New Jersey Highlands Water Protection and Planning Council
Water Resource Management Technical Advisory Committee Work Group
Supplemental Materials

Overview of Water Capacity Analysis Methods and Methods Comparison

Deliberative Working Draft for TAC Members - Not for General Public Distribution

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Introduction

This technical memorandum provides an overview and comparison of the water capacity analyses being performed in support of the Highlands Regional Master Plan. This document is intended to address comments received to date regarding the *New Jersey Highlands Council Regional Master Plan Scoping Document* (Draft; January 2006) and to facilitate discussion among members of the Highlands Water Resource Management Technical Advisory Committee (TAC) members regarding the technical approaches under development by the Highlands Council. This is a working draft document that is intended for use by members of the TAC only and is not intended for public distribution.

It provides an introduction to the methods being employed to assess water capacity, a discussion of various alternative approaches, and an overview of critical policy decisions and technical assumptions that will be necessary to evaluate the issue of water capacity in the Highlands within the established timeframe for adoption of a Regional Master Plan. Once completed, a detailed technical report including the water capacity analysis will be prepared and distributed for public comment.

This revised document supplements the information provided to the TAC on 28 March 2006 by including a comparison of preliminary results utilizing the Low Flow Margin Method currently under development by the Highlands Council, with other approaches.

The New Jersey Highlands Council retained the services of the United States Geological Survey (USGS), New Jersey Water Science Center to provide expert technical support to the Highlands Council to assist in developing appropriate methods to assess ground water capacity in the Highlands Region. The results of their analysis will help to inform subsequent policy decisions regarding surface and ground water protection requirements and available water supply, which in turn will be used by the Highlands Council to establish sustainable limits to growth within the Highlands Region. This memorandum provides a discussion of the methods being utilized by USGS to estimate water capacity, and an explanation of the additional analysis needed to allow the Highlands Council to make any subsequent policy decisions regarding "ground water availability" and "ecological flow need".

It is important to note that while USGS is providing the scientific analyses to help inform policy decisions, they will not be making those policy decisions or how these policies will be implemented. That is the work of the Highlands Council, with some decisions requiring ongoing coordination with other State agencies, most notably the New Jersey Department of Environmental Protection.

The USGS study is designed to be used in concert with numerous other data, analyses, statutory and planning mechanisms to determine the amount of ground water necessary to protect the ecological integrity of Highlands waters and that which is “available” for human (i.e., potable water supply, industrial, agricultural) use. This approach is intended to aid the Council in meeting the dual goals of protecting water supply and ecological stream integrity; goals that the Council has already committed to uphold.

One of the major objectives of the Highlands Regional Master Plan is to promote consistency among municipal, county and state levels of government so that local zoning and land use decisions comply with state resource protection policies and are consistent with “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 Highlands 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.

Purpose of the Analyses

The Highlands Council is guided by the Highlands Act, which calls for the Regional Master Plan to 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 providing for ecological protection. Because every human use has the potential for impact on ecological resources, the methods must address the acceptability of those impacts on the ecological resources. The Highlands Council anticipates that there will be a range of policies that will affect the final determination of what water is “available”.

Although these policy decisions are still under development, the range of policy decisions may include determining that in some areas water use may already exceed available supply, other areas may have no remaining water available for additional human uses, or some may have “available” water that can support additional increases in human population and use. In turn, water availability will drive or constrain, in part, the potential for future development and redevelopment within various areas of the Highlands.

The Highlands Council has focused on ground water availability because nearly all Highlands communities rely on ground water for their drinking water supplies. The Council also recognizes that ground water is integrally connected with surface water supplies and ecosystem integrity. The line between surface and ground water is a fine one that is crossed continually in the natural world.

Ground water is the primary source of water for residents within the Highlands and is a critical component contributing to stream flow. Detailed knowledge of water availability statistics is required to make sound decisions regarding water resource planning, management and regulation. This information is especially critical for estimating ground and surface water availability for water supply, agricultural, industrial and recreational purposes - and for meeting the Highlands goal of maintaining the ecological integrity of Highlands critical water resources. Assessment of the ground water capacity of Highlands watersheds will help to maintain, enhance and restore stream habitat and ecological health while addressing the sometimes competing demands for ground water use and supply needs..

To gain a better understanding of ground water capacity in the Highlands, the Council is utilizing various statistical methods to help inform its work in developing the Regional Master Plan. 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 of water uses (ecological and human) from changes in hydrologic conditions. Models are simplifications of real world conditions, and as such help to make complex decision making feasible.

The Highlands Council recognizes that no model is capable of leading directly to decisions; they are decision aids, not decision determinants. Therefore, results from the model or models chosen must be applied in conjunction with policies and with the results from many other analyses (e.g., ecological resource assessments, identification of open space preservation goals and priorities, utility capacity, growth pattern preferences) before a final estimate of water availability can be developed. Any approach that is used for estimating ground 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.

Considerations in Selecting an Appropriate Method

The Highlands Council will more clearly define the basis upon which subsequent decisions will be made regarding water availability as the Regional Master Plan continues to be developed.

The technical approach for estimating ground water capacity currently under development is based on an understanding of the following major and practical considerations, which will be refined or in some cases, overcome as the Council advances with its planning efforts:

1. New Jersey lacks a commonly accepted, regionally applicable method for defining the “available ground water” for human use within watersheds. The 1996 New Jersey Statewide Water Supply Plan uses a method (20% of annual average recharge) that was considered applicable only to major aquifers (e.g., Buried Valley, Piedmont or Coastal Plain) and therefore is not applicable to the full Highlands. In addition, this method was based on empirical evidence, not detailed statistical analyses. NJDEP water allocation

decisions are based on safe yield models (for surface water) and site-specific analyses (for ground water); unless more sophisticated ground water models are available. The few ground water models that do exist for the Highlands are not sufficient to cover the entire region. Although the Highlands Council acknowledges the need for, and has made a long-term commitment to fully evaluate the ecological flow needs of streams, for purposes of Regional Master Plan development, the Highlands Council must rely on currently available data and methods in the short term.

2. Various methods have been used or developed that could be considered for defining the effects of ground water withdrawals and the derivation of "available ground water"
    a. The Delaware River Basin Commission 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.
    b. NJGS developed a "Low Flow Margin of Safety" approach for potential use in the Statewide Water Supply Plan update process.
    c. NJDEP and USGS are nearing completion of a major modeling approach known as the "Ecological Flow Goals" approach or Hydro-ecological Integrity Model, with the ultimate intent of using this approach in NJDEP's water allocation process. This method addresses many, if not all, of the issues raised by The Nature Conservancy and others on stream flows for ecological support purposes.

As noted above, none of these three methods is routinely used or currently accepted for water supply planning or regulatory purposes in New Jersey. Of the three, the Ecological Flow Goals may best approximate a "gold standard" for future water capacity analysis -but is not ready for Highlands-wide use at this time due to gaps in data availability and the need for to complete the method development process. Therefore, other approaches must be used for the entire region.

    d. Methods recommended by other parties (e.g., Aquatic Base Flow, Tennant) have been developed primarily to protect stream flows from the impact of surface water diversions (which can be altered as needed through flow controls). They are generally considered inapplicable to consumptive use impacts of ground water diversions (which cannot be altered on a schedule because the impacts occur over lengthy periods and are not structurally controlled). Both of these methods require maintenance of surface water flows at specified levels during specific low flow months. For surface water diversions this is achieved through releases from storage. It should be noted that both methods were developed using reference streams from other regions and are not directly transferable to New Jersey. However, variations on these methods might be useful in assessing reservoir passing flows until the Ecological Flow Goals method is finalized. Other methods (wetted stream perimeter, R2Cross) were identified that may hold promise as ecological assessment methods. However, they cannot be implemented regionally within the current planning schedule.

The Highlands Council engaged USGS to provide statistical analyses using three methods: Low Flow Margin of Safety, Base flow Recurrence Interval, and an Ecological Flow Goals pilot. Unfortunately, because the Ecological Flow Goal method is highly data intensive, its use for the entire Highlands Region is not possible at this time. However, four watersheds are being assessed using this method so they can be used as a point of comparison.

It is important to note that at this time <u>no decision has been made</u> as to which approach or combination of approaches is most appropriate for inclusion in the Highlands Regional Master Plan. These choices will be made by the Council once the statistical analyses are completed and a comparison or results of the various methods have been made.

This technical approach is intended to develop a <u>first cut</u> estimate of ground water capacity from each HUC14 subwatershed, and is not to be considered as a final answer. The results will not be directly applied, but rather must be considered in light of a variety of policy issues as noted in this memo.

It is stipulated that in a stream with unregulated flows (i.e., no upstream impoundment that can control its releases), additional consumptive or depletive use of ground water will reduce base flow in streams to which those ground waters usually flow, on a 1:1 basis, unless the ground water is replaced in kind. Replacement could be accomplished through restoration of recharge that had been previously lost, through inducing artificial recharge or other methods. While there may be situations where the 1:1 reduction estimate is not accurate, USGS studies in several states have reached this general conclusion and it is a useful conservative assumption. Therefore, the key policy issue is whether and to what extent additional ground water uses can be accepted within a subwatershed or watershed. In some cases the answer may be "none" while in other cases the answer may be "some." In any case, it is a complex decision.

Policy decisions that will be made by the Council to determine available capacity once the analyses being performed by USGS are completed will include the following considerations:

1. 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 <u>every</u> 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 watershed that has severe impairment due to excessive withdrawals elsewhere. The methods being employed allow for every level of aggregation and assessment to provide an understanding of the water resources.
2. NJDEP is responsible for issuing and enforcing water allocation permits and setting safe yields and passing flows for reservoirs. One policy issue that must be addressed is the extent to which existing stream flows (the current hydrologic regime) are critical to protecting the safe yields of reservoirs. In some cases, it may be that <u>no</u> reductions of

flows can be allowed, because the safe yield (which is a critical factor in assuring an adequate water supply) would be reduced. There may be instances where no net increases in consumptive and depletive water uses would be acceptable 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 <u>only</u> legally recognized determinant of "surface water available capacity." As a result, subwatersheds that contribute to a reservoir may or may not have any "available ground water," as a matter of policy, even if the assessment method used by the Council indicates that capacity does exist. Essentially, the flows of the watershed may have already been allocated, even though they remain in the stream.

3. Selection of an acceptable method or methods for estimating "available ground water" relies on numerous policy considerations. The method(s) 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(s) 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).

4. There may be instances where a finding that there is "available ground water" (which then could potentially support development) 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 "allocated" to address the ecosystem protection goals of the Highlands Act.

5. It is anticipated that the Highlands Council will continue to move forward to implement Ecological Flow Goals in assessing the adequacy of stream flow for both water supply and ecological protection purposes, and that the Regional Master Plan would need to be revised at a future date to accommodate this goal.

6. 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.

Technical Approach for Estimating Ground Water Capacity/Availability

The technical approach for evaluating ground water capacity and availability relies on a comparison of three statistical models that can be used by the Highlands Council to inform policy decisions as illustrated below:

1. Base Flow Recurrence Interval – USGS will provide estimates for each HUC14 of the low base flows that return on an average of once every 2, 5, 10, 25 and 50 years (ranging from relatively wet to relatively dry conditions, respectively), and will be based on actual data from 25 gaged, unregulated streams. This analysis will then be extrapolated to the HUC14 subwatersheds, based on similarities in the HUC14 characteristics. USGS will then provide various statistics on existing consumptive/depletive use and full ground water allocations by HUC14. The existing and predicted consumptive and depletive uses are then subtracted from the selected base flow value to determine "Ground Water Capacity." These values can be negative or positive indicating a surplus or deficit, respectively.

   The Council will then determine whether use of a specific base flow, or a percentage of a specific base flow, is appropriate for use as an indicator of total ground water supplies. Base flows may be zero or positive values. The Highlands Council may then apply additional policy considerations, as discussed above, to determine how much of the "Ground Water Capacity" should actually be made available for additional human use. This final value can serve as an estimate of "Ground Water Availability" for each HUC14. These values can be negative or positive, indicating a deficit or surplus of available water, respectively.

2. Low Flow Margin of Safety – USGS will calculate the September median flows and the 7Q10 (lowest seven day flows that recur on average once every ten years) and the difference between them. This is the basis for determining the "Low Flow Margin." USGS will then provide the Council with calculations of the "Low Flow Margin" times a percentage or percentages determined by the Council to represent the portion of the "Low Flow Margin" that is considered available for human consumption (absent other constraints as discussed above). These estimates will be developed for each HUC14, and will be based on actual data from 25 gaged, unregulated streams and then extrapolated to the HUC14s based on subwatershed characteristics. USGS will then provide various statistics on existing consumptive and depletive use and full ground water allocations by HUC14. The existing/predicted consumptive and depletive uses are then subtracted from the "Low Flow Margin" to determine "Ground Water Capacity."

   It is critical to note that while each stream will always have a positive "Low Flow Margin" (because September median flows will always be greater than 7Q10); the subtraction of existing consumptive and depletive uses means that "Ground Water Capacity" can range from negative to positive.

   As with the Base Flow Recurrence Interval method, the Highlands Council will then apply additional policy considerations, as discussed above, to determine how much of the

"Ground Water Capacity" should actually be made available for additional human consumptive use. The Council will determine what percentage or percentages of this capacity will be used in calculations to represent the portion of the Low Flow Margin that is considered available for human consumption (absent other constraints as discussed above). This final value is the "Ground Water Availability" for each HUC14 under this method, which can range from negative to positive. This result is termed the "Low Flow Margin of Safety."

3. Ecologic Flow Goals Pilot – USGS will provide the results of this pilot study for each of four gaged stream basins. These basins are not HUC14s, as the method uses the full drainage area for each stream flow gauge for which adequate data exists to fully analyze the ecological flow needs. These case studies are intended to help the Council determine the applicability and appropriateness of the other statistical analyses.

By comparing the results of the Low Flow Margin and Base Flow Recurrence methods against the Ecological Flow Goals pilot case studies the Council will determine the method it considers most appropriate for use in determining "available ground water." Where that value is positive, the water could potentially be available for future human consumptive and depletive uses (e.g., agriculture, potable water, industry) and will help inform a build-out model also under development. In turn, the results of the build-out model will be used to help establish capacity-based limits related to municipal land use standards. Where the value is negative, the Council may 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.

Numerous references (see, for example, Ellis, Flynn, Hirsch, Lumb) for the technical approach being developed in conjunction with USGS are included in the bibliography. In further recognition of the critical nature of this issue in planning for the future of the Highlands, additional research is being performed to assure that instream flow regimes, land use policy and regulation are protective of both water supply and ecological needs. This includes review of work currently being developed by USEPA in concert with the Nature Conservancy's Freshwater Initiative (see USEPA); academic research from a variety of sources, including the Journal of the Ecological Society of America (Baron, Dale); the Instream Flow Water Right Project of the San Marcos River Foundation; work of the Instream Flow Council (which has published the widely acknowledged seminal text on this issue, included in the bibliography for this memo - *Instream Flows for Riverine Resource Stewardship*), and Delaware River Basin Commission's Instream Flow Project, among many others, to have state-of-the-art information on the science and policy needed to address this important issue.

Technical Methods for Assessing Ground Water Capacity

The USGS assessment of ground water capacity evaluates water capacity and demand within each of 183 Hydrologic Unit Code 14 (HUC14) subwatersheds, ranging in size from approximately three to 21 square miles. A comprehensive analysis of low flow statistics of Highlands' streams and the physical characteristics of the region's subwatersheds are used in conjunction with water use data to evaluate ground water capacity. Three methods are being developed to estimate ground water capacity limitations and to identify thresholds for current and future demands. The results generated can then be used to help inform the Land Use Capability Map and/or other policy and implementation strategies still under development.

Two methods apply stream flow statistics, basin characteristics and water use to estimate water availability for each of the 183 HUC14 subwatersheds. Both the Base Flow Recurrence Interval and Low Flow Margin of Safety methods use stream low flow statistics to indicate the probable amount of water in streams from ground water discharge through a range of climatic and ecological conditions. The difference in the amount of water estimated using low flow statistics and the current and future consumptive and depletive water use is then used as an indicator of ground water availability in each of the Highlands subwatersheds.

A pilot Ecological Flow Goals analysis is also being conducted that examines the complete stream flow regime within four relatively pristine Highlands basins to assess the ecological impacts that could result from changes in stream flow from surface or ground water withdrawals. The Highlands Council intends to review all three of these studies, using the Ecological Flow Goals analysis as a state-of-the-art benchmark to inform subsequent policy decisions on water availability.

Base Flow Recurrence Interval Method

Stream base flow is a low flow statistic used to estimate ground water discharge to the stream and therefore, ground water availability within a basin. Base flow is an indicator of the water-yielding capacity of the aquifer or aquifers that provide the base flow and the ability of the stream to sustain flow. Under natural conditions, the amount of flow in a stream composed of base flow is determined by the amount of water recharging the ground water by precipitation, infiltration capacity of the soil and underlying aquifer's ability to store and transmit water. The amount of stream flow (composed of base flow and runoff) can be modified by land use changes that reduce recharge to ground water and increase surface runoff. Withdrawal of water from wells or ponds can also influence the amount of ground water available to discharge to stream base flow.

The annual variability in precipitation can have a significant effect on annual stream discharge, particularly during very dry and wet periods. For this reason, a base flow frequency distribution evaluating a range of recurrence intervals is used to show how ground water availability varies based on climatic conditions. The 2, 5, 10, 25 and 50-year annual base flow recurrence intervals represent a range of climatic conditions from wet (2-year recurrence interval) to 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. An event with a 2-year recurrence interval can be expected every two years on average, or with a probability of 50% every year.

The computer program PART was used to determine mean annual base flow from the 25 continuous record stream flow gaging stations in and near the Highlands region. Estimates of annual base flow derived for each of these stations were then analyzed to provide statistics on base flow recurrence intervals. PART automates hydrograph-separation procedures to estimate mean daily base flow from stream flow records using stream flow partitioning to estimate a daily record of ground water discharge.

Low Flow Margin of Safety Method

This method defines water capacity based on a margin between a stream's low flow statistical data over a period of record. 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, known as 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 tends to occur in September. The calculated "Low Flow Margin" is the difference between the September median flow in a stream and the 7Q10 flow. This calculated water capacity value is only one step in determining water availability. Water availability will be defined as some percentage of this margin, after the consumptive water use is subtracted - both involving policy decisions yet to be made by Council.

The purpose of the study is to relate low flow statistics to measured basin characteristics, including drainage area, the amount of forest and impervious cover, area covered by stratified drift, the amount/presence of a particular geology (carbonate vs. crystalline), presence of water bodies (lakes, wetlands, reservoirs), stream channel slope and length and mean basin slope.

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. The 7Q10 for example, is determined from the annual series of minimum 7-day mean flows at a station. The value that recurs, on average, once in 10 years is the 7-day 10-year low flow or 7Q10. 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 September data sets during the period of record at a stream gaging station.

Statistics Computed from Low Flow Partial Record Stations

Low flow statistics 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. The low flow statistics were estimated by using the Maintenance of Variance Extension Type 1 (MOVE1) method of correlation analysis. Daily mean flows from at least three gaging stations, referred to as index sites, are correlated with measurements at each partial record station.

Estimates of stream flow statistics were estimated for sites on streams where no data are available. For this assessment, low flow statistics computed for the 121 gaged basins are 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 (nested). Regression equations can be used to obtain estimates for most ungaged sites.

The drainage area ratio 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 used as an index station. The accuracy of the drainage area ratio method is dependent on how close the gaged and ungaged sites are to one another, similarities in drainage area and other characteristics of their drainage basins.

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 drainage area ratio method is between 0.3 and 1.5. Within these limits, the drainage area ratio method provides equal or better accuracy than the use of regression analysis. Outside these ratios, regression equations are recommended. Low flow statistics for an ungaged basin are calculated by multiplying the ratio by the low flow statistic (i.e., base flow, 7Q10, September median) of the gaged basin. The drainage area ratio method was used to provide low flow statistics for 53 of the 183 HUC14 subwatersheds.

Low Flow Regression Analysis and Basin Characteristics

Multiple linear regression analysis has been used by researchers to develop equations for estimating stream flow statistics for ungaged sites. In regression analysis, a stream flow statistic for a group of data collection stations is statistically related to one or more physical or climatic characteristics of the drainage areas for the stations. This results in an equation that can be used to estimate the statistic for sites where no stream flow data are available.

A total of 42 measurable drainage basin characteristics were selected as possible predictor variables in developing the low flow regression models. Basin characteristics measured for each of the 140 gaged basins, as well as all 183 HUC14 watersheds include the area and percent of specific rock types or aquifers; area and percent land use/land cover; stream geometry; topography; climate and recharge, among others.

> Regression equations to estimate the natural 10 and 25-year base flow recurrence intervals, the 7Q10 and the September Median flow for 183 HUC14 subwatersheds were developed using weighted-least-squares regression analyses.

Hydro-ecological Integrity Assessment Pilot Study

The Hydro-ecological Integrity Assessment, known more commonly as "Ecological Flow Goals", quantifies sustainable water supply within selected impact thresholds. It uses the "natural variability" approach to assess stream flow impacts. This method characterizes stream flow variability using flow statistics, and then predicts changes in stream flow as a result of depletive and consumptive water use change, using low and high flow magnitude, frequency, duration, timing, and rate of change; flow regime baseline (pre-development), current, and impacted (future change); based on allowable limits for alteration of the flow statistics from the baseline or current flow regimes (i.e., when one of the statistics falls outside those limits), a determination may be made that the proposed water use will impair the ecological integrity of the stream.

The Highlands Council intends to use the Ecological Flow Goals as a pilot project, due to limited available gaging data. Four basins have been assessed and the results from these basins will be compared to the Base flow Recurrence Interval and Low Flow Margin results to provide a basis for comparison in examining the confidence and validity of the other ground water capacity model results. Ecological Flow Goals will be examined as a potential "higher level" water capacity tool for future iterations of the Highlands Regional Master Plan.

By comparing the results of the two low flow statistical methods against the Ecological Flow Goals pilot case studies (and possibly other methods as deemed appropriate), the Council will determine the method it considers most appropriate for use in determining "available ground water." Where that value is positive, that water could be available for future human consumptive and depletive uses (e.g., agriculture, potable water, industry) and will help inform a build-out model also under development which will in turn be used to help establish capacity-based limits to municipal land use standards. Where the value is negative, the Council may establish restrictions on future growth and/or consider other options for restoring flows in that HUC14 such as water conservation, recharge augmentation and/or other measures that reduce depletive and consumptive water uses and their impacts. Other goals of the Act, particularly resource protection will also be considered.

Comments Received on Technical Approach

The Highlands Council received comments to the *New Jersey Highlands Council Regional Master Plan Scoping Document* (Draft; January 2006) that identified several key issues of concern regarding the technical approach being employed by the Highlands Council to assess water availability. Some comments received are largely directed at the Pequannock River basin, which has significant stream flow regulation and long-standing concerns regarding insufficient passing flows to maintain ecological integrity. The Council recognizes that the Pequannock and similarly regulated basins represent a challenge in both determining ecological flow needs and developing a program to provide them, in light of other policy and regulatory requirements.

In providing this response, it is hoped that concerned parties understand that the methods being explored by the Council are in fact both scientifically-based and peer reviewed and that they reflect high quality analyses of perennial ground water yield and stream flow in the Highlands. The Council plans to review a variety of methods to determine what approach yields the most scientifically defensible "best fit" for the Highlands within the limited timeframe for adoption of a Regional Master Plan. A comparison of these methods, and the others suggested by other interested parties, are important to assure that the results of the analyses are accurate and appropriate for use in our regional planning efforts.

The following responds to specific comments and concerns (presented in an ***italicized and bold*** font) that were raised regarding the technical approach to determine water availability:

- ***"The study examines water capacity on a HUC14 (subwatershed) basis. This approach seems detailed and conservative, but it is actually flawed. It looks at water "top down" rather than "bottom up" and ignores the interrelation of subwatersheds to larger systems."***

The study actually <u>does</u> examine relationships between and within HUC14 basins. Highlands HUC14 basins range in size between three to 21 square miles, and the streams in every Highlands HUC14 basin receive ground water discharge. It is not correct to say the study ignores the interrelationship of HUC14 subwatersheds to larger systems; in actuality the study depends on these relationships.

Results of the study are reported at the HUC14 level to provide a detailed analysis of stream base flow within each subbasin. This analysis identifies subbasins that are sensitive to reduced recharge (from increasing conversion to urban land use) and water withdrawals, or conversely those that can support some level of withdrawal with minimal change in stream flow.

The subwatershed analysis permits aggregation of HUC14 basins to any scale. The whole is the sum of its parts; the stream discharge within a HUC11 basin is the sum of the discharge of the streams in its nested HUC14 basins. The same would not be true in reverse. A larger scale (HUC11) analysis cannot be accurately disaggregated to analyze subwatershed results.

A base flow analysis at a larger scale (HUC11) would composite the factors that influence stream flow and ground water discharge. Such an analysis could mask the localized effect of these factors when they are averaged over a larger area. The apparent effect of a one million gallon per day withdrawal when viewed on a HUC11 basis is small when compared to the total stream flow within the basin. The effect when viewed at the HUC14 scale allows its real world effect to be better seen and estimated.

- ***Once we know flows are inadequate at a specific point, there is no need to analyze each upstream "HUC14" subwatershed. Any reduction in upstream water will impact downstream flows. No upstream area has "excess capacity."***

This study provides information on stream base flow both above and below areas of a stream where flow is determined to be inadequate (e.g., the Pequannock River below Macopin Dam). Upstream of this dam there are five reservoirs that provide drinking water to the City of Newark. The reservoirs can be viewed as a way of shifting the timing of stream flow. The reservoirs fill during peak flows, and the water is transferred to the consumers throughout the year, with any excess being released to the stream. Normally, releases from the reservoirs should maintain river flow at specified levels. However, during low flow events (i.e., drought conditions) reservoir operators are retaining, not releasing, the water flowing into the reservoirs. The result in this case is that the 7Q10 for the Pequannock River below Macopin Dam is zero.

However, the 7Q10 is zero because the stream flow is regulated, not because there is inadequate ground water discharge upstream. There is no direct correlation between upstream ground water use and reservoir discharge. The former affects base flow into the reservoirs and therefore, part of the storage, but the latter is controlled by reservoir operations. Two watersheds, one with significant ground water use and one with no such use can have the same or different passing flow releases during droughts. The real issue regarding impact of passing flows is one of statutory and regulatory policy.

This study provides information on the base flow of streams feeding the reservoirs, and can be used to help interpret the base flow in the basin above and below the reservoirs under natural conditions. This information may then be of use in informing regulatory policy.

The HUC14 analysis provides estimates of the mean annual base flow, the 10- and 25-year recurrence interval base flow (bracketing the 1960s drought of record), and the Low Flow Margin for each Highlands HUC14 basin. The latter three are all conservative measures of a stream's perennial yield. These values can then be compared to the current conditions, and policy and regulatory decisions made on appropriate limits for surface and ground water withdrawals. The HUC14 perennial yield analysis can also provide information to determine what stream flow can be sustained during low flow conditions. The analysis shows that if the flow was unregulated, the September median flow of the Pequannock River below Macopin would be approximately 19 cubic feet per second (cfs), which is more than adequate to meet the 12.3 cfs minimum passing flow requirement (see NJDEP) proposed to maintain a low temperature stream flow there.

- ***"The Pequannock 7Q10 flow is zero. Median September flow is about 20 cubic feet per second, averaging all records since 1922. The difference is 20 cubic feet per second. The proposed study says this is a "margin of safety" and some of that is excess. Yet, we know the Pequannock has a huge deficit. Does this make sense?"***

The Low Flow Margin method does not use the Pequannock River flows at Macopin for any purpose, because these flows are highly regulated by the upstream reservoirs and therefore are not valid for use in estimating capacity.

The USGS analysis first calculates the low flow stream statistics (7Q10, September median, mean annual base flow, 10 and 25 year recurrence interval base flow) for gaged basins that have little or no alteration in natural stream flow conditions. Estimates of stream flow statistics were needed for streams in basins where no data were available. For this assessment the low flow statistics computed for 96 low flow partial record stations and 25 continuous gaged basins. These statistics were then used to compute similar statistics for all other stream segments within the 183 Highlands HUC14 subwatersheds. The two methods used to estimate statistics for ungaged sites were the drainage area ratio method and multiple linear regression analysis. 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 were developed to obtain estimates for the remaining HUC14 basins.

The results of this statistical analysis are base flow statistics for the 183 HUC14 basins within the New Jersey Highlands. These statistics provide information on low flow conditions within these basins, i.e., the perennial yield of the basin, which is estimated by the low flow margin, and the 10 and 25 year recurrence-interval base flows. All of these low flow statistics represent unregulated conditions.

In basins such as the Pequannock, where stream flow is regulated, this type of base flow analysis provides the “what if” condition – namely, what would the stream base flow be if there was no regulation. It is just one analytical result that will be included in the sources of information used by the Highlands Council to determine available ground water within a basin. Existing stream flows, ground and surface water use, water allocations, and peak water demand (maximum monthly water use) will also be considered, among other factors. Though this integrated, multi-criteria analysis makes the process complicated, it is necessary to make it credible.

As a side point regarding the Pequannock data, the median September flow for the Pequannock River at Macopin is not 20 cfs; that is the mean September flow. The actual median flow is 0.49 cfs. Mean flow is the average of all daily flows. Median flow is the value for which half of the days are greater and half of the days are lower. Median flow is valuable as a statistic in that it tempers the effect of extremely high and low flows.

- ***“The problem is that both 7Q10 flow and median September flow show you “what is” not “what should be”. If you already have a deficit, comparing two numbers that include that deficit is meaningless. In fact, since 7Q10 flow is almost always lower than median September flow, you will always produce a “margin of safety” and some “excess capacity.”***

As explained above, the USGS analysis of a stream’s perennial yield will show “what would be” if there was not regulated flow within or upstream of a HUC14 subbasin. It is correct to say this analysis will always produce a positive low flow margin, because there is ground water discharge to all streams in all HUC14 basins, regardless of how stream conditions are altered via regulated flows or other consumptive uses. This ground water discharge will always result in stream base flow, providing a positive September median flow and a 7Q10 flow. However, this value does not necessarily equate to a positive value for remaining water availability, as discussed earlier, due to existing consumptive water uses and the implications of Highlands Council policy decisions.

In some basins, anthropogenic factors result in the alteration of stream base flow. Dams may decrease or eliminate it; sewer plant discharges may supplement it. In those basins, the low flow statistics are determined for the stream in its unaltered state and these other factors will be considered by the Council in making its planning decisions regarding protection of water supply and a stream's ecological integrity.

- ***Use of the Tennant and New England Aquatic Base flow methods as alternatives to determine flow needs of streams.***

The Tennant method utilizes percentages of mean annual flow in order to recommend seasonally adjusted instream flows necessary for maintaining healthy aquatic habitat conditions. The method was developed for the mountainous western United States where stream flow varies from low in fall and early winter to high in the spring and summer due to snowmelt.

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. 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.

Information was provided to the Highlands Council that showed mean Tennant "good" flow values calculated for several streams in what were represented as relatively pristine basins. Two of these basins (Brass Castle Creek and Upper Cold Brook) had streams with regulated flow during the period of record, and Green Pond Brook at Picatinny Arsenal is 500 feet downstream of the dam on Picatinny Lake. Additionally, water is withdrawn from Picatinny Lake and converted to steam to heat buildings at the Arsenal. Therefore, these three basins have a history of regulated flow. The "good" flow is implied to mean the flow needed to maintain a healthy aquatic ecosystem during summer low flows. The "good" flow was calculated by multiplying the mean annual flow in the basin by 0.40 (40 percent). The good flows were then 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 was determined by a commenter to be 0.67 $ft^3/s/mi^2$. This value was then subtracted from the mean (not the median value) September flow per square mile.

The New England Aquatic Base Flow (ABF) Method was also presented as an alternate for determining flow needs of streams. ABF utilizes August median values 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. In the absence of adequate data from the specific stream, ABF assumes a flow of 0.5 $ft^3/s/mi^2$ 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 and spring, respectively).

As noted by the author of the Instream Flows text (see Annear) and others, the ABF is based on New England hydrology. It was developed in the Connecticut River basin and then expanded to the New England area. The default values should not be used in other regions. Therefore, its use may be inappropriate for the Highlands.

It is also important to note that both the Tennant and ABF methods were developed for the assessment of surface water diversions from impoundments (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 stream flow requirements. A surface water diversion for public water supply that lacks storage in an impoundment has a "safe yield" essentially equal to zero, because the availability of water during the drought of record cannot be guaranteed. 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 these methods is primarily for surface water diversions. Some technical studies have reviewed the potential application to basins with ground water diversions, but to our knowledge the method is not used for the regulation of ground water allocations.

Any direct comparison of methods needs to be based on a full understanding of what the values calculated actually represent. In the case presented here, it must be noted that 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 capacity of ground water that may be available for use. As discussed, in determining actual availability, the proposed approach considers only a percentage of the capacity estimate less existing/predicted consumptive uses in determining the amount of ground water that will be made available for future uses. The Low Flow Margin provides an estimate of how much ground water contributes to the flow of a stream, 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.

Comparison of Alternative Methods for Estimating Flow Needs and Water Availability

It has always been the intent of the Council to review a variety of methods to determine what approach yields the most scientifically defensible "best fit" for the Highlands within the limited timeframe for adoption of a Regional Master Plan. A comparison of these methods, and the others suggested by members of the Highlands Council Water Resource Management Technical

Advisory Committee (TAC), are important to assure that the results of the analyses are accurate and appropriate for use in our regional planning efforts.

The current Low Flow Margin, Base flow Recurrence and Ecological Flow Goals Pilot methods are described briefly above. Following is a summary of several of the alternate instream flow methods discussed with the TAC. We are also providing a comparison of the current methods with the alternate methods, to assist the TAC, and in turn, the Highlands Council in understanding on the method(s) appropriate for use in determining ground water availability for the region. Research on additional methodologies that may prove useful in further development of ecological flow goals as part of future iterations of the RMP is also underway.

Tennant Method

The Tennant method (see Dunbar, et al) utilizes percentages of mean annual flow in order to recommend seasonally adjusted instream flows necessary for maintaining healthy aquatic habitat conditions (Table 1). The method was developed for the mountainous western United States where stream flow varies from low in fall and early winter to high in the spring and summer due to snowmelt.

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.

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). 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 value) September flow per square mile.

Table 1 – 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

New England Aquatic Base Flow Method

The New England Aquatic Base Flow (ABF) Method was also presented as an alternate for determining flow needs of streams. This method was developed as an interim policy in 1981 for minimum stream flows in New England by the US Fish and Wildlife Service.

ABF utilizes August median values for the "summer instantaneous stream flow". 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. It represents the most severe naturally occurring condition that a stream community would experience. In the absence of adequate data from the specific stream, ABF assumes a flow of 0.5 $ft^3/s/mi^2$ is needed to protect native aquatic organisms during the low flow summer months, and 1.0 and 4.0 $ft^3/s/mi^2$ during the fall and spring, respectively.

In applying the ABF method, a commenter used the 0.5 $ft^3/s/mi^2$ default for summer instantaneous stream flow and deducted this volume from the mean September discharge at the selected gaged stations. As indicated in Table 2, 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 mean of the September median 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 (representing September median flows minus ecological flow needs). The deduction of water use from the low flow margin and the implementation of percentages as threshold values, as intended by the Council will only further reduce the amount of available water using the Low Flow Margin Method and increase this difference.

As noted earlier, ABF is based on New England hydrology, was developed in the Connecticut River basin and then expanded to the New England area. The default values should not be used in other regions. Rhode Island has already decided to modify the ABF method for decision making, using stream flow data that are relevant to Rhode Island, and using August median flows rather than August mean flows. Therefore, use of this method may be inappropriate for direct use in the Highlands, but a modified version may be useful for surface water diversion analyses.

Range of Variability Approach

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.

RVA is a multi-step process involving the characterization the range of flows; selecting flow management targets, designing a system to attain the targets chosen; implementation and monitoring; annual revisiting of the above steps and incorporating new information and making revisions to 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 (see Nature Conservancy).

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.

Wetted Perimeter

The wetted perimeter approach (which focuses on submerged stream width in riffles as a critical ecological indicator) is used to determine fish food availability (see Big Hole River Foundation). 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 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 increases. A graph of wetted perimeter vs. stream flow will show inflection points where the wetted perimeter changes abruptly with small changes in flow.

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. 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

The minimum flow necessary to maintain acceptable habitat for fish and macroinvertebrates in critical areas (such as riffles) is determined using the wetted perimeter, depth, and water velocity of a stream (see Montana Water Trust). 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 streams, 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.

Instream Flow Methods Comparison

The following provides a preliminary comparison of several methods under consideration for estimating water availability in the Highlands – specifically a comparison between the Highlands Low Flow Margin method with two alternative methods, Tennant and Aquatic Base Flow.

It is important to note that both the Tennant and ABF methods were developed for the assessment of surface water diversions from impoundments (water supply or hydroelectric), with the ABF being used by the US 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 at need to meet specific stream flow requirements by changing impoundment releases.

A surface water diversion for public water supply that lacks storage in an impoundment has a "safe yield" essentially equal to zero, because the availability of water during the drought of record cannot be guaranteed. 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 these methods is primarily for surface water diversions. Some technical studies have reviewed the potential application to basins with ground water diversions, but to our knowledge the method is not used for the regulation of ground water allocations.

Any direct comparison of methods needs to be based on a full understanding of what the values calculated actually represent. In the case presented here, it must be noted that 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 capacity of ground water that may be available for use.

In determining actual availability, the proposed approach considers the use of only a percentage of the capacity estimate less existing/predicted consumptive uses in determining the amount of ground water that will be made available for future uses. In other words, the Low Flow Margin, Base Flow Recurrence Interval and Ecological Flow Goals methods provide estimates of how much ground water contributes to the flow of a stream, 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.

For discussion purposes, Table 2 provides a comparison of values representing the calculated results of water capacity for the Low Flow Margin at 100, 80 and 60%, September median flow minus the "Good" Tennant flow; and September median flow minus the ABF derived value for instream flow needs at 25 gaged stations in the Highlands. This comparison is also represented graphically in the attached chart (Figure 1). The actual percentage and water use values to be used have yet to be decided upon by the Council. These tables are provided for illustrative purposes only and are subject to change.

These comparisons are adjusted to provide directly comparable results of each of these methods, all expressed in the same terms of cubic feet per second per square mile of land of water "capacity". The ABF method generally provides the greatest volume of water for human uses, making it least conservative, followed by variable results for the Low Flow Margin at 100, 80, and 60% and Tennant methods.

Table 3 provides results the Low Flow Margin method for four HUC14 subwatersheds for which we have both stream flow gaging data and specific consumptive use data and illustrates the potential impact on "available water" volumes, after consumptive water use at full allocation is subtracted from the calculated water capacity. This analysis is still being completed; therefore, we are providing the values calculate for only four subwatersheds at this time. The Low Flow at

100, 80 and 60% minus consumptive water use values for the four subwatersheds as provided in Table 3 are most conservative in terms of providing preliminary estimates of maximum water "availability", due to the wholesale removal of water use volumes. Again these values are preliminary and intended for illustrative purposes only and are subject to change.

Results of the Ecological Flow Goals Pilot are also still preliminary. Comparison of the ecological flow maximum withdrawal versus the 100% Low Flow Margin (before any potential policy reductions) varies over the four streams included in the pilot. For two of the streams, West Brook and Ringwood Creek, the Low Flow Margin is more conservative. It is less conservative, allowing for greater withdrawals, in the Lamington and Mulhockaway. Further analysis is necessary to understand the cause(s) of this variation. These values will also be compared to the Base flow Recurrence Method results once that study is completed.

This comparison between the water *capacity* with the required 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.

Additionally, any comparison of the water capacity 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 Table 2 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 precipitation). This difference in use of the components used in the flow analysis will also cause variation in the values for the two methods.

The application of a single flow regime (such as the 40% "good" flow in Table 1) 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".

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 (Pequannock River at Macopin, Wanaque River at Awosting, Wanaque River at Wanaque, Ramapo River at Pompton Lakes and Rockaway River below Boonton Reservoir) is not technically sound. This assumes all basins have the same physical characteristics, which is not the case. 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.

The New England Aquatic Base Flow Method (ABF) utilizes August median values for the “summer instantaneous stream flow” because August is typically 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. The 0.5 $ft^3/s/mi^2$ default was used for summer instantaneous stream flow which was deducted from the mean September discharge at the selected gaged stations. As with the Tennant method, 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. Because the Highlands Regional Master Plan is a regional document, the estimates of ground water availability must be regional in the extent of their coverage.

Table 2. 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 September discharge; 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

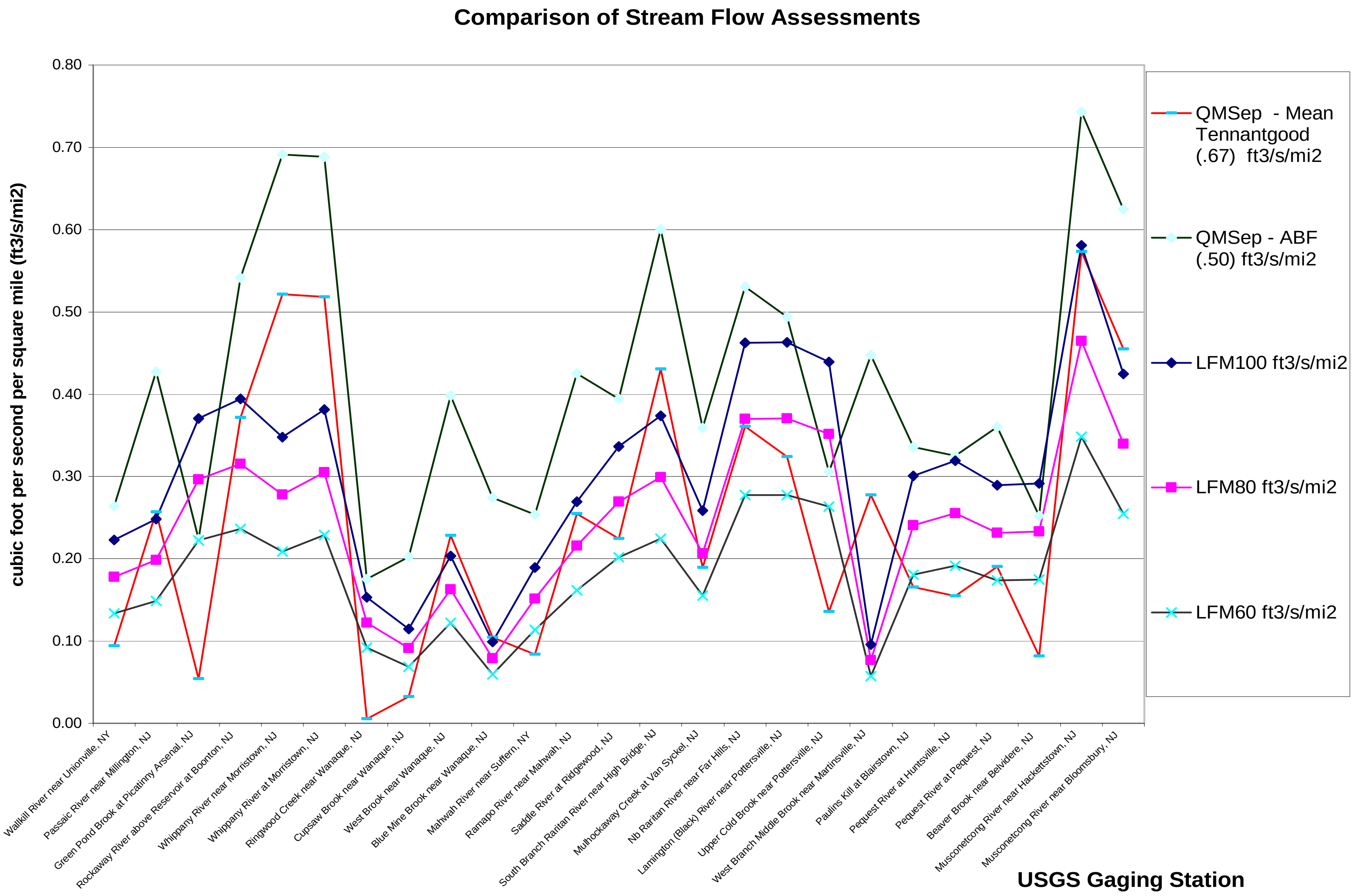

Figure 1: Comparison of estimates of water capacity using a variety of stream flow statistics (Tennant, Aquatic Base Flow and Low Flow Margin at 100%. 80% and 60%). Note: Low Flow method (LFM) values do not reflect reductions due to consumptive/depletive uses at full allocation.

Table 3. Gaged basins or low flow partial-record basins that are also HUC14 basins. (LFM100 is 100% of the Low flow Margin; LFM50 is 50% of the Low flow Margin; Remaining LMF for this table only is illustrated as LFM50 - Consumptive water use at full allocation. Other constraints on water availability could be applied upon this value. Value in red (-) indicates a deficit.)

Site number	Station name	HUC14	Area	Basin Gage	LFM100	LFM50	Consumptive use, full allocation	Remaining LFM50	Remaining LFM50
			Square miles	type	MGD	MGD	MGD	MGD	MGD/ mile square
1379773	Green Pond Brook at Picatinny Arsenal	02030103030050	7.65	Continuous gage	1.83	0.92	0.09	0.83	0.11
1381490	Watnong Brook at Morris Plains	02030103020030	7.77	Low flow partial record	1.85	0.93	0.04	0.89	0.11
1445900	Honey Run near Hope	02040105100020	10.3	Low flow partial record	0.42	0.21	0.44	***-0.23***	***-0.02***
1386000	West Brook near Wanaque	02030103070040	11.8	Continuous gage	1.55	0.78	0.23	0.55	0.05
1390700	Hohokus Brook at Wyckoff	02030103140010	5.31	Low flow partial record	1.32	0.66	0.22	0.44	0.08

Note: The LFM50 is for illustrative purposes only and does not represent the percent of the Low Flow Margin of Safety the Council may decide upon or the type of water use to be subtracted. If the Low Flow Margin of Safety method is selected as the method to be used for water availability calculations, the Council will then decide the values of these figures.

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