WATER BUDGET IN THE RARITAN RIVER BASIN

A Technical Report for the Raritan Basin Watershed Management Project

New Jersey Water Supply Authority

September 2000

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

The NJ Water Supply Authority thanks the NJ Department of Environmental Protection for permission to excerpt and modify material from the NJ Statewide Water Supply Plan and other documents for use in this report. In addition, our thanks to Robert Canace of the NJ Geological Survey for his provision of stream base flow estimates. Thanks also to the Characterization Committee and Project Team of the Raritan Basin Watershed Management Project for all of their comments, hard work and suggestions. Project Team members include:

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

WATER BUDGET
IN THE RARITAN RIVER BASIN

A Technical Report for the

Raritan Basin Watershed Management Project

Summary

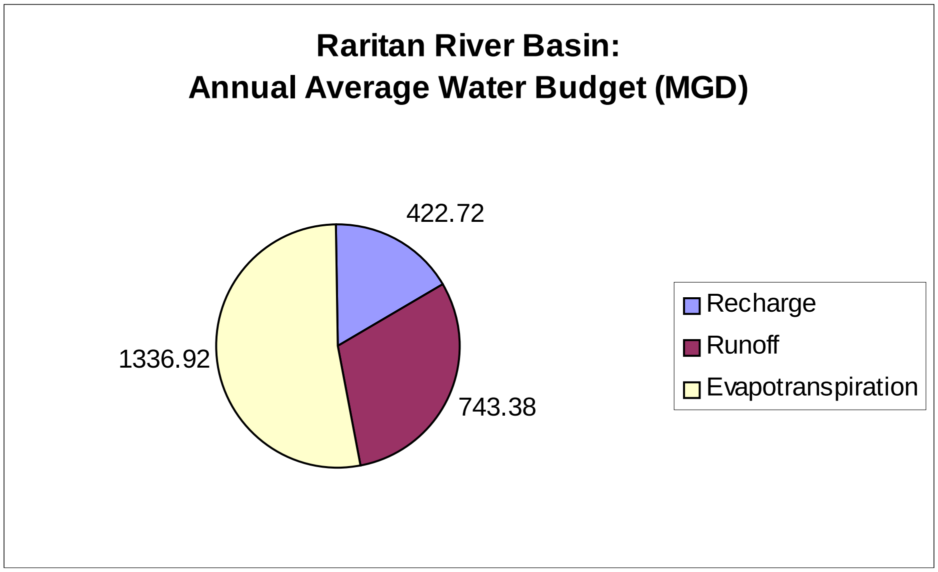
The Raritan River Basin includes a number of major watersheds, comprising approximately 1,100 square miles. The New Jersey Department of Environmental Protection (NJDEP) has aggregated these watersheds into three Watershed Management Areas (WMAs), as shown in Figure 4--Municipalities and Road Network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

"Water budget" is a term for the quantification of precipitation, runoff, recharge, evaporation, transpiration and human uses of water within a watershed. A water budget is used to understand how water arrives, flows through and leaves a watershed, and is valuable in understanding how human activities modify the natural flow of water. Precipitation is the sole natural source of water in a watershed. Of the total precipitation, some evaporates from the land or water surfaces of the Basin or transpires from vegetation (the two are usually combined in the single term "evapotranspiration"), and the remainder either infiltrates to become ground water or runs off the land surface to be surface water during storm and snowmelt periods. Ground water eventually becomes stream flow, contributing to the flow of streams during both wet and dry periods. Human activities within the Basin may add to or subtract from infiltration, evapotranspiration and runoff.

The water budgets presented in this report are long-term averages. They are best described as general estimates. Detailed water budgets can be developed for the Basin or any portion thereof through the use of hydrologic modeling, but such models are fairly costly and well beyond the scope of this project. It may be that such models would be useful for specific watersheds, or for the Basin as a whole; this subject will be addressed in the Management Plan to be developed. For the purposes of this project, a generalized spreadsheet model was developed, using estimates of precipitation, infiltration and runoff based on readily available information. This report draws heavily from water supply studies and plans of the New Jersey Department of Environmental Protection, developed over the last twenty years, as well as from more recent work of the NJDEP's NJ Geological Survey and the US Geological Survey.

BASIN SUMMARY

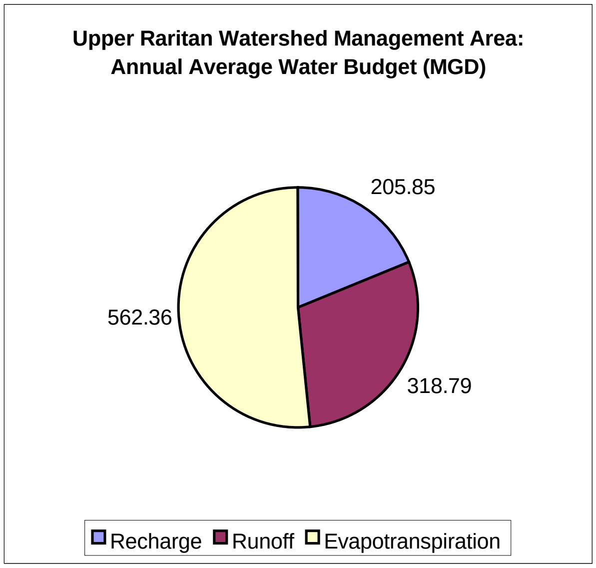
On an annual average basis, the Raritan Basin receives 2500 million gallons per day (MGD) of water from precipitation. That translates to over 900 billion gallons of water per year. By comparison, New Jersey's largest reservoir (Round Valley Reservoir) holds 55 billion gallons of water. Of the total precipitation, over half (53 percent) evapotranspires from the land or water surfaces of the Basin, and the remainder is either ground water recharge (17 percent) or runoff (30 percent). The chart below shows the relationship between the three factors. What is not shown in this chart are the changes made in the water budget due to human uses of water. Based on assessments from the late 1980's, over 150 MGD on average leaves the Basin through human water uses and the discharge of treated wastewater into the Raritan Bay. These uses, known as depletive uses, modify the water budget. The reservoir system of the Raritan Basin was developed to ensure that this modification did not damage the Raritan Basin's water flows during drought periods. Water is stored in the reservoirs during wet periods, which reduces river flows as storage levels increase. It is then released to the river system during dry periods (which increases river flows as storage levels decrease).

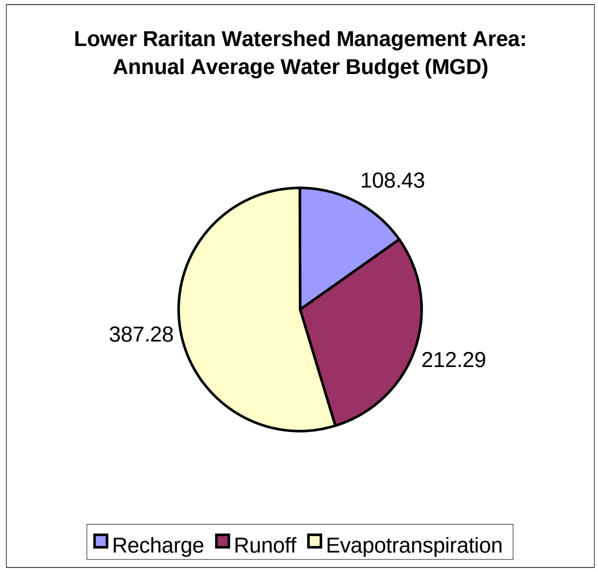


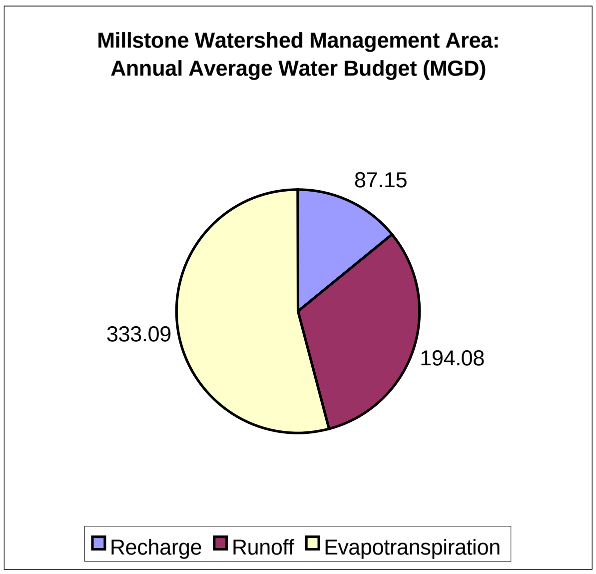
WATERSHED MANAGEMENT AREA SUMMARIES

There are three Watershed Management Areas (WMA) in the Raritan River Basin – the Upper Raritan, the Lower Raritan and the Millstone. The three WMAs show distinct differences in the percent of precipitation that becomes runoff and recharge from infiltration (see charts below). However, the relative amount of evapotranspiration remains relatively constant for all three (approximately 52 percent in the Upper Raritan WMA, 55 percent in the Lower Raritan WMA, and 54 percent in the Millstone WMA). Of the three, the Millstone WMA has the lowest percentage of recharge and the highest percentage of runoff. The Upper Raritan WMA, on the other hand, has the lowest runoff rate and the highest recharge rate, primarily due to the 40 percent of this area located in the Highlands, with limestone and glacial aquifers. The differences in recharge and runoff are probably related primarily to the underlying geology and topography of the three areas, but land development increases runoff and decreases recharge from infiltration as the area covered by impervious surfaces increases, unless specifically managed to avoid that impact.

While the charts below show the water budgets in terms of MGD, they are most useful in understanding the relative differences in evapotranspiration, recharge and runoff. Later sections of the report compare the Watershed Management Areas and their subwatersheds in terms of MGD per square mile. In this way, the size of each area is no longer a factor; the focus is on how much water moves through each square mile of the area. Characterized in this manner, the differences are even more apparent, with considerable variation in recharge from infiltration (from 0.25 to 0.67 MGD per square mile) and runoff (from 0.50 to 0.75 MGD per square mile).







WATERSHED MGT AREA	INFILTRATION/ RECHARGE (%)	RUNOFF (%)	EVAPO-TRANSPIRATION (%)
Upper Raritan (WMA 8)	18.94	29.33	51.74
Lower Raritan (WMA 9)	15.31	29.98	54.70
Millstone (WMA 10)	14.19	31.59	54.22

Purpose of a Water Budget Characterization and Assessment

The Raritan River Basin supports a wide variety of New Jersey ecosystems within the Highlands, Piedmont and Coastal Plain geologic provinces. Many of these ecosystems rely heavily on the near proximity of surface waters, wetlands and high ground water tables. The Raritan River Basin is also a major source of potable and industrial water supply in central New Jersey for approximately 1.2 million people. Finally, the surface waters of the Basin are used for recreational and aesthetic purposes. The vitality and health of all these uses depends on the natural processes of precipitation, runoff and recharge. Therefore, for watershed management purposes it is critical to understand both the general and detailed water budget and hydrology of the Basin.

The characterization portion of this technical report provides information on the current status of the water budget in the Raritan River Basin. The assessment portion compares the current resource status to the historic water budget to the extent that this is possible; the assessment is necessarily more qualitative than quantitative as this time. Both portions of this report are prepared for use in the management planning process that will begin in the year 2000.

Information Sources

The water resources of the Raritan River Basin have been studied extensively since 1950. Primary resources used for this study were developed by or for the NJDEP and date from the 1980's and 1990's, including:

- New Jersey Statewide Water Supply Plan and reference documents
- Eastern Raritan Basin Water Feasibility Study
- NJDEP Water Balance Model (Raritan River Basin portion)
- South River Water Supply Feasibility Study

Much of the information under the following two sections relies heavily on these reports, and the text of the Water Budget – General Approach draws from the Statewide Water Supply Plan.

Water Budgets – General Approach

Water budgets are simple in concept but more difficult to actually quantify. The complexity of a water budget characterization depends in part on the detail desired. Most water budgets are developed based on long-term averages, especially for aquifers and combined ground/surface water analyses. Water budgets for surface water supply systems are often developed based on specific water years that are expected to have the greatest stress on the supplies. This section describes the general approach to water budgets, and also discusses the ways in which water budgets are naturally variable or vulnerable to artificial change. The following section applies this general approach to the Raritan Basin.

Natural Water Budget Equation

The most basic equation for water budgets is based on the hydrologic cycle, where water moves from the atmosphere to the Earth's surface to various destinations, and finally to the atmosphere:

$$P = I + ET + R$$

where "P" represents precipitation of all forms, "I" represents that portion of infiltration of water into the ground that provides ground water recharge, "ET" represents evapotranspiration, and "R" represents runoff. As noted above, this equation can be applied to long-term averages, to specific years, to statistical data, etc., depending on the issue being studied and the level of detail desired. The analysis for regional surface water supplies will be different than the analysis for ground water management in a subwatershed. For this report, we use long-term annual averages (usually 30 years or more) because the data are available to support water budget analyses at this level. The technical report on Water Availability in the Raritan River Basin uses time frames appropriate to water supply planning, primarily focused on drought periods for surface waters and on long-term averages for ground water.

Figure 1 shows a simplified representation of the hydrologic cycle under natural conditions. Figure 2 shows a simplified representation of the hydrologic cycle under "developed" conditions where the water pathways are modified by surface and ground water withdrawals, impervious surfaces, etc.

Precipitation

Precipitation is the sole input to the water budget under natural conditions. Precipitation comes in various forms but is considered as the equivalent of fluid water in water budget calculations. The precipitation patterns for the Raritan Basin are discussed in the technical report on Settings of the Raritan River Basin.

Infiltration/Recharge

Infiltration of water into the land surface is a critical component of the hydrologic cycle and a water budget. Without infiltration, all water would either evaporate from the land surface or runoff to surface waters. Streams would dry up entirely after runoff moved downstream. Under natural conditions the stream flow that can be seen several days after precipitation events comes from the discharge of water from the ground into the stream, known as "base flow." (Under developed conditions, this base flow is sometimes augmented by discharges from wastewater treatment facilities.)

The term "infiltration" is used here to mean that the water has moved downward from the land surface into and through the upper soil layers (including the root zone of plants; essentially, this term becomes equivalent to ground water recharge. Some infiltration is very shallow and moves toward streams just below the land surface. This water is not used for potable water supplies, generally, but is invaluable for ecosystem health. Other infiltration penetrates more deeply and can recharge aquifers. Aquifers are defined as a geologic unit that is saturated with water and from which water can be economically withdrawn for human use. Under natural conditions, water from aquifers is transmitted to surface waters after periods ranging from years to millennia.

Infiltration is highly dependent on the amount, intensity and season of precipitation. A lower percentage of precipitation infiltrates to become ground water during periods where soils are very dry (e.g., summer), brief storms, high-intensity storms, and when the ground is frozen.

Evapotranspiration

Evapotranspiration is a combination of two terms – evaporation and transpiration. Evaporation involves the transformation of surface water to atmospheric water. Transpiration occurs when water in plants moves from shallow soils to the root system to the leaves, transporting nutrients and energy, and then evaporates from the leaves. The two terms are usually considered together in water budget calculations. Both evaporation and transpiration tend to be higher during periods of hot weather, low humidity and high wind. Of course, nearly all transpiration occurs during the growing season.

Runoff

Runoff occurs when precipitation falls onto the land surface and moves toward surface waters. Runoff is affected by a wide variety of factors, such as:

- *soil type and depth,*
- *the presence or absence of vegetation,*
- *the presence or absence of impervious surfaces such as pavement or buildings,*
- *general topography,*
- *the extent to which water is trapped in puddles and never gets to major surface waters,*
- *the intensity of the precipitation,*
- *the form of the precipitation (such as snow or rain),*
- *the amount of moisture in the soil just before the precipitation, and*
- *whether or not the soil is frozen.*

Because of these factors, runoff from two similar storms in the same watershed and season can be very different. For this reason, calculations of runoff in a water budget will vary depending on the use. Generally, runoff calculations for stormwater and flood management are generated for specific storms in a specific watershed or subwatershed, and will address stream flows over very short time periods (such as by the hour). Runoff calculations for water supply purposes will usually focus on more long-term (daily, weekly, monthly or annual) conditions in larger watersheds.

Artificial Modifications to Natural Water Budgets

Human development of water supplies and the land surface has a significant impact on water budgets. The major issues here are depletive and consumptive water uses, recharge loss, vegetation changes, runoff increases and impoundments, and "temporal displacements."

Depletive and Consumptive Uses

Depletive and consumptive uses are those water uses that permanently remove water from a water body (either surface or ground water) for human use. The water may be evaporated such as through agricultural or lawn irrigation, power plant cooling, or manufacturing which is termed a "consumptive" use. It may be transported physically to another water body such as through water supply lines to customers who then discharge their wastes to wastewater treatment facilities that then discharge treated effluent into another water body, which is termed a “depletive” use. In either case, the water is no longer available for stream flow or aquifer storage in the original watershed.

Recharge Loss

Changes in the land surface can reduce ground water recharge by increasing runoff. These changes can include the construction of buildings, paving, soil compaction and similar activities. The more impervious the land surface becomes, the more recharge is lost. Recharge loss leads to reduced stream flows during dry periods, and reduced availability of both ground and surface water for human consumption. Essentially, the loss of recharge changes the timing of water flow – less water flows during dry periods as base flow to streams whereas more water flows during wet periods as immediate runoff to streams. These changes have ecological and water supply impacts, by creating more stress on ecosystems and water supply storage during dry periods.

Vegetation Changes

Each vegetative land cover has different water needs and creates different microclimates. Changing the land cover from forest to irrigated crop to non-irrigated vegetation to lawns to bare ground will affect evapotranspiration rates significantly. One difficulty in preparing a short-term water budget is that evapotranspiration rates can change dramatically from year to year. Assessing water budget changes caused by long-term vegetation changes is even more difficult, because complete data on vegetative patterns are lacking from periods before aerial photographic surveys, and the older aerial surveys have not been interpreted for vegetation patterns. Therefore, assessments of changes in evapotranspiration are necessarily qualitative.

Runoff Increases

The result of reduced recharge and evapotranspiration is increased runoff. While evapotranspiration and stream base flow are generally low-intensity, continuous events, runoff happens only during wet weather periods including snowmelt and therefore is more concentrated. Greatly increased runoff is capable of carrying larger amounts of pollutants, eroding soil more heavily, and increasing flooding of streams and flood plains.

Temporal Displacements

Impoundments such as reservoirs reduce the flow of streams into the ocean during certain periods by capturing higher flows and storing them for later use. Storage in this manner does not affect the long-term average water budget of a watershed (unless the water is then diverted to another watershed through a depletive use as discussed above). However, reservoir storage does cause a change in water flow patterns because it alters the timing. The nature of the reservoir determines the extent of the impact. Water supply reservoirs may cause a significant reduction of moderate flows and a minimal reduction of very high flows. Reservoirs that receive natural stream flow from a watershed will have a greater effect than reservoirs that receive water only through pumping. Both kinds of reservoirs can cause significant increases in natural low stream flows, because State rules require the release of water from the reservoirs to maintain specified flow levels in the streams.

Flood control reservoirs, on the other hand, are designed to have their greatest impact at the highest flows, so as to impound a significant percentage of flood flows and reduce flooding in downstream areas. The Raritan Basin has no large flood control reservoirs at this time.

Finally, small ponds and lakes can have very short-term temporal impacts. These water bodies receive direct stream flow, tend to be full at all times, and store very little extra water during high flow periods. In addition, there are many stormwater detention and retention basins located in developments around the Raritan River Basin. Each stormwater basin stores water during precipitation events. However, the aggregate impact of these stormwater basins on stream flooding is not known. Depending on various factors, stream flows can be exacerbated or mitigated by such stormwater basins.

Safe Yields and Dependable Yields

The water budget for a watershed provides a general estimate of how water flows through the system, and can be calculated using information on the various components. However, a water budget does not determine directly how much water can be withdrawn without damaging the system. The terms “safe yield” and “dependable yield” are used to describe how much surface water and ground water, respectively, can be used while maintaining the sustainable nature of the water system. The technical report “Water Availability in the Raritan River Basin” addresses this issue in depth.

The definition of safe yield for surface water systems has long been associated with the so-called "drought of record." Specifically, a surface water system's safe yield has been defined by NJDEP as "the yield maintainable by a water system continuously throughout a repetition of the most severe drought of record, after compliance with requirements for maintaining minimum passing flows." Safe yield is a term indicating that a supply source can provide a set amount of water supply, defined in annual average daily flows (i.e. MGD), during a specific historical drought. This yield has been determined for most major surface water systems in New Jersey, including those in the Raritan Basin, based on the 1960’s drought.

Ground water systems also have sustainable yields, referred to as the "dependable yield" in the current regulations. To date, firm figures for the dependable yield of aquifers have not been established. The continuous decline of water levels in an aquifer and related effects such as saltwater intrusion and intolerable reductions in stream flow are considered evidence that the dependable yield is being exceeded, although the actual yield has not been formally quantified. The Statewide Water Supply Plan estimated for planning purposes that up to 20 percent of ground water recharge can be withdrawn from non-coastal aquifers without causing unacceptable impacts, and up to 10 percent of coastal aquifer recharge can be withdrawn. The lower threshold for coastal aquifers is to prevent saltwater intrusion into those aquifers.

Two critical points must be understood. First, if water is withdrawn, used and then returned to its point of origin, the yield of the system is only limited by the ability to pump and by the introduction of pollutants with the return water. However, it should be noted that no return method is 100 percent effective, and so there will be some losses with each cycle. New Jersey currently discharges 80 percent of its wastewater to estuaries and the ocean, rather than recycling it to upland aquifers or streams. Second, storage capacity essentially defines the safe yield of surface water supplies. A surface water intake with no upstream storage will encounter times during dry periods (more frequent than true droughts) where no water is available for withdrawal because all the water must be allowed to flow downstream.

Variability and Vulnerability

Monthly Variations in Budget Components

The physiographic provinces provide a pattern for the geographic distribution of precipitation throughout the State. Annual precipitation ranges from 40 inches in the southeast to 52 inches in the north-central mountains, following a general pattern where the greatest rainfall is in northern New Jersey. The State averages approximately 44 inches per year (Figure 3), while the Raritan River Basin average is approximately 46 inches per year. Precipitation (when viewed as long-term, monthly averages) does not exhibit a significant seasonal pattern, being distributed fairly uniformly throughout the year. However, while precipitation is relatively even throughout the year, evapotranspiration is by far the highest during the warmer months. This phenomenon results in significant reductions in stream flow during this time and compounds the effects of drought. Runoff varies both geographically and seasonally in New Jersey, with March and April exhibiting periods of highest runoff. Generally, northern New Jersey has a greater amount of runoff than southern New Jersey due to higher slopes, thinner soils with lower infiltration rates and larger amounts of snow in winter months. However, glacial deposits and limestone aquifers counteract this tendency. As noted in the technical report “Setting of the Raritan River Basin”, precipitation in the summer months tends to be more intense from thunderstorms and tropical depressions, while precipitation in other months is generally from less intense but longer storms.

Summer precipitation results in more runoff due to rainfall intensity, while evapotranspiration is also very high. The result is reduced infiltration, lower stream base flow, and limited aquifer recharge. This effect continues into early fall, until evapotranspiration decreases low enough for additional infiltration to occur. For this reason, stream flow tends to be more variable in the summer and early fall, with lower base flows and higher storm flows. However, winter and early spring storm flows can also be high due to runoff from frozen ground, especially when combined with snowmelt.

Uncertainties in Water Supply Yields

The 1993 amendments to the Water Supply Management Act emphasize the need for a refined definition of safe or dependable yield to allow a determination of whether the dependable yield of an aquifer is being exceeded. A method of quantifying ground water yields directly to guide resource allocations has not been determined. The definition of surface water "safe yield" is not satisfactory with regard to ground water yields because drought often will not significantly affect the availability of ground water in many aquifers, except in small, poorly yielding or already impaired aquifers.

The definition of safe yield is flexible in two regards. First, the drought of record can change, and second, the minimum passing flows to maintain stream flow below reservoirs can change. Changes to either parameter affect the safe yield of a surface water system. A change in the definition of the drought of record would be necessary if severe climatic and hydrological conditions demonstrated the safe yield of a source was over estimated. Currently, many surface water supplies have estimated safe yields based on the 1960's drought. If a more severe drought or a different drought pattern occurs, these systems may not be able to supply their nominal "safe yield."

Changes in minimum passing flow requirements could result from regulatory decisions to increase or decrease the amount of water allowed to pass the point at which it is diverted. The type of regulatory decision can include interbasin transfers of upstream sewage effluent, an increase in stream flow for instream flow protection or an extension of sewerage collection system to upstream areas currently served by septic systems. In times of severe drought, minimum passing flows are often reduced administratively by NJDEP to maintain storage in reservoirs.

The dependable yield of a ground water system can also change. In this case, changes in the minimum acceptable water level in the aquifer or a decision to allow a certain amount of saltwater intrusion would alter the definition of its yield. A change in ground water use patterns can increase ground water yields, specifically when pumping centers are moved away from sources of saltwater intrusion. The loss of recharge also can reduce dependable yields.

In the current state regulations (N.J.A.C. 7:19-6) the term safe yield is used with surface supplies, while the term dependable yield is used with ground water supplies. This idea of two separate terms indicates there are two separate sources of water supply – ground water and surface water. In fact, the interrelationship of ground and surface water has been documented through water supply studies throughout the State. It is clear that the use of ground water in many areas directly affects the availability of surface water supplies. This connection has direct implication on how yields are defined and how they will be allocated. This is a particular problem with rural water systems supplied by ground water in the headwaters of rivers feeding major reservoirs and direct intakes. In addition, there are environmental limitations to safe yields as some are set for ecological reasons such as trout maintenance in streams.

In addition, an increasing number of water systems are using both ground and surface water conjunctively. The Statewide Water Supply Plan concluded that these factors point to the need for a new discussion on the definition of safe/dependable yield and how the regulatory programs should use the terms.

Depletive and Consumptive Uses

Because they are caused by human activity, depletive and consumptive uses can readily change due to demographic change, economic pressures, land use modifications, etc. For example, New Jersey has seen an increase in both agricultural land and suburban lawns that use irrigation. Manufacturing use of water has declined significantly since the early 1980's in reaction to economic shifts, wastewater treatment costs and the vulnerability of water supplies to drought. Power generation has increased, leading to an increased need for cooling water. However, such cooling systems have increased in efficiency, and some power plants are using municipal wastewater effluent for cooling purposes. The interconnection of watersheds through the transfer of untreated potable water, treated potable water and wastewater has increased the level of depletive uses (inter-watershed transfers). Ground water withdrawals have increased in some areas, and nearly all used ground water is discharged to surface waters after treatment. However, use of some aquifers has declined due to NJDEP regulations or the threat or presence of pollution. All of these factors, and more, can cause significant changes in depletive and consumptive uses that should be taken into account when calculating a water budget and available water supplies.

Land Use and Land Cover Changes

Changes in land use, and especially in land cover, are critical factors that drive changes in nearly all the other water budget parameters. Runoff and recharge are clearly affected, as is evapotranspiration. Land uses drive the need for water supplies and therefore influence the development of water supplies. These water supply systems create temporal changes in water flows, and may be linked to depletive uses (transfers of water or sewerage from the watershed) or consumptive uses such as lawn watering. Finally, land cover can even change precipitation patterns locally, through the creation of "heat islands" caused by major urban areas.

Characterization of Water Budgets in the Raritan Basin

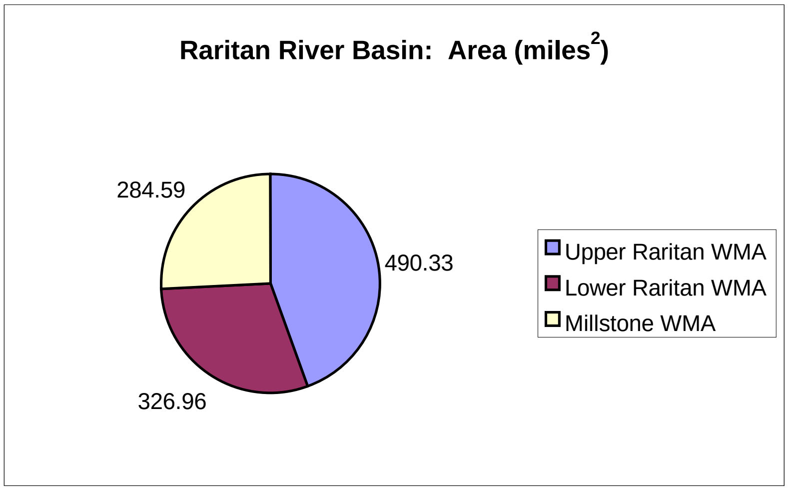
Methodology

Precipitation values are generalized from NOAA-National Weather Service data in the Raritan Basin, applied to specific watershed areas, and translated into terms of million gallons per day (MGD). Long-term annual averages are used in this report, although shorter time periods can also be used. Recharge/infiltration rates are inferred from stream base flow rates developed by the NJDEP-NJ Geological Survey. The assumption is that long-term stream base flow is equivalent to long-term ground water recharge (below the root zone), except for the impacts of depletive and consumptive uses within the watershed. Therefore, net depletive uses are calculated using available data from NJDEP (recognizing that water can be both imported to and exported from a watershed). This method assumes that consumptive uses within the watersheds are reflected in lower infiltration or increased evapotranspiration. Long-term runoff rates are calculated as total annual average stream flow minus annual average base flow. Evapotranspiration rates are calculated last, as the remainder of precipitation that has not become infiltration/recharge or runoff. These values are all broad estimates that can be improved upon, as needed, for specific watersheds or the entire Basin. This methodology was derived for this project to make use of generally accepted hydrologic concepts and readily available information.

Hydrology and Topography of the Raritan Basin

Variations in rock type and geologic history of different regions of the state have created three different physiographic provinces in the Raritan Basin with unique surface topographies: the Coastal Plain, Piedmont and Highlands provinces. Each province consists of different types of consolidated (i.e., rocks) and unconsolidated (i.e., sand, gravel and silt) deposits with characteristic properties (Figure 4). In the northwest portion of the Basin, glacial deposits cover parts of the Piedmont and Highlands. Each of the physiographic provinces and the glacial deposits are associated with characteristic aquifer units and ground water flow types. The major aquifer units within these physiographic provinces in the Raritan Basin will be discussed later in this report.

The Basin has an area of more than 1,100 square miles. Based on the national system of hydrologic units, the Basin (which is identified by an 8-digit Hydrologic Unit Code) is divided into 16 sub-areas identified by 11-digit Hydrologic Unit Codes (HUC-11). There are eight of these units in the Upper Raritan WMA, five in the Lower Raritan WMA, and three in the Millstone WMA. The size of these HUC-11 drainage areas ranges from nearly 25 square miles to over 130 square miles. The areas for each of the three Watershed Management Areas are illustrated in the figure below, and total approximately 1144 square miles for the entire Raritan River Basin:



WATERSHED MGT AREA	Area as Percent (%) of Basin
Upper Raritan (WMA 8)	42.85
Lower Raritan (WMA 9)	28.57
Millstone (WMA 10)	24.87

The ratio between ground water and surface water withdrawals is highly variable among watersheds because of differences in geology, topography and proximity to major water bodies. Consequently, southern New Jersey is more dependent on ground water supplies and northern New Jersey is more dependent on surface water. The inherent geological characteristics determine the relative underground storage of water, while natural topography influences the viability of water storage in above-ground reservoirs.

Surface water movement is generally from west to east in the central part of the Basin, from north to south in the northern portion, and from south to north in the southern portion. The technical report “Settings of the Raritan River Basin” includes information and maps describing the hydrologic and geographic system in the Basin.

Water Budgets

Net Water Budgets by Watershed

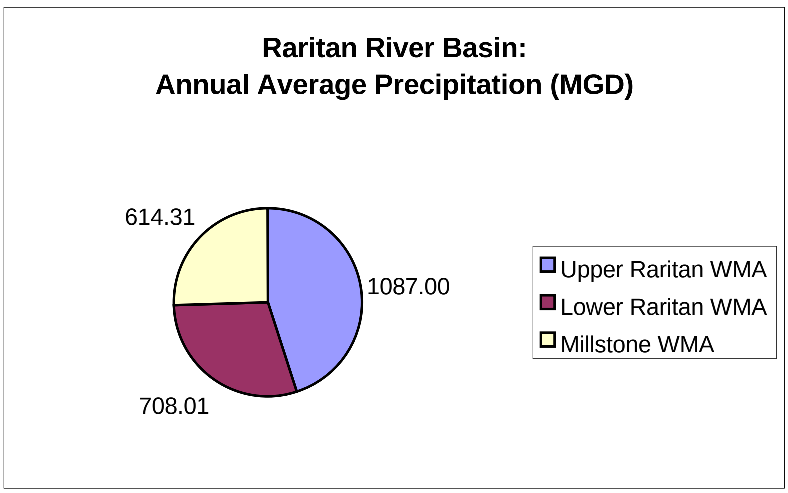
Table 1 (appended) provides a summary of the water budgets for each major watershed, watershed management area and the Raritan River Basin. It provides estimates of precipitation, infiltration/recharge, runoff and evapotranspiration (all of which represent the components of a natural water budget). These figures are all presented as long-term annual averages of water volumes per time (MGD, or million gallons per day, and cfs, or cubic feet per second) to indicate the differences among watersheds that reflects size, physical properties and depletive uses. They are also presented as long-term averages of precipitation depth (inches of water) to provide a perspective of watersheds that focuses less on size and more on other differences. Tables 1-A, 1-B and 1-C (also appended) provide supporting information used to develop Table 1.

Precipitation

Table 1 reflects differences in broad precipitation patterns in the Raritan Basin from the coastal (southeastern) section to the Highlands (northwestern) section. As is typical for New Jersey, annual average precipitation rates are higher to the north than to the south. Precipitation is provided in inches, cfs, cfs per square mile, MGD and MGD per square mile. These values are based on the averages in the table below, based on a 30-year average using National Weather Service data, as discussed in the technical report on “Setting of the Raritan River Basin.”

GEOLOGIC PROVINCE	AVERAGE PRECIPITATION RATE
Coastal Plain	46 inches per year
Piedmont	45 inches per year
Highlands	49 inches per year

Total precipitation to the Basin on an annual average basis is approximately 2500 MGD, enough water to fill the Round Valley Reservoir (largest in New Jersey) in twenty-two days. The precipitation is distributed by Watershed Management Area, as shown in the following chart.



WATERSHED MGT AREA	Precipitation as Percent (%) of Basin
Upper Raritan (WMA 8)	43.43
Lower Raritan (WMA 9)	28.29
Millstone (WMA 10)	24.54

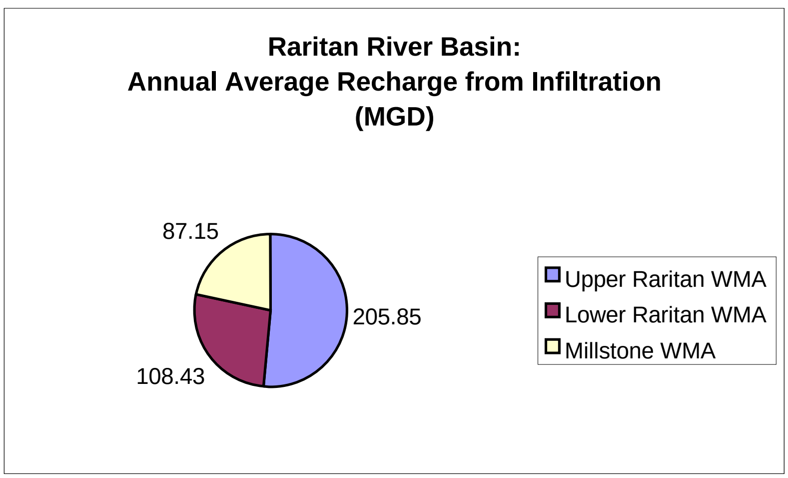
Infiltration/Recharge

The New Jersey Geological Survey developed estimates of stream base flow by geographic province (Canace, 1999) using long-term flow monitoring data. Thirteen estimates were developed within the Raritan Basin. Of these, three sets were based on flow monitoring stations located within watersheds that are entirely contained within a single geologic province. A fourth set included monitoring stations for which the upstream watersheds contained areas within two or more provinces, and thus represent average base flows from the upstream areas. The stations in the fourth set also tended to cover larger areas and are more likely affected by depletive uses.

Therefore, the sets for the Highlands, Piedmont and Coastal Plain were used for this characterization. The following values are used to represent infiltration/recharge (in inches per year) of water to ground water that ultimately flows to surface waters and wells.

GEOLOGIC PROVINCE	INFILTRATION RATE	NUMBER OF STATIONS
Coastal Plain	8.97 inches per year	2
Piedmont	5.25 inches per year	5
Highlands	14.50 inches per year	3

The Highlands have a much higher infiltration/recharge rate than other areas. However, the benefit is limited by the relatively small area of the Highlands within the Basin; 40 percent of the Upper Raritan WMA and none of the others. Even so, the Upper Raritan WMA has an infiltration/recharge rate 47 percent higher than that of the Lower Raritan WMA and 58 percent higher than the Millstone WMA. These values are then applied in a weighted average basis to each watershed to derive values in inches per year, cfs, cfs per square mile, MGD and MGD per square mile. These values are aggregated to the watershed management area and Basin level. Using this method, total infiltration/recharge to the Basin on an annual average basis is approximately 423 MGD, enough water to fill the Round Valley Reservoir in 130 days. The annual average rate of infiltration/recharge, therefore, is only 17 percent of the total precipitation. The infiltration/recharge is distributed by Watershed Management Area, as shown in the following chart.



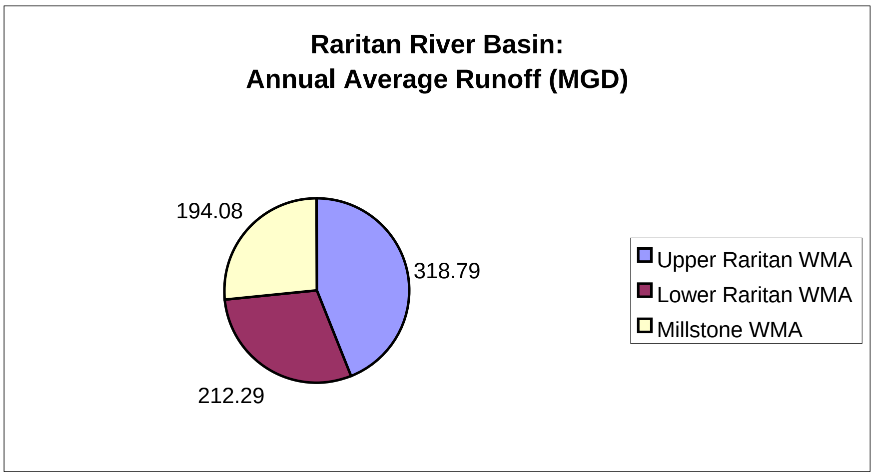
WATERSHED MGT AREA	Recharge from Infiltration as Percent (%) of Basin
Upper Raritan (WMA 8)	48.70
Lower Raritan (WMA 9)	25.65
Millstone (WMA 10)	20.62

Comparing the results in Table 1 to the NJGS base flow values in Table 1-B for the three “mixed province” monitoring stations, indicate that the estimates developed using this method are significantly different. The three “mixed province” monitoring stations yield an average base flow of 0.51 MGD/mi^2, while the results using the method above yields an average base flow for the Basin of 0.37 MGD/mi^2. The reasons for the difference are not known, but could include insufficient examples or biased locations of the “mixed province” monitoring stations, inadequacies of this general technique for estimates, or errors caused by depletive and consumptive water uses. Upcoming efforts by NJDEP to assess depletive/consumptive uses at the watershed level, combined with improved ground water recharge estimates, will be used to update this report when available.

A later version of this technical report will provide information on ground water recharge by Basin, Watershed Management Area, watershed and subwatershed.

Runoff

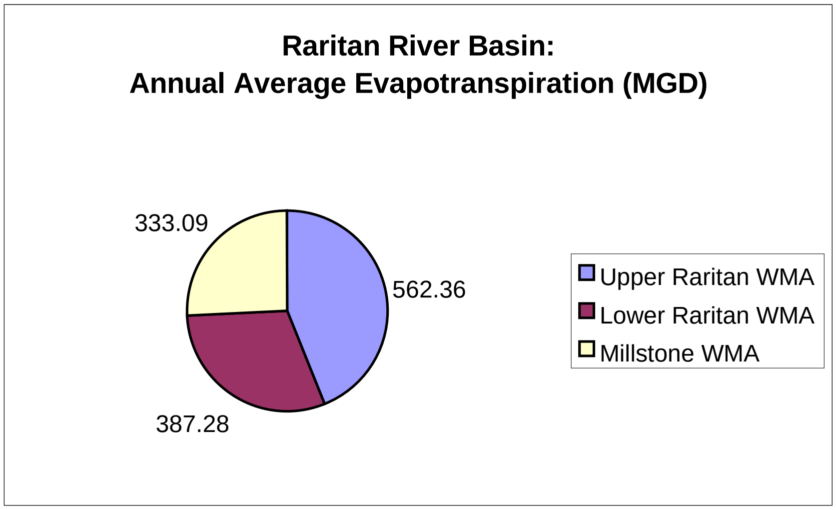
The annual average stream flow values were determined for each of the ten monitoring stations used in the infiltration analysis above. The runoff estimates were calculated by subtracting the infiltration values (as represented by base flow values) from the annual average stream flow values provided by USGS for each monitoring station. The runoff estimates were then expressed in Table 1 as inches per year, cfs, cfs per square mile, MGD and MGD per square mile. The total average runoff for the Basin is approximately 740 MGD, or about 30 percent of total precipitation for the average year. The three Watershed Management Areas show little variation, from 0.65 to 0.68 MGD per square mile. The rates per square mile for individual watersheds are quite variable across the Basin, however, ranging from 0.50 to 0.75 MGD per square mile, with an average of 0.65. This Basin average compares somewhat better than infiltration/recharge to the average from the three "mixed province" monitoring stations of 0.55 MGD per square mile (see Table 1-C).



WATERSHED MGT AREA	Runoff as Percent (%) of Basin
Upper Raritan (WMA 8)	42.88
Lower Raritan (WMA 9)	28.56
Millstone (WMA 10)	26.11

Evapotranspiration

Evapotranspiration values in Table 1 are calculated values, as **ET = P – I – R**, and are expressed in inches per year, cfs, cfs per square mile, MGD and MGD per square mile. The total average evapotranspiration for the Basin is approximately 1340 MGD, or about 53 percent of total precipitation for the average year. The rates per square mile are very consistent across the Basin, ranging from 1.14 to 1.24 MGD per square mile for the three Watershed Management Areas.



WATERSHED MGT AREA	Evapotranspiration as Percent (%) of Basin
Upper Raritan (WMA 8)	42.06
Lower Raritan (WMA 9)	28.97
Millstone (WMA 10)	24.91

Temporal Displacement

The Raritan River Basin has several water supply reservoirs. The smaller ones such as Spruce Run Reservoir and the Lawrence Chain of Lakes receive natural stream flow, while the largest (Round Valley Reservoir) relies on pumped storage. When these facilities are full, there is essentially no temporal displacement in the water budget. Water enters the reservoirs as precipitation, stream flow and ground water contributions, and at the same time a nearly equal volume leaves the reservoirs through evaporation and stream flow. It is when the facilities have available storage capacity that water flow from upstream to downstream locations can be delayed for significant periods of time, ranging from months to years. It is important to note that the total storage capacity of the reservoirs exceeds 66 billion gallons, while the annual runoff in the Basin is approximately 271 billion gallons per year. The total storage is a relatively small percentage of annual water flow in the water budget, especially because that storage is compiled over years of time. As mentioned above, the major impact of temporal displacement is that low flows are augmented. None of the reservoirs has sufficient capacity to significantly attenuated regional flood flows, although some attenuation may occur immediately downstream of the reservoirs.

Depletive/Consumptive Uses

NJDEP performed an analysis of depletive water uses in the early 1990's using data from the late 1980's (Zripko and Hasan, 1994) and used the results in the New Jersey Statewide Water Supply Plan. The primary use of the analysis was in the development of a Water Balance Model for the plan. The data were organized by Regional Water Resource Planning Areas (RWRPAs) as used in the water supply plan; the South River watershed is in RWRPA 11 and the remainder of the Raritan Basin is in RWRPA 10. The depletive uses are broken into three categories – surface water depletive use, ground water depletive use and "Interbasin Transfers." The results from that report are shown in the tables below. The first two values reflect the removal of local waters from that area, and do not include the use of imported water. The last value addresses the movement of water to and from other areas.

As can be seen from the table below, the Raritan RWRPA as of the late 1980's had a significant depletive use of surface water, while the South River RWRPA had almost none. Conversely, the smaller South River area shows a greater depletive use of ground water than the much larger Raritan area. This situation reflects the status of water supply development in the two areas as of that time.

RWRPA	DEPLETIVE USE OF GROUND AND SURFACE WATERS (MGD)
10 -- Raritan	87.52 Surface Water 23.49 Ground Water 111.01 TOTAL
11 – South River	0.84 Surface Water 40.25 Ground Water 41.09 TOTAL

The table below shows that much of the water entering the South River watershed derived from surface water supply sources in the Raritan (RWRPA 10). As discussed in the Statewide Water Supply Plan, that transfer was expected to increase as Raritan Basin surface water supplies replaced the overextended ground water supplies of the South River watershed. The result would be an increased in net out-transfers from RWRPA 10 and both an increase in net in-transfers to RWRPA 11 and a reduction in ground water depletive use.

RWRPA	INTERBASIN TRANSFERS (MGD)	NET TRANSFERS (MGD)
10 -- Raritan	-90.3 (Transfer out by service connections) +48.2 (Transfer in by Delaware & Raritan Canal) -8.9 (Transfer out from Farrington Lake) -4.0 (Transfer out from Spruce Run/Round Valley Reservoirs	-55.0
11 – South River	+6.8 (Transfer in by service connections) +8.9 (Transfer in from Farrington Lake) +18.5 (Transfer in from Delaware & Raritan Canal) +4.0 (Transfer in from Spruce Run/Round Valley Reservoirs)	+38.3

NJDEP anticipates updating the Water Balance Model in FY 2001, including updates of the depletive use and interbasin transfer estimates. A future version of this technical report will incorporate those results. Table 1 includes a "placeholder" for those new estimates.

Safe Yields and Dependable Yields

The safe yields of surface water supply systems in the Raritan River Basin have been extensively studied and modeled. The New Jersey Institute of Technology prepared for NJDEP the primary model used in the Eastern Raritan Feasibility Study, covering the non-tidal Raritan River and its tributaries (i.e., excluding Lawrence Brook and South River). The NJ Water Supply Authority relies on a model for the same area prepared by the U.S. Geological Survey. The Lawrence Brook system has a nominal safe yield of 10 MGD based on earlier studies, though the Eastern Raritan Water Feasibility Study noted that siltation of the Lawrence Chain of Lakes probably had reduced its actual safe yield by 2 to 4 MGD. Surface water supplies in the South River watershed are used primarily to recharge ground water systems in the Old Bridge area. Safe yields for the major surface water supplies are:

WATER SUPPLY	STORAGE	SAFE YIELD	RESPONSIBLE ENTITY
Round Valley/Spruce Run Reservoirs	66 billion gallons	160 MGD	NJ Water Supply Authority
Delaware & Raritan Canal	Not applicable	65 MGD	NJ Water Supply Authority
Lawrence Brook Chain of Lakes	Not available	8 MGD	City of New Brunswick

The dependable yields of aquifers in the Basin are more difficult to determine. Major aquifers tend not to be drought-sensitive, and so the primary issue becomes an aquifer's long-term ability to provide sufficient water for stream flow, human use and aquifer storage levels. As discussed above, the NJ Statewide Water Supply Plan estimated that 20 percent of the total ground water recharge in non-coastal aquifers could be used and not returned to the aquifer without significant harm to stream flows. Coastal aquifers can be sensitive to saltwater intrusion, and so the assumption was made that only 10 percent of total recharge is available from those areas. The assumption made is that ground water recharge will equal stream base flow over long periods, if ground water is not diverted through water supply withdrawals. Based on an NJGS analysis from that time, and the application of the 20 percent threshold for interior aquifers and 10 percent for exterior aquifers, the following quantities are used in the Statewide Water Supply Plan for annual average dependable yields from aquifers in the Basin. On average, this equates to a dependable yield of approximately 0.12 MGD per square mile.

AQUIFER AREA	DEPENDABLE YIELD NJ SWSP	DEPENDABLE YIELD UPDATE (2001?)
Raritan River Basin (except South River)	110 MGD	NA
South River Watershed	25 MGD	NA

Because the South River area is included within the Water Supply Critical Area #1 and is subject to extensive restrictions on ground water withdrawals, NJDEP assumed in the Statewide Water Supply Plan that little if any additional ground water is available from that region. Using the ground water infiltration estimates by the NJDEP-NJ Geological Survey (discussed above), infiltration/recharge values are presented in Table 1. Using a total infiltration/recharge rate of 0.37 MGD per square mile from this technical report, and assuming an availability of 20 percent from the Piedmont and Highlands and 10 percent from the Coastal Plains using the Statewide Water Supply Plan methodology, the dependable yield would be 86 MGD. Clearly the two estimates (86 MGD and 135 MGD) are significantly different, showing the need for further assessment. It is interesting to note that the Eastern Raritan Water Supply Feasibility Study estimated that a total of 79 MGD of ground water is available from the Raritan Basin, a value that is much closer to the 86 MGD estimated in this report. The Statewide Water Supply Plan acknowledged that the use of 10 and 20 percent thresholds was based on empirical evaluation of existing "problem areas" in New Jersey, and should not be used for detailed water management.

It should be recognized also that the estimates for dependable yields of ground water are general estimates for large areas, and are not appropriate for use in small watersheds, site-specific or municipal planning, etc. For such localized applications, estimates should be tailored to the actual area. A later version of this technical report will provide information on ground water recharge by Basin, Watershed Management Area, watershed and subwatershed.

Summary of the Characterization

The water budget developed through this technical report is a broad estimate of precipitation, infiltration/recharge, runoff and evapotranspiration, with an additional characterization of depletive and consumptive uses and a qualitative characterization of some additional water budget issues.

The overall annual average precipitation in the Basin is 2500 million gallons per day, or 2.19 million gallons per day per square mile. Because of the different geology underlying parts of the Basin, the average figures must be used with caution. Varying percentages of precipitation exit the Basin through evapotranspiration, human uses and stream flow, based on differences in land cover, geology, soils and human uses of water.

From this estimate, it can be seen that there is little variation in precipitation (from 2.14 to 2.33 MGD per square mile) and evapotranspiration (from 1.14 to 1.24 MGD per square mile). However, there is considerable variation in infiltration/recharge (from 0.25 to 0.67 MGD per square mile) and runoff (from 0.50 to 0.75 MGD per square mile). The predominant cause of variation among runoff and infiltration/recharge values is undoubtedly geologic in nature, but changes in the landscape can also cause differences, generally by increasing runoff and decreasing infiltration/recharge.

Detailed information can be found on Tables 1, 1-A, 1-B and 1-C.

Assessment of Water Budget Changes

Methodology and Information Sources

Water availability has been studied extensively by the NJDEP over the last 20 years, culminating in the designation of a Water Supply Critical Area affecting the South River watershed area, construction of a pipeline to move surface water supplies to that area, and adoption by NJDEP of a NJ Statewide Water Supply Plan with recommendations for future water supply projects in the Raritan Basin. This assessment relies heavily on the reports and planning documents developed by NJDEP.

Water Budget Problems

In its 1982 Water Supply Master Plan the NJDEP identified two areas where overuse was threatening the long-term reliability of ground water supplies. These areas are referred to as Water Supply Critical Areas (WSCA). In both areas, water levels in the major aquifers were declining and salt water intrusion was evident. One area, WSCA #1,is in part within the Raritan River Basin. It covers Monmouth County and portions of Middlesex and Ocean Counties and includes four depleted aquifers (the Englishtown, Mt. Laurel/Wenonah, Old Bridge and Farrington). In both water supply critical areas, water allocation permittees were required to reduce the use of ground water from the depleted aquifers and develop a replacement supply. In WSCA #1, the reductions of withdrawals went into effect in 1990. Raritan Basin surface water supplies were used as the replacement supply. Since then, USGS has documented substantial increases in the water levels in each of the depleted aquifers. The Englishtown and Mt. Laurel-Wenonah Aquifers have shown fast recoveries (over 100 feet of potentiometric head – a measure of water pressure in a confined aquifer) by 1993. USGS ground water models predict the rise in water levels will continue for approximately ten years before they stabilize. A reanalysis by USGS and NJDEP of WSCA #1 is in progress.

Water Budget Alterations

Precipitation

Precipitation does vary from year to year and within the year. However, for the purposes of this technical report, the primary issue of concern is whether precipitation is showing long-term trends. Changes in climate are important to the Basin. Increased or decreased precipitation will have impacts, as will any trends toward more or fewer severe storms. An increase in severe storms will increase the relative amount of precipitation that becomes runoff. An increase in long, mild storms will increase infiltration/recharge. Increases in rainfall during the non-growing season where ground is not frozen will increase infiltration. However, increases in summer rainfall would probably increase evapotranspiration rates and may only have a limited effect on infiltration/recharge because summer months already have relatively low infiltration/recharge rates due to high evapotranspiration rates. At this time, there are no consensus estimates on precipitation trends and forecasts.

Infiltration/Recharge

As development in the Basin increases, we can reasonably expect a reduction in infiltration/recharge rates. Historically, artificial ground water recharge has not been a component of development projects; the increased runoff is almost always handled solely as a surface water issue.

A future version of this technical report will include an analysis of infiltration/recharge rates based on 1986 land use/land cover and 1995/1997 land use/land cover.

Changes in Stream Flow Estimates

The normal variation in stream flow makes it very difficult to assess incremental changes in stream flows. No new water supply projects have been constructed in the Basin for some time, and no flood control reservoirs of any significant size exist in the Basin. Therefore, the larger changes that such projects can cause would not be evident. It is reasonable to assume that the low (dry weather) flows of streams will drop as the impervious surface ratio increases within a watershed; the level of ground water infiltration/recharge as discussed above will be an important method to evaluate such changes. In addition, increased use of ground water wells (for public water supply, domestic wells, industrial wells, golf courses, agriculture, etc.) can have a significant impact on dry-weather stream flows.

NJDEP anticipates developing a new Water Balance Model with updated estimates of depletive uses in the Basin. A future version of this technical report will include the results of those analyses and compare them to the results of the current Statewide Water Supply Plan to assess changes from 1988 to 2000.

Runoff

As impervious surface increases, the rate of runoff will increase as infiltration/recharge decreases. Population data for the Basin clearly show that many municipalities and subwatersheds have seen very significant growth in the last several decades (see the technical report “Setting of the Raritan River Basin”). A future version of this technical report will incorporate the analysis of ground water recharge and relate it to runoff increases.

Evapotranspiration

One interesting finding of the water budget characterization is that evapotranspiration rates are fairly constant across watersheds and watershed management areas. The various areas have wide differences in development densities and vegetation, and yet evapotranspiration only differs slightly. For this reason, there is some question about whether to expect evapotranspiration rates to change greatly due to the loss or gain of plant cover related to increased development, although changes in irrigation practices could have greater impacts. Climatic changes, however, could have a significant impact but we have no information at this time to know whether such changes have occurred or are anticipated.

Temporal Displacement

As discussed above, the existing water supply system has been in place for decades. Therefore, there have been no significant changes in the temporal displacement of water since the Round Valley Reservoir was first filled.

Depletive/Consumptive Uses

Water is increasingly shifted around the Basin and from the Basin to discharge points elsewhere. The most significant changes in the water supply system over the last twenty years have been the Delaware and Raritan

Canal improvements that greatly increased the importation of water from the Delaware River, and the increased transfer of water into the South River watershed to replace ground water supplies from overextended aquifers.

The most significant changes in the wastewater system have been the gradual but striking extension of sewer lines into former agricultural and forested areas south, southeast and west of the historic urban areas of Middlesex and Union Counties. While some of the wastewater is discharged back into the Raritan Basin, a large quantity is discharged either to the tidal Raritan or the Raritan Bay.

Finally, vegetation changes caused by human action may be changing the consumptive use of water, but this factor is very hard to assess properly. The Basin has been losing agricultural land for decades, but more of the remaining farms use irrigation. As forests are changed to developed lands, evapotranspiration rates change, but the extent of the change depends on the type of forest, the type of new land use, and how water is used on that new land use. The new land uses, such as houses and golf courses, can use very large amounts of water. Spray irrigation, whether for grass or agriculture, has large evaporative losses.

A future version of this technical report will provide the results of the NJDEP assessment of current depletive uses. Consumptive uses probably will not be assessed other than for large water uses such as industry, golf courses and agriculture. The impacts of many small uses will probably be assessed primarily through the analysis of stream flows during dry weather periods; increased consumptive uses will result in less stream flow. However, the availability of new data at the watershed level (11-digit Hydrologic Unit Code) will provide a much greater level of detail regarding this issue than is currently available.

Surface Water Quantity and Quality Interactions

The technical report on "Water Quality Assessment" provides information on surface water quality concentrations and trends. At this time, there are no significant losses of surface water safe yields due to water quality problems caused by human action. Natural quality (especially the salinity of the estuarine Raritan and South Rivers) creates limitations on water quality use that can only be overcome by the use of treatment technology. No current proposals or plans anticipated the use of desalination technology in the Raritan Basin.

Ground water availability, on the other hand, has been significantly affected by ground water quality in several areas. The Elizabethtown Water Company has closed a large number of wells over the last twenty years due to local contamination problems. South Brunswick and other municipal water systems have also experienced industrial contamination of wells that have forced the use of treatment or alternate supplies. The technical report, "Ground Water", will address this issue in more detail.

Data, Information and Assessment Needs for Water Budgets

As population increases in the Raritan Basin, there will be an increased need to periodically characterize and assess the water budget of the region. Critical needs include:

1. Periodic updates of land use and land cover, including impervious surface estimates for each land use or land cover area mapped;

2. Periodic updates of depletive and consumptive water uses;

3. Periodic updates of stream flows, including an assessment of the extent to which those flows are modified by surface water or ground water withdrawals;

4. Periodic assessments of changes in infiltration/recharge and runoff rates;

5. An improved understanding of ground water dependable yields at a watershed scale, replacing the current analyses at a near-Basin scale.

Conclusions

The Raritan River Basin benefits from a moderate climate with well over 40 inches of precipitation per year, on average. Geologic and soil differences among the watersheds of the Basin result in wide differences regarding rates of infiltration/recharge and runoff. Evapotranspiration, on the other hand, is relatively constant around the Basin.

There is a wide variety of impacts that human activity (e.g., land development, movement of water and wastewater between watersheds, consumptive uses of water such as irrigation) can have on the natural water budget. The Raritan Basin has both significant water imports (through the Delaware and Raritan Canal) and significant inter-watershed exports (e.g., from the Basin to the Raritan Bay, from the Basin to other river basins). Increased impervious surfaces will tend to increase runoff and decrease infiltration/recharge to ground water, resulting in higher storm flows and lower dry weather flows in watershed streams.

This characterization and assessment is based on a spreadsheet analysis of water budget components using readily available information and a long-term averaging period. More detailed analyses are possible using sophisticated models at the watershed or Basin scale, but were beyond the scope of Phase 1 of the Raritan Basin Watershed Management Project.

Glossary of Terms for Water Budgets

"Aquifer" means any water-saturated zone in sedimentary or rock stratum that is significantly permeable so that it may yield sufficient quantities of water from wells or springs in order to serve as a practical source of water supply.

"Allocation permit" means the document issued by the NJDEP to a person, granting that person the privilege, so long as the person complies with the conditions of the permit, to divert water for any purpose other than agricultural or horticultural use.

"Confined aquifer" is an aquifer that is overlain by a relatively impermeable or significantly less permeable material so that its water is under pressure. If a well was installed, the water would rise above the top of the aquifer.

"Confining Unit" means a body of relatively impermeable material that is above or below one or more aquifers, restricting the flow of water to or from the aquifer(s)

"*Consumptive water use*" means the use of water in such as way that a portion of the water used is lost to evaporation, transpiration, incorporation in product, etc., and not discharged to any location.

"Critical water supply area" or "critical area" means a water supply area in which it is officially determined by the New Jersey Department of Environmental Protection, after public notice and a public meeting, that adverse conditions exist, related to the ground or surface water, which require special measures in order to achieve the objectives of the Water Supply Management Act.

"Dependable yield of combined surface/ground water sources" means the yield of water by a water system that is available continuously throughout a repetition of the most severe drought of record, without causing undesirable effects.

"Depletive water use" means the withdrawal of water from a water supply resource (ground or surface water) where the water, once used, is not discharged to the same water supply resource in such a manner as to be useable within the same watershed.

"Drought" means a condition of dryness due to lower than normal precipitation, resulting in reduced stream flows, reduced soil moisture and/or lowering of the potentiometric surface in wells.

"Facility" means a medium through which the base source is transmitted to the user. It is either man-made or manipulated in an attempt to maximize the water that may be derived from a base source. A facility for ground water is a well or well field and for surface waters is a reservoir or intake facility.

"Fresh water" means all nontidal and tidal waters generally having a salinity due to natural sources of less than or equal to 3.5 parts per thousand at near high tide.

"*Impervious surface*" means an artificial surface (such as pavement, concrete, buildings or compacted earth) that prohibits or essentially prohibits the infiltration of water from the land surface into the ground.

"Interbasin transfer" means the movement of water (as raw, treated or used water) from one watershed to another.

"Multiple sources" means one or more production wells, surface water intakes, or interconnection or a combination of wells, surface water intakes or interconnections utilized to meet the demands of a public community water system.

"Normal demand" means the annual average demand during the three preceding non-drought years, including normally occurring peaks.

"Potable water" means water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption using conventional water treatment processes (e.g., chemical coagulation/flocculation, clarification, filtration, disinfection).

"Purveyor" means any company, authority, or person who owns or operates a public community water supply system.

"Safe yield from surface sources" means the yield maintainable by a water system continuously throughout a repetition of the most severe drought of record, after compliance with requirements of maintaining minimum passing flows, assuming no significant changes in upstream or upgradient depletive withdrawals.

"Semi-confined aquifer" is an aquifer that is overlain by a layer of material with low permeability, which permits water to slowly flow through it to recharge the underlying aquifer.

"Single prime source" means a single diversion of surface or ground water, including an interconnection, capable of providing the peak water demand of a public community water supply system.

"Stipulated surface water withdrawals" these are surface water uses that are not supported by storage, have no associated safe yield, and can be rescinded during droughts.

"Treated wastewater" means the treated spent water of a community. From the standpoint of source, it may be a combination of the liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with any ground water, surface water, and storm water that may be present.

"Unconfined aquifer" means an aquifer close to the land surface with continuous layers of materials with high permeability, extending from the land surface to the base of the aquifer. This type of aquifer has a water table.

"User" means any person or other entity that utilizes water.

"Water allocation: or certification" means the authority to withdraw surface or groundwater for use, pursuant to a permit issued under N.J.A.C. 7:19-1 et seq. or 7:20A-1.1 et seq.

"Watershed" means a geographic area in which all water, sediments and dissolved material drain to a particular receiving body.

"Watershed Management Plan" means a strategy of which the goals and objectives are to achieve the restoration, protection and management of the water resources and any associated uses within the watershed.

"Water supply deficit" means the amount or amounts by which the available resources fall short of a given demand.

"Water supply system" means a facility for providing potable water.

"Water table" means the water surface of the water-saturated zone that is at atmospheric pressure.

"Water table aquifer" is synonymous with unconfined aquifer.

"Yield of a water resource system" means the output of water from a system, available with monthly variations corresponding to the needs of the system.

Common Acronyms for Water Budgets

cfs	cubic feet per second
gpcd	gallons per capita (person) per day
HUC	Hydrologic Unit Code
MGD	million gallons per day
NJDEP	NJ Department of Environmental Protection
NJGS	New Jersey Geological Survey
NJPDES	NJ Pollutant Discharge Elimination System
NJSWSP	1995 NJ Statewide Water Supply Plan
RWRPA	Regional Water Resource Planning Areas
USGS	US Geological Survey
WBM	Water Balance Model
WSCA	Water Supply Critical Area
WSMA	Water Supply Management Act

References for Water Budgets

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Figure 1

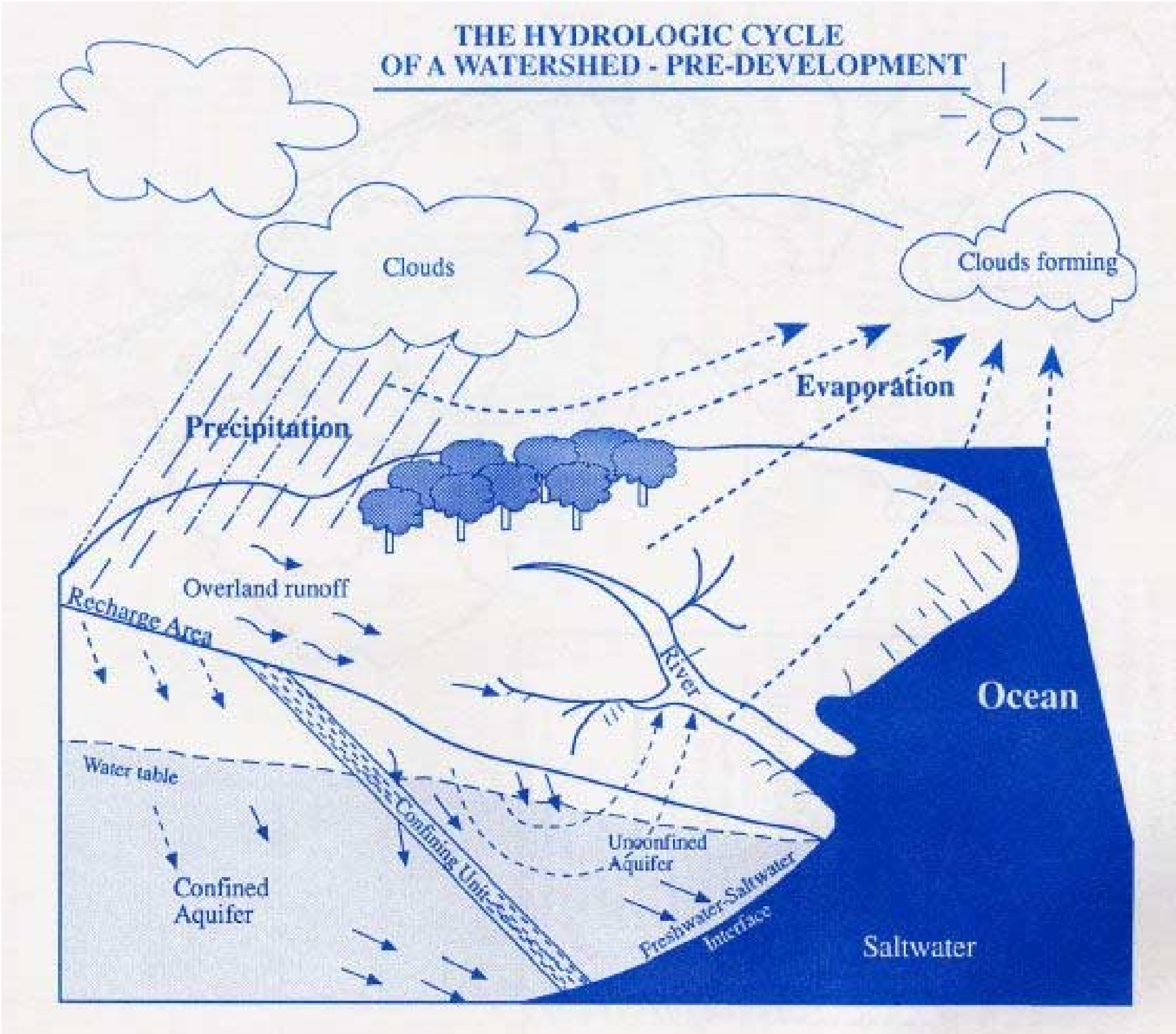
THE HYDROLOGIC CYCLE
OF A WATERSHED - PRE-DEVELOPMENT
Clouds
Clouds forming
Evaporation
Precipitation
Overland runoff
Recharge Area
River
Ocean
Water table
Confining Unit
Unconfined
Aquifer
Confined
Aquifer
Freshwater-Saltwater
Interface
Saltwater

Figure 2

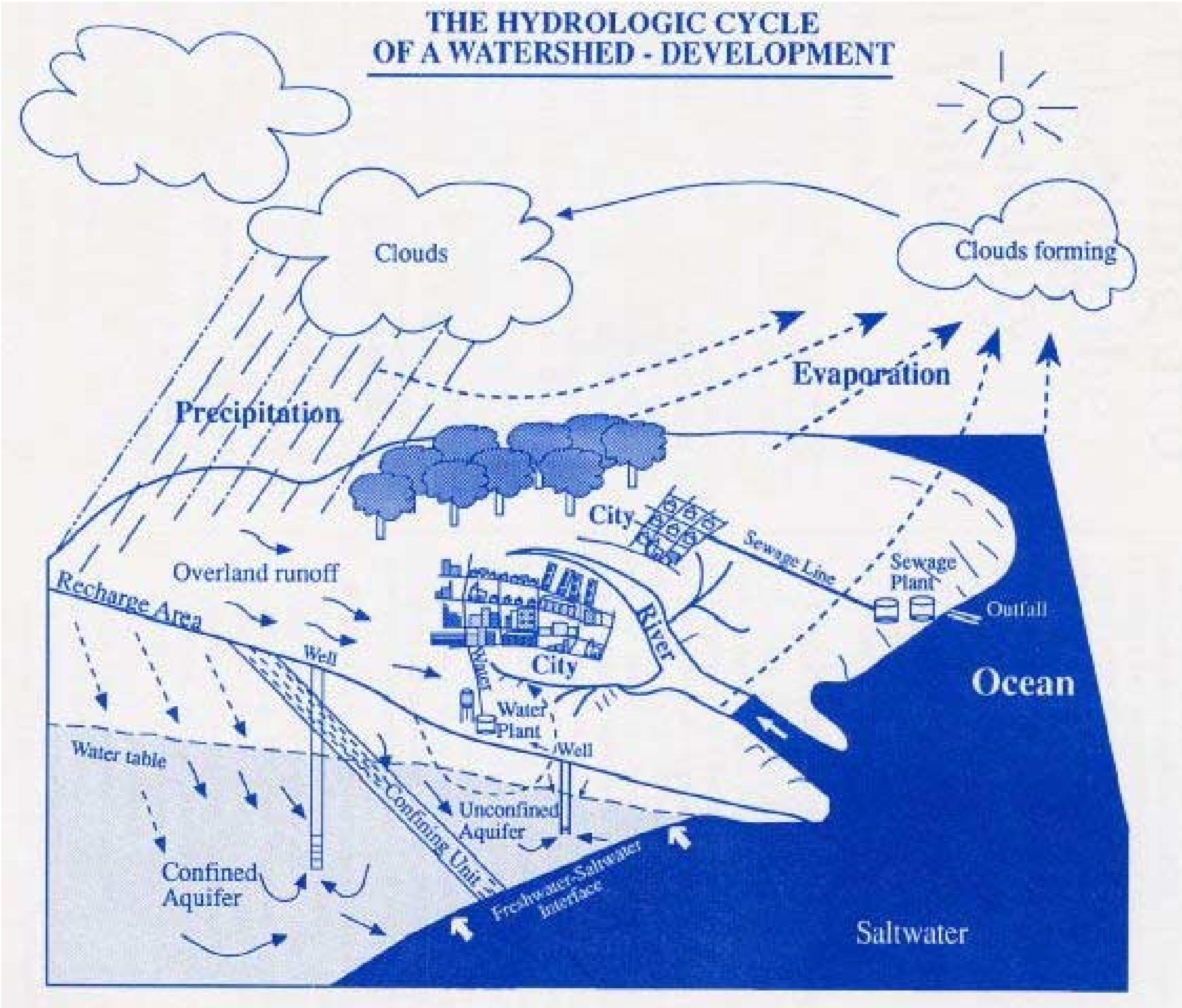
THE HYDROLOGIC CYCLE
OF A WATERSHED - DEVELOPMENT
Clouds
Clouds forming
Evaporation
Precipitation
City
Sewage Line
Sewage Plant
Outfall
Overland runoff
Recharge Area
Well
River
City
Ocean
Water Plant
Well
Water table
Confining Unit
Unconfined Aquifer
Confined Aquifer
Freshwater-Saltwater Interface
Saltwater

Figure 3

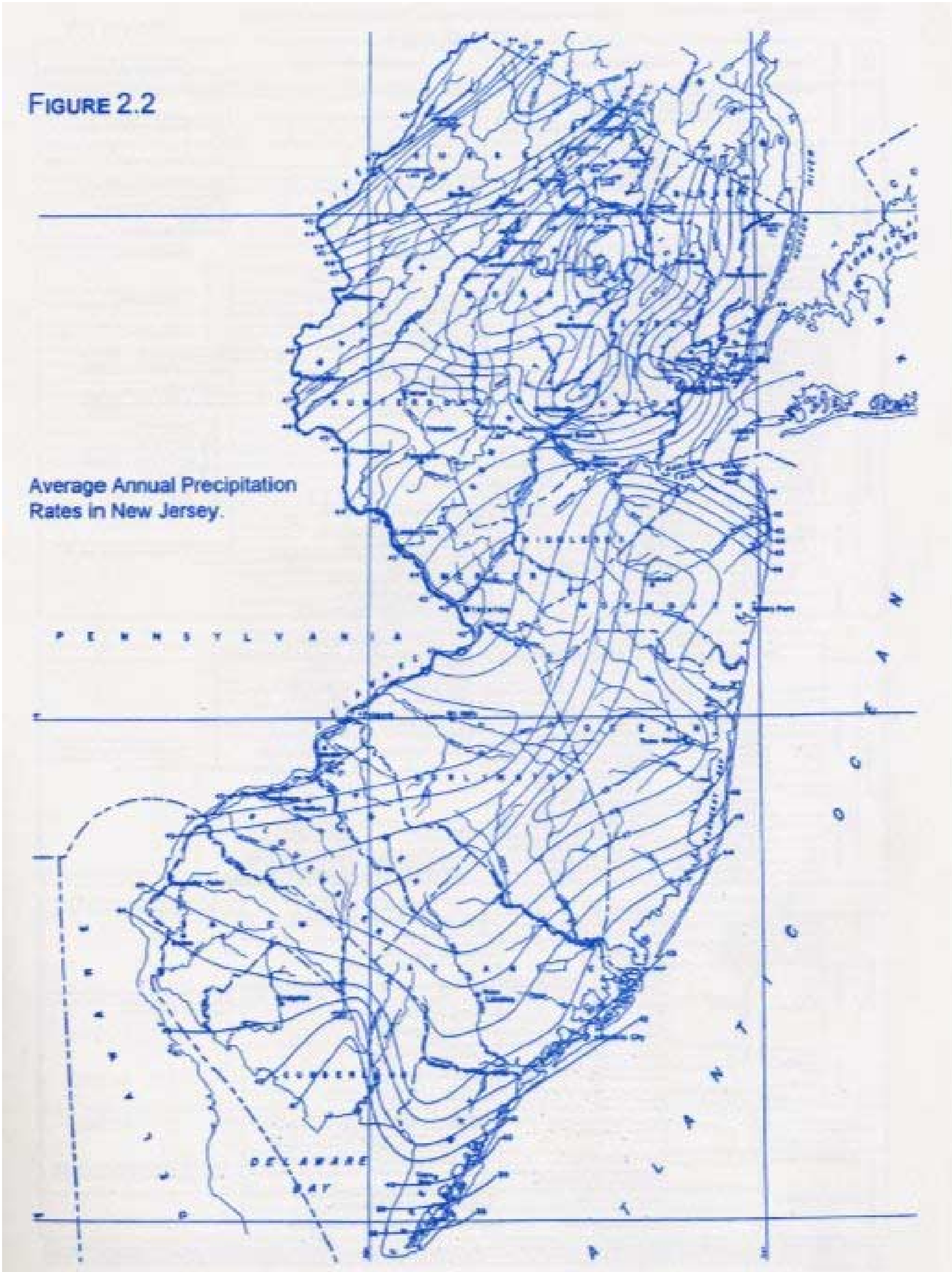
FIGURE 2.2
Average Annual Precipitation Rates in New Jersey.
P E N N S Y L V A N I A
DELAWARE BAY

TABLE 1:
Raritan River Basin Water Budget

WATERSHED AREA		**Raritan River Basin**	**Upper Raritan WMA**	Upper South Branch Raritan River	Middle South Branch Raritan River/Spruce Run	Neshanic River	Lower South Branch Raritan River	Lamington River	Upper North Branch Raritan River	Lower North Branch Raritan River	Raritan River Confluence	**Lower Raritan WMA**	Green Brook/Lower Raritan River	Lawrence Brook	Manalapan Brook	Matchaponix Brook	South River/Tidal Raritan River	**Millstone WMA**	Stony Brook	Upper Millstone River	Lower Millstone River/Bedens Brook
Land Area	$miles^2$	1144.25	490.33	70.96	108.32	55.73	41.84	99.31	63.96	25.55	24.66	326.96	119.34	46.21	43.92	44.25	73.24	284.59	55.37	98.83	130.39
Precipitation	inches	45.92	46.54	48.84	46.01	45.00	45.00	47.22	47.37	45.00	45.00	45.46	45.00	45.28	46.00	46.00	45.67	45.32	45.05	45.88	45.00
	MGD	2503.02	1087.00	165.08	237.42	119.46	89.69	223.40	144.33	54.77	52.86	708.01	255.81	99.67	96.24	96.96	159.33	614.31	118.83	215.99	279.49
	MGD/mi^2	2.19	2.22	2.33	2.19	2.14	2.14	2.25	2.26	2.14	2.14	2.17	2.14	2.16	2.19	2.19	2.18	2.16	2.15	2.19	2.14
	cfs	3872.71	1681.83	255.41	367.34	184.83	138.76	345.64	223.32	84.74	81.78	1095.44	395.79	154.21	148.90	150.02	246.52	950.47	183.85	334.19	432.44
	cfs/mi^2	3.38	3.43	3.60	3.39	3.32	3.32	3.48	3.49	3.32	3.32	3.35	3.32	3.34	3.39	3.39	3.37	3.34	3.32	3.38	3.32
Recharge	inches	7.76	8.81	14.13	7.60	5.25	5.25	10.40	10.74	5.25	5.25	6.96	5.25	6.30	8.97	8.97	7.75	6.43	5.45	8.53	5.25
(From Infiltration)	MGD	422.72	205.85	47.75	39.21	13.95	10.47	49.17	32.73	6.39	6.17	108.43	29.87	13.86	18.77	18.91	27.03	87.15	14.37	40.14	32.63
	MGD/mi^2	0.37	0.42	0.67	0.36	0.25	0.25	0.50	0.51	0.25	0.25	0.33	0.25	0.30	0.43	0.43	0.37	0.31	0.26	0.41	0.25
	cfs	318.50	318.50	73.88	60.67	21.58	16.20	76.08	50.64	9.89	9.55	167.77	46.21	21.44	29.04	29.25	41.83	134.84	22.24	62.11	50.49
	cfs/mi^2	0.57	0.65	1.04	0.56	0.39	0.39	0.77	0.79	0.39	0.39	0.51	0.39	0.46	0.66	0.66	0.57	0.47	0.40	0.63	0.39
Runoff	inches	13.60	13.61	10.37	14.35	15.78	15.78	12.65	12.44	15.78	15.78	13.59	15.78	14.45	11.02	11.02	12.59	14.28	15.53	11.59	15.78
	MGD	743.38	318.79	35.15	74.26	42.01	31.54	59.99	37.99	19.26	18.59	212.29	89.97	31.89	23.12	23.29	44.03	194.08	41.08	54.70	98.30
	MGD/mi^2	0.65	0.65	0.50	0.69	0.75	0.75	0.60	0.59	0.75	0.75	0.65	0.75	0.69	0.53	0.53	0.60	0.68	0.74	0.55	0.75
	cfs	1150.17	493.24	54.38	114.89	65.00	48.80	92.82	58.78	29.80	28.76	328.46	139.20	49.34	35.77	36.04	68.12	300.28	63.56	84.63	152.09
	cfs/mi^2	1.01	1.01	0.77	1.06	1.17	1.17	0.93	0.92	1.17	1.17	1.00	1.17	1.07	0.81	0.81	0.93	1.06	1.15	0.86	1.17
Evapotranspiration	inches	24.56	24.11	24.34	24.06	23.96	23.96	24.18	24.20	23.96	23.96	24.90	23.96	24.54	26.01	26.01	25.34	24.61	24.07	25.77	23.96
	MGD	1336.92	562.36	82.18	123.95	63.50	47.67	114.23	73.62	29.11	28.10	387.28	135.98	53.92	54.35	54.76	88.27	333.09	63.37	121.15	148.57
	MGD/mi^2	1.17	1.15	1.16	1.14	1.14	1.14	1.15	1.15	1.14	1.14	1.18	1.14	1.17	1.24	1.24	1.21	1.17	1.14	1.23	1.14
	cfs	2404.04	870.09	127.15	191.78	98.25	73.76	176.74	113.90	45.04	43.47	599.21	210.38	83.43	84.09	84.73	136.58	515.36	98.05	187.44	229.86
	cfs/mi^2	1.81	1.77	1.79	1.77	1.76	1.76	1.78	1.78	1.76	1.76	1.83	1.76	1.81	1.91	1.91	1.86	1.81	1.77	1.90	1.76
Depletive Uses	inches																				
(to be added from	MGD																				
upcoming NJDEP	MGD/mi^2																				
report)	cfs																				
	cfs/mi^2																				

Data Sources: See Tables 1-A, 1-B and 1-C

Table 1-A
Precipitation, Recharge (Infiltration) and Runoff by Hydrologic Unit

	Area (sq.mi.)				Portion of Area			Annual Average Precipitation					Annual Average Recharge (Infiltration)					Annual Average Runoff				
HUC 11 Area	Total	Highlands	Piedmont	Coastal	Highlands	Piedmont	Coastal	Inches	MGD	MGD/mi^2	cfs	cfs/mi^2	Inches	MGD	MGD/mi^2	cfs	cfs/mi^2	Inches	MGD	MGD/mi^2	cfs	cfs/mi^2
BASIN	1144.25	188.77	654.88	300.6	0.16	0.57	0.26	45.92	2503.02	2.19	3872.71	3.38	7.76	422.72	0.37	654.03	0.57	13.60	743.38	0.65	1150.17	1.01
Upper Raritan WMA	490.33	188.77	301.56	0	0.38	0.62	0.00	46.54	1087.00	2.22	1681.83	3.43	8.81	205.85	0.42	318.50	0.65	13.61	318.79	0.65	493.24	1.01
02030105010 -- Upper South Branch	70.96	68.1	2.86	0	0.96	0.04	0.00	48.84	165.08	2.33	255.41	3.60	14.13	47.75	0.67	73.88	1.04	10.37	35.15	0.50	54.38	0.77
02030105020 -- Middle South Branch/Spruce Run	108.32	27.48	80.84	0	0.25	0.75	0.00	46.01	237.42	2.19	367.34	3.39	7.60	39.21	0.36	60.67	0.56	14.35	74.26	0.69	114.89	1.06
02030105030 -- Neshanic River	55.73	0	55.73	0	0.00	1.00	0.00	45.00	119.46	2.14	184.83	3.32	5.25	13.95	0.25	21.58	0.39	15.78	42.01	0.75	65.00	1.17
02030105040 -- Lower South Branch	41.84	0	41.84	0	0.00	1.00	0.00	45.00	89.69	2.14	138.76	3.32	5.25	10.47	0.25	16.20	0.39	15.78	31.54	0.75	48.80	1.17
02030105050 -- Lamington	99.31	55.22	44.09	0	0.56	0.44	0.00	47.22	223.40	2.25	345.64	3.48	10.40	49.17	0.50	76.08	0.77	12.65	59.99	0.60	92.82	0.93
02030105060 -- Upper North Branch	63.96	37.97	25.99	0	0.59	0.41	0.00	47.37	144.33	2.26	223.32	3.49	10.74	32.73	0.51	50.64	0.79	12.44	37.99	0.59	58.78	0.92
02030105070 -- Lower North Branch	25.55	0	25.55	0	0.00	1.00	0.00	45.00	54.77	2.14	84.74	3.32	5.25	6.39	0.25	9.89	0.39	15.78	19.26	0.75	29.80	1.17
02030105080 -- Raritan Confluence	24.66	0	24.66	0	0.00	1.00	0.00	45.00	52.86	2.14	81.78	3.32	5.25	6.17	0.25	9.55	0.39	15.78	18.59	0.75	28.76	1.17
Lower Raritan WMA	326.96	0	176.66	150.3	0.00	0.54	0.46	45.46	708.01	2.17	1095.44	3.35	6.96	108.43	0.33	167.77	0.51	13.59	212.29	0.65	328.46	1.00
02030105120 -- Green Brook/Lower Raritan	119.34	0	119.34	0	0.00	1.00	0.00	45.00	255.81	2.14	395.79	3.32	5.25	29.87	0.25	46.21	0.39	15.78	89.97	0.75	139.20	1.17
02030105130 -- Lawrence Brook	46.21	0	33.25	12.96	0.00	0.72	0.28	45.28	99.67	2.16	154.21	3.34	6.30	13.86	0.30	21.44	0.46	14.45	31.89	0.69	49.34	1.07
02030105140 -- Manalapan Brook	43.92	0	0	43.92	0.00	0.00	1.00	46.00	96.24	2.19	148.90	3.39	8.97	18.77	0.43	29.04	0.66	11.02	23.12	0.53	35.77	0.81
02030105150 -- Matchaponix Brook	44.25	0	0	44.25	0.00	0.00	1.00	46.00	96.96	2.19	150.02	3.39	8.97	18.91	0.43	29.25	0.66	11.02	23.29	0.53	36.04	0.81
02030105160 -- South River/Tidal Raritan	73.24	0	24.07	49.17	0.00	0.33	0.67	45.67	159.33	2.18	246.52	3.37	7.75	27.03	0.37	41.83	0.57	12.59	44.03	0.60	68.12	0.93
Millstone WMA	284.59	0	194.62	89.97	0.00	0.68	0.32	45.32	614.31	2.16	950.47	3.34	6.43	87.15	0.31	134.84	0.47	14.28	194.08	0.68	300.28	1.06
02030105090 -- Stony Brook	55.37	0	52.46	2.91	0.00	0.95	0.05	45.05	118.83	2.15	183.85	3.32	5.45	14.37	0.26	22.24	0.40	15.53	41.08	0.74	63.56	1.15
02030105100 -- Upper Millstone	98.83	0	11.77	87.06	0.00	0.12	0.88	45.88	215.99	2.19	334.19	3.38	8.53	40.14	0.41	62.11	0.63	11.59	54.70	0.55	84.63	0.86
02030105110 -- Lower Millstone/ Bedens Brook	130.39	0	130.39	0	0.00	1.00	0.00	45.00	279.49	2.14	432.44	3.32	5.25	32.63	0.25	50.49	0.39	15.78	98.30	0.75	152.09	1.17

Data Sources: NJDEP (hydrologic unit areas); NJWSA (portion of area); Table 1-C (runoff by province)

Table 1-B
Stream Base Flow by Province

Stream Gaging Station	Drainage Area mi2	Mean Base flow---------------------- inches	cfs	cfs/mi2	mgd/mi2	Base flow exceedance -------------------------------- 90% cfs	50% cfs	90% cfs/mi2	50% cfs/mi2	90% mgd/mi2	50% mgd/mi2	USGS 7Q10 cfs
Inner Coastal Plain Province												
01400730 Millstone River at Plainsboro NJ	65.80	9.07	43.94	0.67	0.43	12.26	39.89	0.19	0.61	0.12	0.39	4.70
01405300 Matchaponix Brook at Spotswood NJ	43.90	8.87	28.67	0.65	0.42	8.35	25.98	0.19	0.59	0.12	0.38	3.20
Average Values		8.97	36.30	0.66	0.43							
Piedmont Province - Glacial Drift Thin or Absent												
01398500 Walnut Brook at Flemington	2.24	6.41	1.06	0.47	0.30	0.01	0.59	0.00	0.26	0.00	0.17	0.00
01402600 Royce Brook Tributary near Belle Mead NJ	1.20	4.23	0.37	0.31	0.20	0.01	0.25	0.01	0.21	0.01	0.13	NA
01398000 Neshanic River at Reaville NJ	25.70	5.51	10.42	0.41	0.26	0.75	6.34	0.03	0.25	0.02	0.16	0.30
01403500 Green Brook at Plainfield NJ	9.75	5.00	3.59	0.37	0.24	0.14	2.24	0.01	0.23	0.01	0.15	0.00
01401000 Stony Brook at Princeton NJ	44.50	5.12	16.77	0.38	0.24	0.96	10.16	0.02	0.23	0.01	0.15	0.10
Average Values		5.25	6.44	0.39	0.25							
Highlands Province												
01396500 So. Branch Raritan River near High Bridge NJ	65.30	14.96	71.92	1.10	0.71	26.86	59.25	0.41	0.91	0.27	0.59	21.00
01398500 North Branch Raritan River near Far Hills NJ	26.20	13.89	26.79	1.02	0.66	6.55	20.97	0.25	0.80	0.16	0.52	2.40
01399500 Lamington (Black) River near Pottersville NJ	32.80	14.65	35.37	1.08	0.70	10.06	28.46	0.31	0.87	0.20	0.56	4.80
Average Values		14.5	44.69	1.07	0.69							
Mixed Province												
01400500 Raritan River at Manville NJ	490.00	9.43	340.17	0.69	0.45	78.47	261.46	0.16	0.53	0.10	0.34	48.00
01397000 South Branch Raritan River at Stanton NJ	147.00	12.28	132.89	0.90	0.58	38.15	106.35	0.26	0.72	0.17	0.47	31.00
01400000 North Branch Raritan River near Raritan NJ	190.00	10.30	144.07	0.76	0.49	36.49	111.49	0.19	0.59	0.12	0.38	19.00
Average Values		10.67	205.71	0.79	0.51							

Source: R. Canace, NJDEP-New Jersey Geological Survey, 1999

Table 1-C
Precipitation and Runoff by Province

Stream Gaging Station	Drainage Area mi2	Mean Precip (inches)	Mean Stream Flow cfs	Mean Base Flow cfs	Mean Runoff cfs	Mean Runoff cfs/mi2	Mean Runoff MGD	Mean Runoff MGD/mi2
Inner Coastal Plain Province								
01400730 Millstone River at Plainsboro NJ	65.80		100.4	43.94	56.46	0.86	36.49	0.55
01405300 Matchaponix Brook at Spotswood NJ	43.90		62.5	28.67	33.83	0.77	21.87	0.50
Average Values		46				0.81		0.53
Piedmont Province - Glacial Drift Thin or Absent								
01398500 Walnut Brook at Flemington	2.24		3.23	1.06	2.17	0.97	1.40	0.63
01402600 Royce Brook Tributary near Belle Mead NJ	1.20		2.42	0.37	2.05	1.71	1.32	1.10
01398000 Neshanic River at Reaville NJ	25.70		38	10.42	27.58	1.07	17.82	0.69
01403500 Green Brook at Plainfield NJ	9.75		12.9	3.59	9.31	0.95	6.02	0.62
01401000 Stony Brook at Princeton NJ	44.50		67	16.77	50.23	1.13	32.46	0.73
Average Values		45				1.17		0.75
Highlands Province								
01396500 So. Branch Raritan River near High Bridge NJ	65.30		123	71.92	51.08	0.78	33.02	0.51
01398500 North Branch Raritan River near Far Hills NJ	26.20		48.5	26.79	21.71	0.83	14.03	0.54
01399500 Lamington (Black) River near Pottersville NJ	32.80		56.3	35.37	20.93	0.64	13.52	0.41
Average Values		49				0.75		0.48
Mixed Province								
01400500 Raritan River at Manville NJ	490.00		780	340.17	439.83	0.90	284.28	0.58
01397000 South Branch Raritan River at Stanton NJ	147.00		249	132.89	116.11	0.79	75.04	0.51
01400000 North Branch Raritan River near Raritan NJ	190.00		312	144.07	167.93	0.88	108.54	0.57
Average Values						0.86		0.55

Data Sources: R. Canace, NJGS (mean base flow, drainage area); USGS Water Resources Data - NJ, 1998 (mean stream flow)