-	-		0.125	5.9221	(5.7967)	Y	--
Black Brook (Hanover)	02030103020070	0.6843	-	-		0.137	1.4454	(1.3085)	Y	--
Troy Brook (above Reynolds Ave)	02030103020080	1.8286	-	-		0.366	7.4743	(7.1086)	Y	--

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Net Water Availability by HUC14

Subwatershed Name	HUC14	Ground Water Capacity[1] (MGD)	Ag Net Water Availability			Net Water Availability (non-ag)			Water Availability Constraints	
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Troy Brook (below Reynolds Ave)	02030103020090	0.6813	0.068	0.0000	0.0681	0.034	1.8027	(1.7686)	Y	--
Whippany R (Rockaway R to Malapardis Bk)	02030103020100	0.3263	-	-		0.065	0.2932	(0.2279)	Y	--
Russia Brook (above Milton)	02030103030010	2.3210	-	-		0.116	0.3080	(0.1919)	Y	--
Russia Brook (below Milton)	02030103030020	0.7516	-	-		0.038	0.1189	(0.0813)	Y	--
Rockaway R (above Longwood Lake outlet)	02030103030030	1.0369	-	-		0.052	0.3657	(0.3139)	Y	--
Rockaway R (Stephens Bk to Longwood Lk)	02030103030040	1.0808	-	-		0.054	0.0647	(0.0107)	Y	--
Green Pond Brook (above Burnt Meadow Bk)	02030103030050	1.7922	-	-		0.090	0.0254	0.0642	--	Y
Green Pond Brook (below Burnt Meadow Bk)	02030103030060	1.0256	-	-		0.051	0.7587	(0.7075)	Y	--
Rockaway R (74d 33m 30s to Stephens Bk)	02030103030070	1.6148	-	-		0.323	4.3815	(4.0586)	Y	--
Mill Brook (Morris Co)	02030103030080	0.7925	-	-		0.158	0.0354	0.0396	--	Y
Rockaway R (BM 534 brdg to 74d 33m 30s)	02030103030090	1.0810	-	-		0.216	1.1617	(0.9455)	Y	--
Hibernia Brook	02030103030100	1.2721	-	-		0.064	0.0268	0.0368	--	Y
Beaver Brook (Morris County)	02030103030110	2.4029	-	-		0.120	2.6197	(2.4996)	Y	--
Den Brook	02030103030120	1.5077	-	-		0.302	0.0275	0.0754	--	Y
Stony Brook (Boonton)	02030103030130	1.4585	-	-		0.073	0.2447	(0.1718)	Y	--
Rockaway R (Stony Brook to BM 534 brdg)	02030103030140	0.8356	-	-		0.167	2.2522	(2.0851)	Y	--
Rockaway R (Boonton dam to Stony Brook)	02030103030150	0.9074	-	-		0.181	0.0212	0.0454	--	Y
Montville tribs.	02030103030160	1.6402	-	-		0.082	0.0841	(0.0021)	Y	--
Rockaway R (Passaic R to Boonton dam)	02030103030170	1.3573	-	-		0.271	0.0285	0.0679	--	Y
Passaic R Upr (Pompton R to Pine Bk)	02030103040010	0.4546	-	-		0.023	0.0463	(0.0235)	Y	--
Pequannock R (above Stockholm/Vernon Rd)	02030103050010	0.6235	-	-		0.031	0.0301	0.0010	--	Y
Pacock Brook	02030103050020	0.9600	-	-		0.048	0.0425	0.0055	--	Y
Pequannock R (above OakRidge Res outlet)	02030103050030	1.5853	-	-		0.079	0.0513	0.0279	--	Y
Clinton Reservior/Mossmans Brook	02030103050040	2.1373	-	-		0.107	0.0811	0.0258	--	Y
Pequannock R (Charlotteburg to OakRidge)	02030103050050	3.6690	-	-		0.183	0.3604	(0.1769)	Y	--
Pequannock R(Macopin gage to Charl'brg)	02030103050060	1.1297	-	-		0.056	0.0580	(0.0015)	Y	--
Stone House Brook	02030103050070	1.0341	-	-		0.052	0.5217	(0.4700)	Y	--
Pequannock R (below Macopin gage)	02030103050080	2.6525	-	-		0.133	1.7820	(1.6494)	Y	--
Belcher Creek (above Pinecliff Lake)	02030103070010	0.7595	-	-		0.038	0.1965	(0.1585)	Y	--
Belcher Creek (Pinecliff Lake & below)	02030103070020	1.2982	-	-		0.065	0.1780	(0.1131)	Y	--
Wanaque R/Greenwood Lk(aboveMonks gage)	02030103070030	2.1429	-	-		0.107	0.1217	(0.0146)	Y	--
West Brook/Burnt Meadow Brook	02030103070040	1.5835	-	-		0.079	0.0856	(0.0064)	Y	--
Wanaque Reservior (below Monks gage)	02030103070050	3.2083	-	-		0.160	0.3492	(0.1888)	Y	--
Meadow Brook/High Mountain Brook	02030103070060	0.7716	-	-		0.039	0.6814	(0.6428)	Y	--
Wanaque R/Posts Bk (below reservior)	02030103070070	1.6727	-	-		0.084	0.4380	(0.3543)	Y	--
Ramapo R (above 74d 11m 00s)	02030103100010	0.7708	-	-		0.039	1.7370	(1.6985)	Y	--
Masonicus Brook	02030103100020	0.3561	-	-		0.071	0.5233	(0.4521)	Y	--

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Subwatershed Name	HUC14	Ground Water Capacity[1] (MGD)	AG GW Availability[1] (MGD)	AG Cons. Use (MGD)	AG Net Availability[1] (MGD)	Non-Ag Ground Water Avail.[1] (MGD)	Total Max Month C/D Use[1] - (MGD)	Net Water Availability[1] (MGD)	Current Deficit Area	Existing Constrained Area[2]
Ramapo R (above Fyke Bk to 74d 11m 00s)	02030103100030	0.8504	-	-		0.043	2.7781	(2.7356)	Y	--
Ramapo R (Bear Swamp Bk thru Fyke Bk)	02030103100040	0.1689	-	-		0.008	0.0119	(0.0034)	Y	--
Ramapo R (Crystal Lk br to BearSwamp Bk)	02030103100050	0.9139	-	-		0.046	3.0268	(2.9811)	Y	--
Crystal Lake/Pond Brook	02030103100060	0.5172	-	-		0.103	0.4392	(0.3357)	Y	--
Ramapo R (below Crystal Lake bridge)	02030103100070	0.8189	-	-		0.041	0.1746	(0.1337)	Y	--
Lincoln Park tribs (Pompton River)	02030103110010	1.1967	-	-		0.060	2.4322	(2.3724)	Y	--
Pompton River	02030103110020	0.4753	-	-		0.095	0.0256	0.0695	--	--
Hohokus Bk (above Godwin Ave)	02030103140010	0.4349	-	-		0.087	0.0807	0.0063	--	Y
Hohokus Bk(Pennington Ave to Godwin Ave)	02030103140020	0.2899	-	-		0.058	0.4356	(0.3776)	Y	--
Saddle River (above Rt 17)	02030103140040	0.1076	-	-		0.022	0.1553	(0.1338)	Y	--
Drakes Brook (above Eyland Ave)	02030105010010	1.8452	-	-		0.092	0.6136	(0.5213)	Y	--
Drakes Brook (below Eyland Ave)	02030105010020	1.6170	-	-		0.323	3.5375	(3.2141)	Y	--
Raritan River SB(above Rt 46)	02030105010030	1.3315	-	-		0.067	0.4232	(0.3567)	Y	--
Raritan River SB(74d 44m 15s to Rt 46)	02030105010040	1.7642	-	-		0.088	0.4325	(0.3443)	Y	--
Raritan R SB(LongValley br to 74d44m15s)	02030105010050	3.9936	-	-		0.200	0.3803	(0.1806)	Y	--
Raritan R SB(Califon br to Long Valley)	02030105010060	3.2737	-	-		0.164	0.1541	0.0096	--	Y
Raritan R SB(StoneMill gage to Califon)	02030105010070	1.5442	-	-		0.077	0.0773	(0.0000)	Y	--
Raritan R SB(Spruce Run-StoneMill gage)	02030105010080	0.6805	-	-		0.136	0.2513	(0.1152)	Y	--
Spruce Run (above Glen Gardner)	02030105020010	2.1600	-	-		0.108	0.1886	(0.0806)	Y	--
Spruce Run (Reservior to Glen Gardner)	02030105020020	0.4799	-	-		0.024	0.0720	(0.0480)	Y	--
Mulhockaway Creek	02030105020030	2.5176	-	-		0.126	0.0549	0.0710	--	Y
Spruce Run Reservior / Willoughby Brook	02030105020040	2.1108	-	-		0.106	0.5891	(0.4835)	Y	--
Beaver Brook (Clinton)	02030105020050	1.2327	0.123	0.0000	0.1233	0.062	1.6194	(1.5577)	Y	--
Cakepoulin Creek	02030105020060	0.7214	0.072	0.0618	0.0104	0.036	0.0150	0.0210	--	--
Raritan R SB(River Rd to Spruce Run)	02030105020070	1.1304	-	-		0.226	0.0269	0.1992	--	--
Raritan R SB(Prescott Bk to River Rd)	02030105020080	0.7876	-	-		0.158	0.0626	0.0949	--	--
Prescott Brook / Round Valley Reservior	02030105020090	1.4798	-	-		0.074	0.0384	0.0356	--	--
Pleasant Run	02030105040020	0.0102	0.001	0.0000	0.0010	0.001	0.0006	(0.0001)	Y	--
Holland Brook	02030105040030	0.0017	-	-		0.000	0.0004	(0.0003)	Y	--
Lamington R (above Rt 10)	02030105050010	1.2275	-	-		0.245	0.4470	(0.2015)	Y	--
Lamington R (Hillside Rd to Rt 10)	02030105050020	3.4283	-	-		0.171	2.0181	(1.8466)	Y	--
Lamington R (Furnace Rd to Hillside Rd)	02030105050030	1.0973	0.110	0.0124	0.0974	0.055	0.2196	(0.1648)	Y	--
Lamington R(Pottersville gage-FurnaceRd)	02030105050040	2.7669	-	-		0.138	0.1611	(0.0227)	Y	--
Pottersville trib (Lamington River)	02030105050050	0.9838	-	-		0.049	0.0211	0.0281	--	Y
Cold Brook	02030105050060	1.4496	0.145	0.0106	0.1344	0.072	0.0233	0.0492	--	Y
Lamington R(HallsBrRd-Pottersville gage)	02030105050070	3.1167	0.312	0.0000	0.3117	0.156	0.4838	(0.3280)	Y	--
Rockaway Ck (above McCrea Mills)	02030105050080	3.9790	0.398	0.0050	0.3929	0.199	0.0724	0.1266	--	Y

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Rockaway Ck (RockawaySB to McCrea Mills)	02030105050090	0.5245	-	-		0.026	0.0117	0.0145	--	Y
Rockaway Ck SB	02030105050100	1.6583	-	-		0.332	0.1701	0.0829	--	Y
Lamington R (below Halls Bridge Rd)	02030105050110	0.5596	-	-		0.028	0.0672	(0.0392)	Y	--
Raritan R NB (above/incl India Bk)	02030105060010	1.6055	0.161	0.0000	0.1606	0.080	0.2044	(0.1241)	Y	--
Burnett Brook (above Old Mill Rd)	02030105060020	1.7913	0.179	0.0000	0.1791	0.090	0.0364	0.0532	--	Y
Raritan R NB(incl McVickers to India Bk)	02030105060030	2.3095	-	-		0.115	0.1265	(0.0110)	Y	--
Raritan R NB(Peapack Bk to McVickers Bk)	02030105060040	1.3183	-	-		0.066	0.0424	0.0235	--	Y
Peapack Brook (above/incl Gladstone Bk)	02030105060050	1.2732	-	-		0.064	0.0388	0.0249	--	Y
Peapack Brook (below Gladstone Brook)	02030105060060	1.0430	0.104	0.0000	0.1043	0.052	0.1403	(0.0882)	Y	--
Raritan R NB(incl Mine Bk to Peapack Bk)	02030105060070	1.8594	-	-		0.372	0.1331	0.0930	--	Y
Middle Brook (NB Raritan River)	02030105060080	1.4922	0.149	0.0000	0.1492	0.075	0.0197	0.0549	--	Y
Raritan R NB (Lamington R to Mine Bk)	02030105060090	1.8374	0.184	0.0000	0.1837	0.092	0.0165	0.0754	--	Y
Raritan R NB (Rt 28 to Lamington R)	02030105070010	0.6456	0.065	0.0000	0.0646	0.032	0.0920	(0.0597)	Y	--
Middle Brook EB	02030105120050	0.0340	-	-		0.007	0.0023	0.0045	--	--
Middle Brook WB	02030105120060	0.1328	-	-		0.007	0.0169	(0.0103)	Y	--
Lafayette Swamp tribs	02040105040040	0.0149	-	-		0.001	0.0003	0.0005	--	Y
Sparta Junction tribs	02040105040050	2.0154	-	-		0.101	0.9033	(0.8025)	Y	--
Paulins Kill (above Rt 15)	02040105040060	0.0065	0.001	0.0001	0.0005	0.000	0.0004	(0.0001)	Y	--
Paulins Kill (Blairstown to Stillwater)	02040105050010	1.0762	-	-		0.054	0.0520	0.0018	--	--
Delawanna Creek (incl UDRV)	02040105060020	0.3615	-	-		0.018	0.0198	(0.0018)	Y	--
Lake Lenape trib	02040105070010	0.1551	-	-		0.008	0.0531	(0.0453)	Y	--
New Wawayanda Lake/Andover Pond trib	02040105070020	0.5454	-	-		0.027	0.0652	(0.0379)	Y	--
Pequest River (above Brighton)	02040105070030	0.8016	-	-		0.040	0.0183	0.0218	--	Y
Pequest River (Trout Brook to Brighton)	02040105070040	1.9964	0.200	0.0000	0.1996	0.100	0.0260	0.0738	--	Y
Trout Brook/Lake Tranquility	02040105070050	1.4398	-	-		0.072	0.0212	0.0508	--	Y
Pequest R (below Bear Swamp to Trout Bk)	02040105070060	0.6083	-	-		0.030	0.6076	(0.5772)	Y	--
Bear Brook (Sussex/Warren Co)	02040105080010	0.7644	0.076	0.0000	0.0764	0.038	0.0534	(0.0152)	Y	--
Bear Creek	02040105080020	1.7750	-	-		0.089	0.0185	0.0702	--	Y
Pequest R (Drag Strip--below Bear Swamp)	02040105090010	1.1591	-	-		0.058	0.4204	(0.3624)	Y	--
Pequest R (Cemetary Road to Drag Strip)	02040105090020	1.2841	-	-		0.064	0.1886	(0.1244)	Y	--
Pequest R (Furnace Bk to Cemetary Road)	02040105090030	1.4983	-	-		0.075	0.5846	(0.5097)	Y	--
Mountain Lake Brook	02040105090040	0.8329	-	-		0.042	0.0297	0.0119	--	--
Furnace Brook	02040105090050	1.0869	-	-		0.054	0.2691	(0.2148)	Y	--
Pequest R (below Furnace Brook)	02040105090060	1.4525	-	-		0.073	0.0555	0.0171	--	--
Union Church trib	02040105100010	1.2701	-	-		0.064	0.0178	0.0457	--	--
Honey Run	02040105100020	0.2778	-	-		0.014	0.0188	(0.0049)	Y	--
Beaver Brook (above Hope Village)	02040105100030	1.1930	-	-		0.060	0.0181	0.0415	--	Y

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Beaver Brook (below Hope Village)	02040105100040	1.2653	-	-		0.063	0.0324	0.0309	--	--
Pophandusing Brook	02040105110010	0.2510	0.025	0.0000	0.0251	0.013	0.4336	(0.4211)	Y	--
Buckhorn Creek (incl UDRV)	02040105110020	2.5288	0.253	0.0000	0.2529	0.126	0.0837	0.0428	--	--
UDRV tribs (Rt 22 to Buckhorn Ck)	02040105110030	1.2309	0.123	0.0000	0.1231	0.062	5.8074	(5.7458)	Y	--
Lopatcong Creek (above Rt 57)	02040105120010	1.1010	-	-		0.055	0.2617	(0.2066)	Y	--
Lopatcong Creek (below Rt 57) incl UDRV	02040105120020	2.3181	-	-		0.464	0.0713	0.3923	--	--
Pohatcong Creek (above Rt 31)	02040105140010	1.5989	-	-		0.080	0.0659	0.0141	--	Y
Pohatcong Ck (Brass Castle Ck to Rt 31)	02040105140020	2.0971	-	-		0.105	0.3054	(0.2006)	Y	--
Pohatcong Ck (Edison Rd-Brass Castle Ck)	02040105140030	1.6887	0.169	0.0000	0.1689	0.084	0.0232	0.0613	--	Y
Merrill Creek	02040105140040	1.2158	-	-		0.061	0.0161	0.0447	--	Y
Pohatcong Ck (Merrill Ck to Edison Rd)	02040105140050	0.9852	0.099	0.0000	0.0985	0.049	0.0163	0.0330	--	Y
Pohatcong Ck (Springtown to Merrill Ck)	02040105140060	1.1851	0.119	0.0000	0.1185	0.059	0.0217	0.0375	--	Y
Pohatcong Ck(below Springtown) incl UDRV	02040105140070	0.7924	0.079	0.0000	0.0792	0.040	0.2862	(0.2466)	Y	--
Weldon Brook/Beaver Brook	02040105150010	0.3794	-	-		0.019	0.0412	(0.0222)	Y	--
Lake Hopatcong	02040105150020	2.7060	-	-		0.541	1.5268	(0.9856)	Y	--
Musconetcong R (Wills Bk to LkHopatcong)	02040105150030	0.7257	-	-		0.145	0.4590	(0.3139)	Y	--
Lubbers Run (above/incl Dallis Pond)	02040105150040	1.0269	-	-		0.051	0.4528	(0.4015)	Y	--
Lubbers Run (below Dallis Pond)	02040105150050	1.2957	-	-		0.065	0.0622	0.0025	--	Y
Cranberry Lake / Jefferson Lake & tribs	02040105150060	0.5393	-	-		0.027	0.0198	0.0072	--	Y
Musconetcong R(Waterloo to/incl WillsBk)	02040105150070	1.0588	-	-		0.053	0.3694	(0.3165)	Y	--
Musconetcong R (SaxtonFalls to Waterloo)	02040105150080	1.2355	-	-		0.062	0.0468	0.0149	--	Y
Mine Brook (Morris Co)	02040105150090	0.1230	-	-		0.006	0.0692	(0.0631)	Y	--
Musconetcong R (Trout Bk to SaxtonFalls)	02040105150100	1.5667	-	-		0.078	1.2232	(1.1449)	Y	--
Musconetcong R (Hances Bk thru Trout Bk)	02040105160010	2.9534	-	-		0.148	0.3568	(0.2091)	Y	--
Musconetcong R (Changewater to HancesBk)	02040105160020	3.8812	-	-		0.194	0.1201	0.0739	--	Y
Musconetcong R (Rt 31 to Changewater)	02040105160030	1.7505	0.175	0.0000	0.1751	0.088	0.6968	(0.6093)	Y	--
Musconetcong R (75d 00m to Rt 31)	02040105160040	0.9955	0.100	0.0000	0.0995	0.050	0.1178	(0.0680)	Y	--
Musconetcong R (I-78 to 75d 00m)	02040105160050	2.7663	0.277	0.0000	0.2766	0.138	0.0648	0.0735	--	Y
Musconetcong R (Warren Glen to I-78)	02040105160060	0.9672	-	-		0.048	0.2138	(0.1654)	Y	--
Musconetcong R (below Warren Glen)	02040105160070	0.9834	-	-		0.049	1.0326	(0.9834)	Y	--
Holland Twp (Hakihokake to Musconetcong)	02040105170010	0.7436	-	-		0.037	0.0392	(0.0020)	Y	--
Hakihokake Creek	02040105170020	2.8906	-	-		0.145	0.2611	(0.1166)	Y	--
Harihokake Creek (and to Hakihokake Ck)	02040105170030	1.1578	0.116	0.0000	0.1158	0.058	0.2525	(0.1947)	Y	--
Nishisakawick Creek (above 40d 33m)	02040105170040	1.2693	0.127	0.0000	0.1269	0.063	0.0239	0.0396	--	Y
Nishisakawick Creek (below 40d 33m)	02040105170050	0.3451	0.035	0.0000	0.0345	0.017	0.0384	(0.0211)	Y	--

[1] Indicates values is adjusted to % area of HUC14 within Highlands Region

[2] Net availability for ECA may not be difference of GWA and Use. It is constrained to 5% of Ground Water Capacity