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Technical Report: **Water Resource Assessment**
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Memorandum Title: **Ecological Flow Goals Pilot Study Hydroecological Integrity Assessment and Effects of Water Withdrawals in Four Gaged Stream Basins in the New Jersey Highlands Methodology and Results**
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Technical memorandum prepared by the New Jersey Highlands Council, based on work done in cooperation with the United States Geological Survey Water Science Center, West Trenton, New Jersey

EXECUTIVE SUMMARY

The Hydroecological Integrity Assessment Process, known more commonly in New Jersey as the "Ecological Flow Goals Method", quantifies sustainable water supply within selected impact thresholds. It uses the "natural variability" approach (Poff and others, 1997) to assess stream flow impacts. This method characterizes streamflow 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 data (pre-development) and current and impacted flow regime data (reflecting the potential for future change).

Based on policy decisions regarding "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 may impair the ecological integrity of the stream. It should be noted that related policy decisions have not yet been made.

The New Jersey Highlands Water Protection and Planning Council ("Highlands Council") is responsible, through development of a Regional Master Plan for protecting, maintaining, and where necessary, improving stream water quality to preserve and enhance aquatic and land-based habitats, and meet the water supply needs of the State. One of the regulatory tools under the statutory authority of the New Jersey Department of Environmental Protection ("NJDEP") is to manage the water resources of the State through establishing passing flow requirements for

regulated stream reaches as part of some water allocation permits. NJDEP passing flow requirements typically are based on the lowest average flow for seven days that occurs on average once every 10 years, which is referred to as the 7 day, 10 year low flow ("7Q10"). The purpose of the Ecological Flow Goals pilot study is to examine alternative approaches to determine the ecological flow requirement of a stream to help inform the determination of ground water availability in the Highlands.

Introduction

The Highlands Council, in coordination with the United States Geological Survey ("USGS") is currently evaluating new methods to assess regional water availability that is protective of the ecological integrity of freshwater aquatic ecosystems (Henriksen and others, 2006). The NJDEP is also developing new methods that can be used to assess the effects of water withdrawals on stream flow and ecological health in streams that are highly dependent on natural flow regimes (Poff and others, 1997; Olden and Poff, 2003).

The Hydroecological Integrity Assessment Process (HIP) is comprised of a users' manual and a set of assessment software which includes the New Jersey Hydrologic Assessment Tool (NJHAT). This tool uses nationally available USGS continuous streamflow data to calculate a set of ecologically relevant hydrologic indices (ERHIs). ERHIs are streamflow indices that characterize elements of the flow regime that most significantly affect biological health and ecological sustainability. The major elements of the flow regime include the magnitude, timing, frequency, duration and rate of change of streamflow under low-flow, high-flow and average conditions.

NJHAT (also known as the Ecological Flow Goals Method) allows for assessment of water availability within selected threshold ranges by evaluating changes in specified ERHIs that may be altered by changes in land use such as urban development and other anthropogenic processes including regulations, diversions, withdrawals and returns (Poff and Ward, 1989; Olden and Poff, 2003).

These thresholds can represent an upper or lower limit of ecological sustainability in streams. Localized issues related to water use, such as effects of water withdrawal for consumption, effects on the sustainability of freshwater aquatic ecosystems and contamination threats would place further stress on the resource.

LEGAL REQUIREMENT FROM THE HIGHLANDS ACT

The Highlands Act, in Sections 10 and 11, sets forth the following requirements:

10. a. The goal of the regional master plan with respect to the entire Highlands Region shall be to protect and enhance the significant values of the resources thereof in a manner which is consistent with the purposes and provisions of this act.

For both the Preservation Area and Planning Area, a common goal of the Regional Master Plan is to "*protect, restore, and enhance the quality and quantity of surface and ground waters therein.*"

11. a. The regional master plan shall include, but need not necessarily be limited to:

(1) A resource assessment which:

(a) determines the amount and type of human development and activity which the ecosystem of the Highlands Region can sustain while still maintaining the overall ecological values thereof, with special reference to surface and ground water quality and supply; contiguous forests and woodlands; endangered and threatened animals, plants, and biotic communities; ecological factors relating to the protection and enhancement of agricultural or horticultural production or activity; air quality; and other appropriate considerations affecting the ecological integrity of the Highlands Region; …

(6) A smart growth component that includes an assessment, based upon the resource assessment prepared pursuant to paragraph (1) of subsection a. of this section, of opportunities for appropriate development, redevelopment, and economic growth, and a transfer of development rights program which shall include consideration of public investment priorities, infrastructure investments, economic development, revitalization, housing, transportation, energy resources, waste management, recycling, Brownfields, and design such as mixed-use, compact design, and transit villages. In preparing this component, the council shall: …

(g) identify special critical environmental areas and other critical natural resource lands where development should be limited;

The assessment of ecological flow goals is an integral part of the Resource Assessment, and also provides critical information for the land use capability map, helping to inform a determination of how much ground water may be available for human consumptive use, and how much needs to be allocated to sustain ecological processes. Preserving aquatic ecological integrity is a vital requirement to meet the Highlands Act goal for protection of the quantity of ground and surface water resources.

METHOD

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

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

Surrogate indices were also identified, i.e., other indices within each sub-component that are collinear with the indices of interest (Henriksen and others, 2006). Each basin analyzed in this pilot study was identified in the initial cluster analysis as stream type C which are characterized by moderately stable streams with moderately high base flow. The 10 primary and surrogate indices for this stream type are listed in Table 1.

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

ECOLOGICAL FLOW GOALS PILOT STUDY

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

1. Stream gages are located in "small" (defined as less than 35 square miles) headwater basins.

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

3. Records include at least 20 years of continuous daily discharge data, and reflect a minimum of 10 years where the biotic integrity of the stream has been evaluated by the NJDEP as unimpaired.

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

Table 1 Primary and Surrogate Indices for Stream Type "C"

INDEX	GENERAL DEFINITION	SPECIFIC DEFINITION	INDEX TYPE	PRIMARY OR SURROGATE
DL16	Low flow duration - Pulse Duration	Combine the average pulse duration for each year for flow events below a threshold equal to the 25th percentile value for the entire flow record. DL16 is the median of the yearly average durations.	Temporal	Primary
DH11	High flow duration - annual maximum of 1-day moving average flows divided by the median for the entire record.	Compute the maximum of a 1-day moving average flow for each year. Dl11 is the mean of these values divided by the median for the entire record.	Temporal	Primary
FH3	Frequency of high flow events - high flow pulse count	Compute the average number of days per year that the flow is above a threshold equal to three times the median flow for the entire record. FH3 is the median of the annual number of days for all years.	Temporal	Surrogate
FL1	Frequency of low flow events - low flow pulse count	Compute the average number of flow events with flows below a threshold equal to the 25th percentile value for the entire flow record. FL1 is the median number of events.	Temporal	Primary
MA24	Magnitude of average flows - Variability (coefficient of variation) of monthly flow values	Compute the standard deviation for January in each year over the entire flow record. Divide the standard deviation by the mean for each month. The median of these values across all years is the MA24.	Temporal	Primary
MH14	Magnitude of high flow events - Median of annual maximum flows	Compute the annual maximum flows from monthly maximum flows. Compute the ratio of annual maximum flow to median annual flow for each year. MH14 is the median of these ratios.	Temporal	Primary

INDEX	GENERAL DEFINITION	SPECIFIC DEFINITION	INDEX TYPE	PRIMARY OR SURROGATE
ML3	Magnitude of low flow events - median minimum flow for March for all years	Compute the minimums for each March over the entire flow record	Temporal	Primary
RA6	Rate of change of average flows.	Compute the $\log_{10}$ of the flows for the entire flow record. Compute the change in log of flow for days in which the change is positive for the entire flow record. RA6 is the median of these values.	Temporal	Primary
TH3	Timing - high flow events - Seasonal predictability of non-flooding.	Computed as the maximum proportion of a 365-day year that the flow is less than the 1.67 year flood threshold and also occurs in all years. Accumulate non-flood days that span all years. TH3 is maximum length of those flood free periods divided by 365 days.	Spatial	Primary
TL1	Timing - low flow events - Julian date of annual minimum	Determine the Julian date that the minimum flow occurs for each water year. Transform the dates to relative values on a circular scale (radians). Compute the x and y components for each year and average them across all years. Compute the mean angle as the arc tangent of y-mean divided by x-mean. Transform the resultant angle back to Julian date.	Spatial	Surrogate

(Olden and Poff, 2003)

The four gaged basins selected are located on Figure 1 below. From north to south they are Ringwood Creek near Wanaque (01384500), West Brook near Wanaque (01386000), Lamington River near Pottersville (01399500), and the Mulhockaway Creek at Van Syckel (01396660). Background information for the selected gaging stations is listed in Table 2 and Table 3. Ringwood Creek and West Brook basins have had relatively low development over the period of record. These sites are considered to be index sites for New Jersey. The only major change in basin land use over the course of the period may result from reforestation from former agricultural lands. The Mulhockaway Creek and Lamington River basins currently have more moderate urban development but this development is mostly agricultural and low to medium density urban. Urban land use has increased by 5-10% in these sites over the past 30 years.

These two sites were still included in the study because they reach the first three criteria for site selection, and would increase the available results for the study.

Table 2. Stream Gages Selected For Pilot Implementation of the Hydroecological Integrity Assessment Process

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

To quantify the effects of increased water withdrawal on selected basins (Table 2) for calculated stream flow indices, the 10 primary or surrogate indices were evaluated for a series of withdrawal scenarios for four sites to determine how much withdrawal is needed for the index statistic to reach the selected critical value (that is, the 25/75 percentage range). Calculations were also performed for the 40/60 percentage range to demonstrate the impacts of an alternative critical value, in order to better understand the potential implications of policy decisions still to be made. This approach implies that when the index reaches or exceeds this critical value, the withdrawal amount may significantly alter the ecological integrity of the stream.

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

Table 3. Land Use and Land Cover Characteristics of Study Basins

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

Critical thresholds were established for each index and each stream for stream data sets without withdrawal alteration. Daily flow data for each site over the course of the period of record were entered into the NJHAT program to calculate all significant indices and index thresholds at the 25^{th} and 75^{th} (25/75) and 40^{th} and 60^{th} (40/60) percentile range.

All daily flow data used for the calculations were retrieved from the USGS National Water Information System (NWIS). This data can be accessed on the web at http://waterdata.usgs.gov/nwis).

For temporal indices, the upper and lower thresholds were determined to be the (25/75) and (40/60) percentile range. For spatial indices, the threshold limits are the index value plus and minus the inter-quartile or inter-percentile range (based on the 25/75 or 40/60 percentile index values) of that index for all sites in Stream Type C.

See Table 1 for definitions of each index and Table 4 and 5 for both the 25/75 and 40/60 threshold values for each index and each stream.

These thresholds were calculated for each index for the stream data sets without withdrawal alteration. It should be noted that the 25/75 percentile range used for determining critical values for indices is based on a well established literature value (Richter et al. 1996) and is used as the default setting in HIP.

Table 4. Upper and Lower Thresholds Representing Critical Values for Indices based on 25/75 Percentile Default Values

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

Other possible critical threshold values, such as the 40/60 percentile range, could be used if the study objectives were based on a need to be more conservative in response to projected water source development or other needs in a given basin. For example, choice of a narrower range would restrict the variability in the threshold interval for specific index values and result in decreased maximum allowable withdrawals being calculated using this model.

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

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

The minimum passing flow for each gaging station is defined as the seven day, 10 year low flow for the entire period of record. Exceedance flows, passing flows, and the percent of the record below passing flow are listed in Table 6.

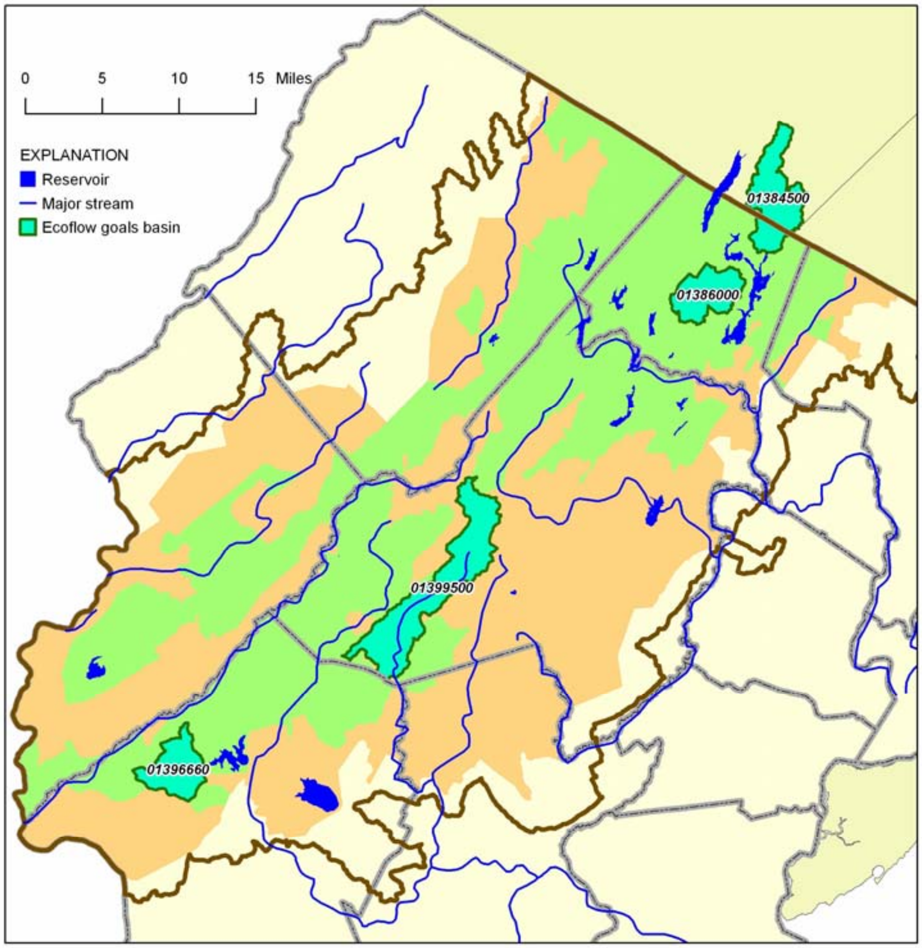

Figure 1. Map of Selected Basins for Ecological Flow Goals Pilot

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

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

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

Where,

DQf = Calculated daily flow for withdrawal scenario

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

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

M = the 50-percent exceedance flow for the entire period of record (M values for each site are listed in Table 6)

An example of one daily flow calculation that represents a time period where the stream level was naturally below the passing flow volume (therefore, the recalculated withdrawal values were set for passing flow - assuming regulatory compliance) is presented below. This example is for the same 10% withdrawal scenario as illustrated in Figure 2 and for the same site (Ringwood Creek) shown in Figure 3.

In this example, for the 10% withdrawal scenario for Ringwood Creek near Wanaque (01384500) with a daily flow on July 2, 1944 of 5.2 cubic feet/second (taken from NWIS), the recalculated daily flow for the scenario would be determined by the following equation:

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

Figure 2 illustrates an example of this procedure applied for Ringwood Creek near Wanaque (01384500) with a 10% median withdrawal.

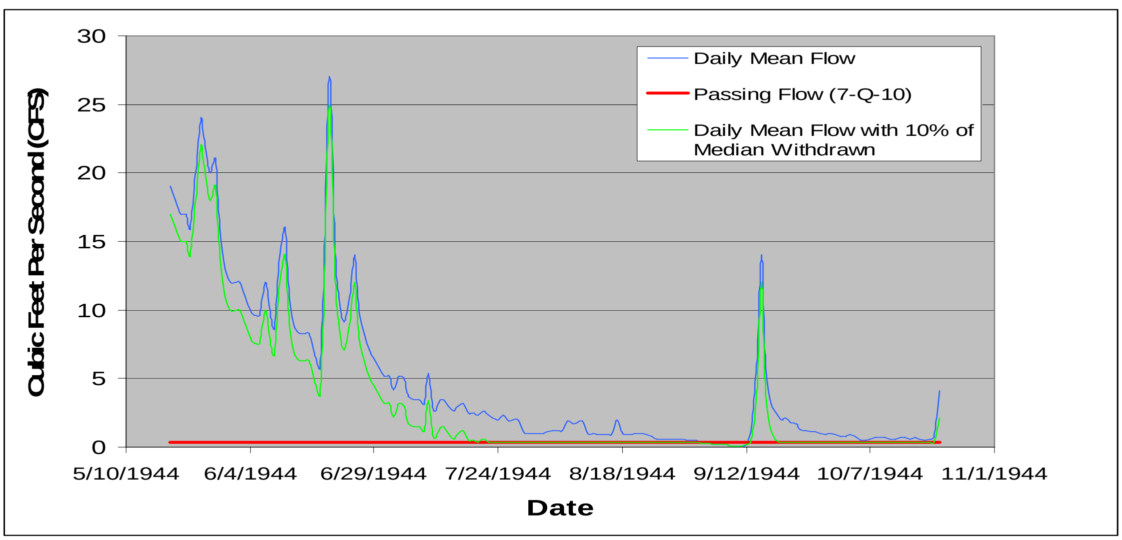

Figure 2. Example of 10% withdrawal scenario of median flow for Ringwood Creek near Wanaque compared to original daily flow values and minimum passing flow

Table 5. Upper and Lower Thresholds Representing Critical Values for Indices based on 40/60 Percentile Values

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

Table 6. Exceedance and Passing Flow Statistics for Period of Record at Study Sites

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

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

Ten datasets for each withdrawal scenario were recalculated, where each dataset incorporated "n" values of 0.01, 0.02, 0.03…… to 0.10, respectively. For each dataset, DQf was determined for each day for the entire period of record for daily flows only. Instantaneous peak flows were not recalculated. Each withdrawal scenario dataset was used to recalculate each of the 10 selected indices listed in Table 1.

From each data set and each site, a correlation was determined for the percentage of the 50 percent exceedance value for the entire flow record, which was removed from each daily value using the above formula and each calculated index value. This correlation was determined by least squares regression, and the regression was used to predict the withdrawal value in millions of gallons per day (MGD) that would cause the index to reach the pre-established critical value, as defined by the default thresholds listed in Table 4. An example of this procedure is shown in Figure 3, which illustrates the effects of withdrawal on MA24 (variability of January median flow values) at Ringwood Creek near Wanaque (01384500).

RESULTS

The results from the analysis of 10 withdrawal scenarios for 10 indices at four sites using the 25/75 thresholds are shown in Table 7, and the results using the 40/60 thresholds are presented in Table 8. A summary of the results is depicted in Figures 4 - 7.

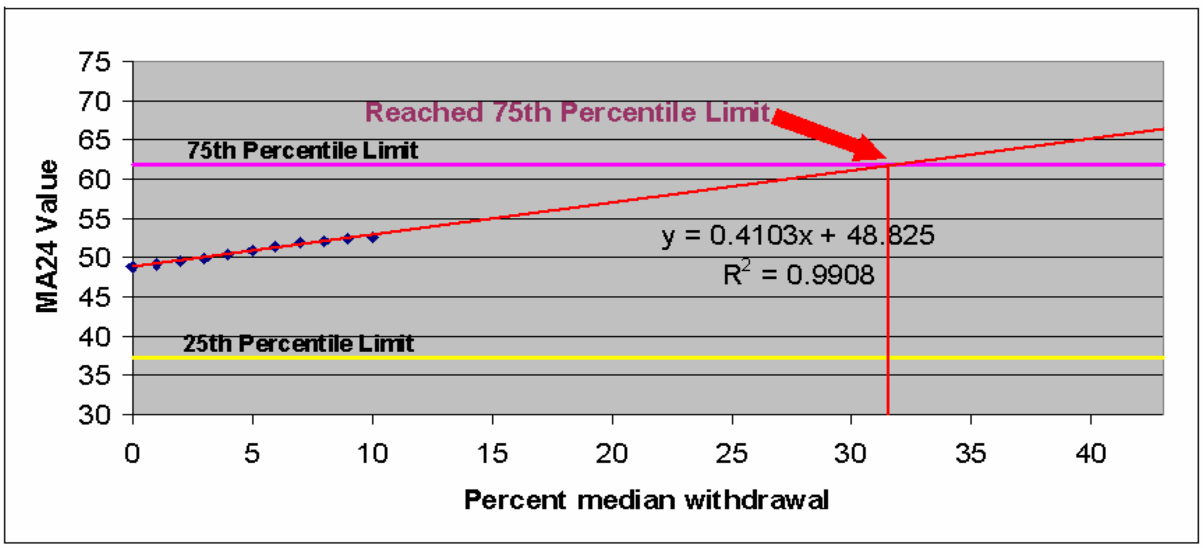

Figure 3. Example of regression line extrapolation for MA24 and percent median withdrawal using the 25/75 threshold at Ringwood Creek near Wanaque

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

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

For West Brook near Wanaque (01386000), the maximum withdrawal is 1.76 MGD or 0.149 MGD per square mile (index FH3); for Mulhockaway Creek at Van Syckel (01396660), the maximum withdrawal is 1.29 MGD or 0.109 MGD per square mile (index ML3); for the Lamington River near Pottersville (01399500), the maximum withdrawal value is 3.68 MGD or 0.112 MGD per square mile (index TL1).

However, for a predicted withdrawal with a more significant regression, 5.52 MGD, or 0.168 MGD per square mile, can be withdrawn (index DH11) before reaching a critical value at Pottersville.

As a comparison to the 25/75 threshold results, the withdrawals required to reach the 40/60 threshold were much lower for all four sites and clearly demonstrated that using this narrower criteria which limits hydrograph alteration is a much more conservative approach.

For Ringwood Creek near Wanaque (01384500), the maximum amount that could be withdrawn using the 40/60 threshold before the index reached critical value for at least one of the indices is 0.29 MGD.

For West Brook near Wanaque (01386000) and Lamington River near Pottersville (01399500), no water could be withdrawn to avoid crossing the critical value (0.01 and 0.03 MGD, respectively, can both be considered a negligible withdrawal quantity); and for Mulhockaway Creek at Van Syckel (01396660), the maximum withdrawal is 0.46 MGD.

For all four sites, DH11 (high flow duration) was the index in which threshold values were first surpassed (Table 8).

Table 7. Predicted Withdrawal Required for Indices to Reach Critical Value for 25/75 Thresholds

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

	Indicates a poor R-squared value for the regression
	Indicates that there was no trend in the effect of withdrawal on the index value
*	Minimum value that can be withdrawn to surpass the critical threshold
**	This value is the minimum value predicted to cause the index to reach critical value using a significant regression.

Table 8. Predicted Withdrawal Required For Indices to Reach Critical Value for 40/60 Thresholds

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

	Indicates a poor R-squared value for the regression
	Indicates that there was no trend in the effect of withdrawal on the index value
*	Minimum value that can be withdrawn to surpass the critical threshold
**	This value is the minimum value predicted to cause the index to reach critical value using a significant regression.

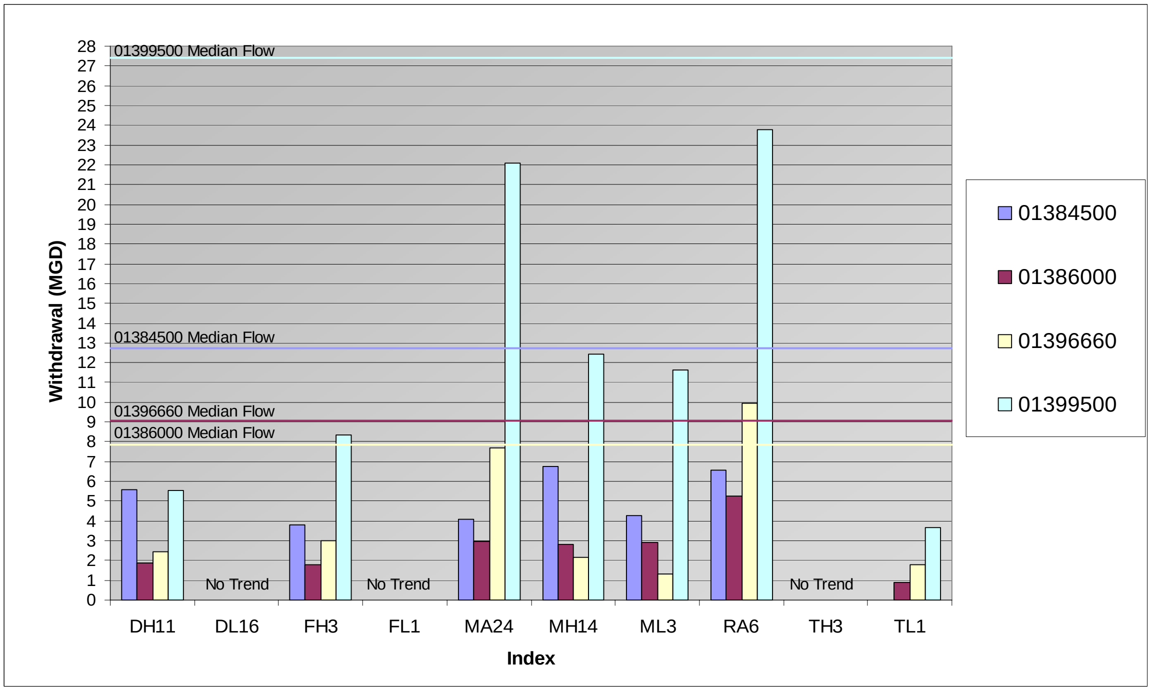

Figure 4. Withdrawal (MGD) by site required to surpass the 25/75 index threshold based on regression analysis

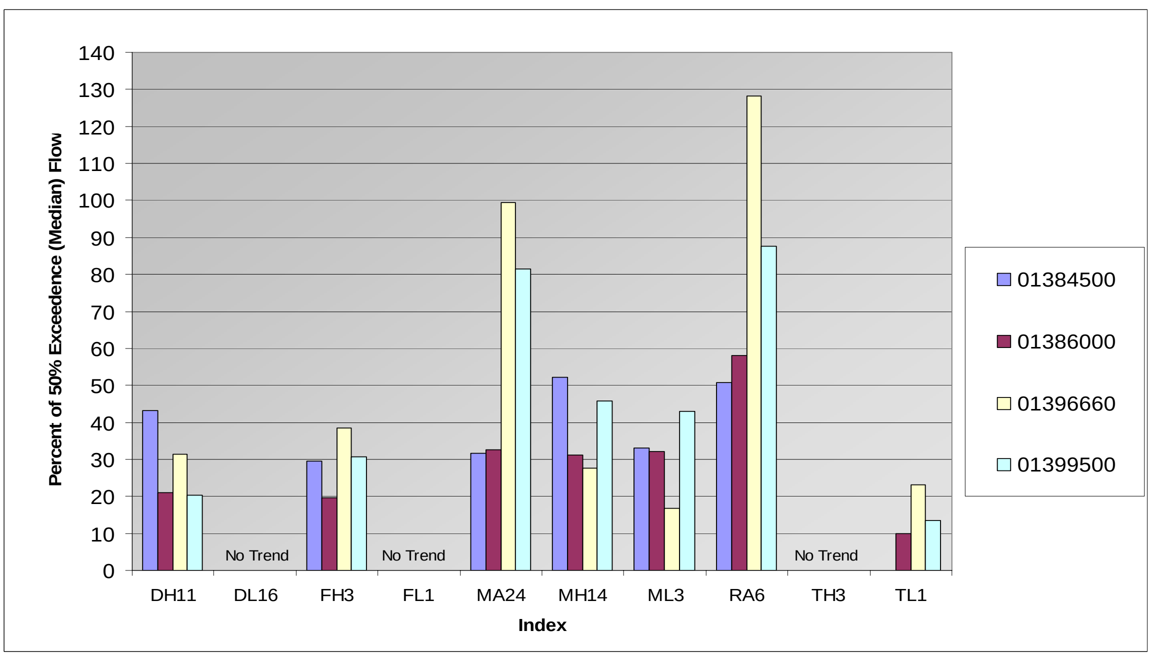

Figure 5. Withdrawal (MGD) by site required for index to reach critical value for 25/75 thresholds in percent of median flow

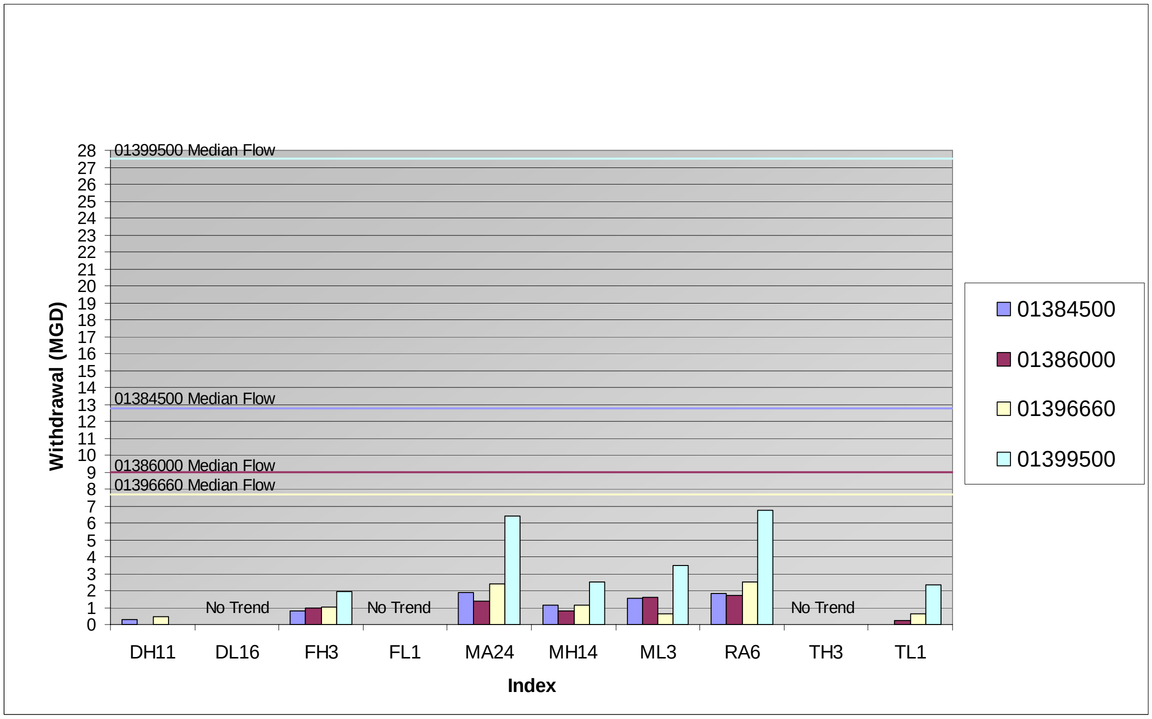

Figure 6. Withdrawal (MGD) by site required to surpass the 40/60 index threshold based on regression analysis

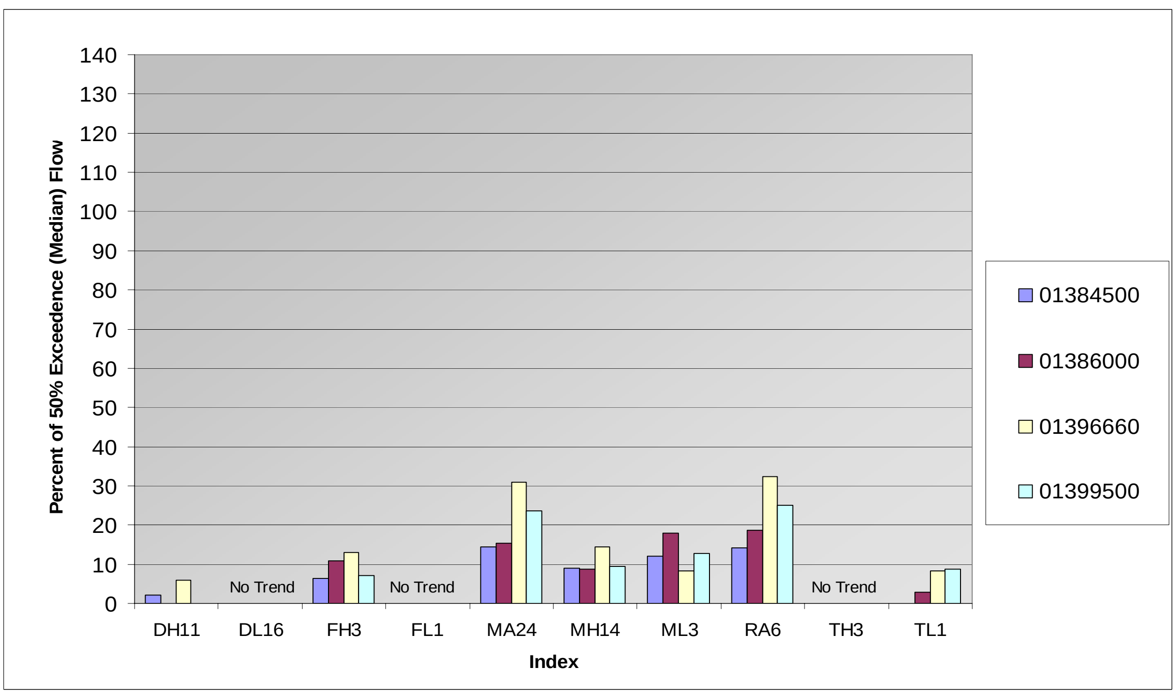

Figure 7. Withdrawal (MGD) by site required for index to reach critical value for 40/60 thresholds in percent of median flow

These results of the extrapolated regression line analysis above can be compared to an alternative approach for calculating the maximum allowable withdrawal. This method, referred to as the "Low-Flow Margin of Safety" (LFM), assumes that some portion of streamflow can be removed without affecting stream ecology. This quantity is based on a percentage of the difference between the typical volume of water that flows from the watershed during the most stressed month (using the September median flow, a typical dry month), and the 7Q10 flow. For this analysis, the percentage shown is 100 percent; but in practice the Highlands Council will establish the percentage for each watershed. A comparison of the results from the 25/75 threshold analysis, 40/60 threshold analysis, and the LFM method are illustrated in Figure 8 and demonstrate the potential utility of the ecological flow method to inform water capacity determinations.

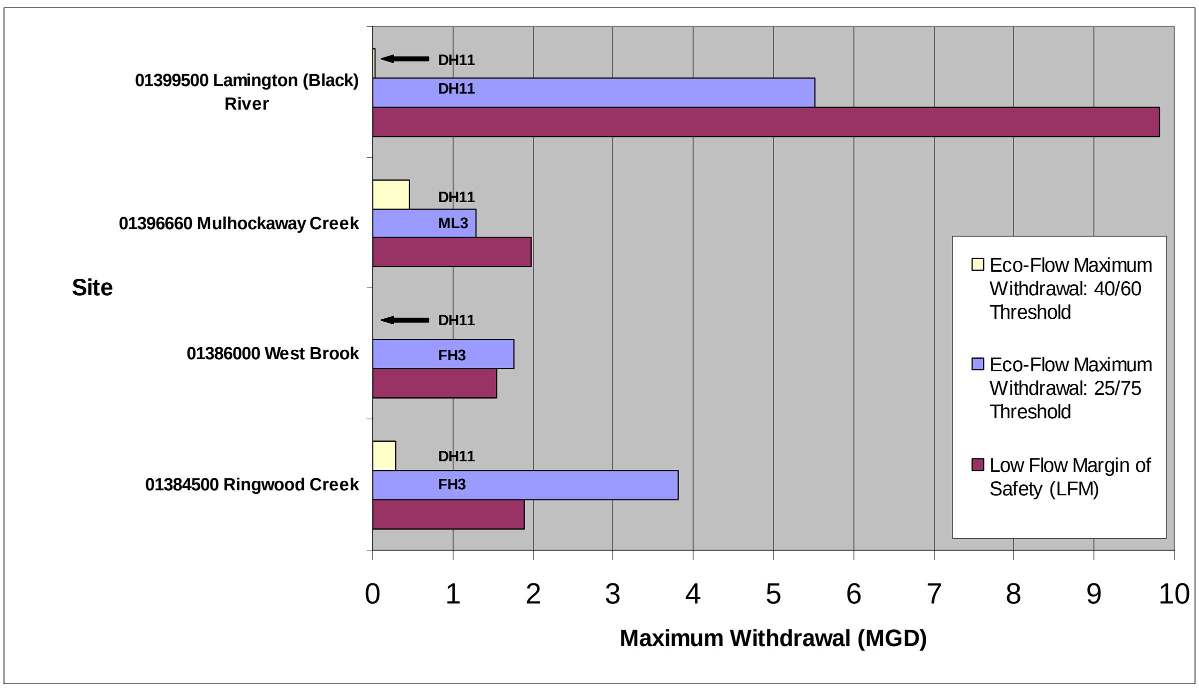

Figure 8. Comparison of Ecological-Flow Maximum Withdrawal vs. Low Flow Margin of Safety (LFM)

DISCUSSION

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

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

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

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