MODIFIED AQUATIC BASE FLOW (RI-ABF) FOR RHODE ISLAND

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Preface

The attached RIABF methodology is a technical modification to the US Fish and Wildlife ABF methodology, representative of a simplified reconnaissance level method. These flows are presumed to be protective of aquatic life but this methodology itself does not address the concept of maximum sustainable use.

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1.0 PURPOSE

The Rhode Island Department of Environmental Management Office of Water Resources is charged with setting state standards for water quality and freshwater wetland protection. Integral to water quality and wetland protection is the need for adequate water quantity. Currently, the Department's Water Quality Regulations contain a narrative standard which states that water quality standards should, whenever attainable, provide water quality, including quantity, for the protection and propagation of fish and wildlife and for recreation in and on the water and take into consideration their use and value as public water supplies, propagation of fish and wildlife, recreation in and on the water, agricultural, industrial, and other purposes including navigation. These standards are applicable to activities that will likely cause or contribute to flow alterations therefore the streamflow condition must be adequate to support existing and designated uses.

To better define the narrative standard, the Office of Water Resources worked with a committee to develop the modified Aquatic Base Flow methodology (RI-ABF) utilizing gauged stream flow data measured at selected Rhode Island and nearby Connecticut and Massachusetts rivers. The RI-ABF methodology has been endorsed by this committee as a technical modification to the US Fish and Wildlife ABF approach without consideration as to how it may be implemented. The RI-ABF standard is intended to be presumptive meaning that the standard is representative of natural flow in streams not significantly altered by withdrawals and therefore, if met, aquatic resources will be protected. Alternatively, site-specific streamflow standards may be applied, provided that adequate scientific studies support their use.

The need for more detailed streamflow standards is evident in the growing concern over the adequacy of the State's water resources to meet all demands including environmental protection. The concern is particularly acute during periods of drought, however is evident more generally as watersheds show signs of stress due to an imbalance between supply (for example, precipitation and groundwater recharge) and demand (for example, withdrawals and out-of-basin transfers). Sustainable water use is critical to our ability to meet demands for drinking water now and in the future. Moreover, the viability of the state's fisheries, agriculture, recreation and tourism, and other economic activities are also dependent upon the reliable availability of suitable quality water. Therefore, the purpose here is to develop instream flow standards including a site-specific standard that allows for maximum sustainable use of the State's waters and are protective of the biological, chemical, and physical integrity of those waters.

2.0 BACKGROUND

The structure and function of riverine systems are based on five components: hydrology, biology, geomorphology, water quality, and connectivity. The proposed instream standard is intended to mimic a natural flow regime that will in turn protect aquatic life functions dependent on the natural flow regime.

Research has found that the natural biota is dependent upon basic hydrology: longitudinal (headwater to mouth), lateral (channel to floodplain), vertical (channel bed with groundwater), and chronological[1]. Significant disruptions in any of these hydrologic features will be detrimental to the natural biota. For example, change the timings of releases in the spring and any natural spawning cues of anadromous fish will be affected. Remove flooding flows and water from the floodplain and wetlands are lost, riparian zones are changed, and siltation of gravel beds remove spawning habitat. Information regarding how flows affect the natural biota can be found in the book "Instream Flows for Riverine Resource Stewardship" by the Instream Flow Council, 2004[1]. For the purposes of this paper, we will assume that the reader is familiar with the need for instream flow for riverine species.

There are several desktop standard-setting methods available. Some include the US Fish and Wildlife Service Aquatic Base Flow Method (USFWS ABF), the Flow Duration Curve Method, and the Tennant Method. Standards developed by standard setting methods often provide results that approximate those provided by more detailed, site-specific methods, but they lack the ability to quantitatively and incrementally assess the relationship between habitat availability and flow. Given this uncertainty, flow standards derived from these kinds of methods are conservative in terms of the resource protection[2].

The Department has conducted a thorough review of the desktop standard setting methods. Interestingly, the review showed that when the various methods were applied to two different rivers, the resulting flows centered around the 0.5 cubic feet per second per square mile (cfsm), which is the USFWS ABF default summer flow. Therefore, after looking at the pros and cons of each of the methods, it was determined that the USFWS ABF warranted further investigation. The salient principle of this method is that it protects the low summer time flow when temperatures are highest and oxygen is lowest. The method's ecological underpinnings are that the natural ecological-hydrological system serves as a baseline or reference condition from which stream flow conditions suitable for the protection and propagation of aquatic life could be identified. Aquatic life in natural stream systems are subject to an inherently complex array of imperfectly understood relationships and conditions that serve to limit or promote life in lotic environments. The USFWS concluded that aquatic life in free flowing New England streams have evolved and adapted to naturally occurring chemical, physical and biological conditions, and that if these environmental conditions could be emulated, aquatic life would be sustained at a level commensurate with populations existing under similar natural environments[3].

The USFWS ABF also showed potential because of its long-standing use in Federal Energy Regulatory Commission re-licensing applications and its successful defense in court. This paper discusses the proposed adaptation of the methodology used by the USFWS to the conditions seen in Rhode Island.

When developing the state standard, the Department followed four main criteria: 1. The reference streams selected to develop the standard should not be significantly influenced by current pumping or dams (regulation); 2. The standard must be flexible (this means allowing for site-specific alternatives and that the standard may be applied to varying sized watersheds); 3. The standard must recognize Rhode Island's hydrogeologic features; and 4. The standard must be simple to apply.

3.0 DISCUSSION OF USFWS ABF METHODOLOGY

Since the foundation of the standard that the Department has developed is based on the USFWS ABF, a review of this method is warranted. The USFWS used historical flow records for New England to describe stream flow conditions that will sustain and perpetuate indigenous aquatic fauna. The USFWS evaluated gage data from 48 unregulated rivers with drainage areas greater than 50 square miles (mi^2) and with a 25 year gage record (mainly in northern New England since most in the southern portion are heavily regulated). The USFWS ABF method assumes that the most critical flows to be maintained are in August when the metabolic stress to aquatic organisms is at its highest due to high water temperatures, diminished living space, low dissolved oxygen, and low or diminished food supply. It was determined that the historical (unaltered) median flows will protect critical reproductive functions. Where adequate records (25 years of unaltered, free-flowing, 50 $mi.^2$ or greater USGS gaging measurements) exist the USFWS recommends that using the median of the monthly means of August flows will be adequate throughout the year unless additional flow releases are necessary for fish spawning and incubation. If spawning and incubation are an issue, the USFWS recommends flow releases equivalent to the historical median of monthly means stream flow throughout the applicable spawning and incubation period. Where inadequate records exist or for rivers regulated by dams or upstream diversions, the USFWS recommends using 0.5 cfsm unless spawning and incubation are a concern where the recommendation is 1.0 cfsm in the fall/winter and 4.0 cfsm in the spring. This policy has been successfully defended in court and is widely used in New England.

The USFWS ABF is a simple, time-tested, well proven minimum flow that has shown itself to be protective of the environment. However, refinements can be made to the USFWS ABF to develop a more representative hydrograph for Rhode Island. In the development of the USFWS ABF, the median of the August mean flow was calculated for 48 gages and divided by drainage area. Only one gaging station of the 48 selected for the USFWS study was actually located in Rhode Island. These normalized flow values (in cfsm) were averaged across all drainages to arrive at an August median flow of 0.48 (which was then rounded to 0.5 cfsm.

In addition, there are hydrogeologic and climatic dissimilarities between areas that were evaluated to develop the USFWS policy and Rhode Island. The large majority (>75%) of the rivers that were evaluated were in areas that have significant snowpack and resulting snowmelting flows. These areas see higher spring flows at different times of the year and lower winter flows than what is seen in Rhode Island. The differences are clearly seen in the monthly hydrographs (Figure 3.1) and in particular, in the amplitude and timing of the spring flows. These differences are addressed in the RI-ABF method to more closely reflect RI conditions.

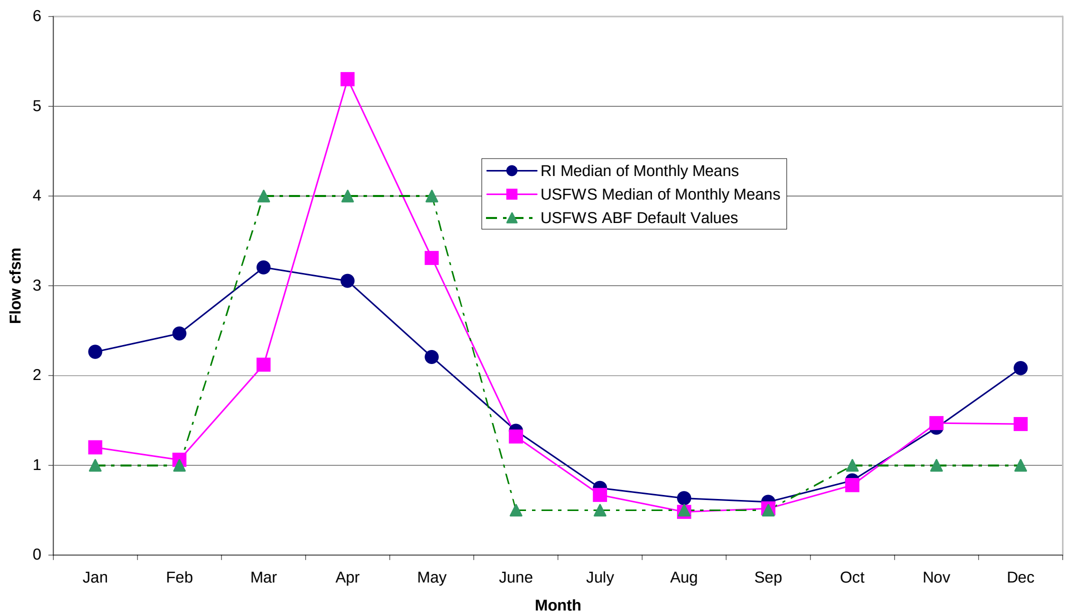


Figure 3.1 - Comparison of Hydrographs: NE ABF vs. Unregulated Gages in Rhode Island.

4.0 DEVELOPMENT OF THE RI-ABF STANDARD

The Department is proposing four ways in which the USFWS ABF will be adapted to better represent Rhode Island conditions. Much of these changes derive from concepts presented by Colin Apse, 2000[5].

1. Selection of gages in and around Rhode Island.
2. The use of the August median flow rather than the median of the monthly August mean flows
3. The use of monthly criteria rather than 3 seasonal values
4. The use of physiographic regions within the state.

4.1 Selection of Stream Gages

The first step in selecting the gages to be used in developing the RIABF standard was to identify the continuous stream gages with 9 or more years of record located in Rhode Island, and in Massachusetts and Connecticut within 20 miles of the State Line. The gages were eliminated from the list if the gages were on “regulated” streams (that is, those streams significantly affected by water withdrawals or diversions). Gages were also eliminated if they had intermittent flow (which we defined as periods of zero flow). Lastly, based upon statistical analyses, described in detail below, indicating that gages on watersheds of < 5 sq. mi. are statistically significantly different than gages with > 5 sq. mi., therefore watersheds of < 5 sq. mi. were eliminated as reference sites.

4.1.1 Regulated vs. Unregulated

As described above, only unregulated gages were selected as reference sites. The hydrologic records were individually reviewed and examined for the following impacts that could eliminate them as a reference site:

- Impoundments that significantly dampen the hydrograph;
- Surface or groundwater withdrawals that significantly alter the hydrograph;
- Significant evapotranspiration from large wetland complexes that alter the daily hydrograph; and

- Signals in the historical record that indicate other disturbances.

Representatives from the USGS, RIDEM – Agriculture, RIDEM – Water Resources and RIDEM – Dam Inspection met to evaluate the list of stream gages. The list was culled to 31 unregulated gages. Later conversations with the USGS resulted in the elimination of the Nipmuc Gage at Harrisville due to the instability of the gage at lower flows leaving the 30 unregulated gages shown below.

Table 4.1 - Unregulated continuous stream gages in and around Rhode Island.

USGS Site Number	Gage Site	Drainage Area	Period of Record
RI01126200	Bucks Horn	5.52	1965-1974
RI01118500	Pawcatuck at Westerly	295.00	1963-2002
RI01118000	Wood at Hope Valley	72.40	1953-2002
RI01117800	Wood near Arcadia	35.20	1964-2002
RI01117500	Pawcatuck at Wood	100.00	1940-2002
RI01117468	Beaver near Usquepaug	8.87	1974-2002
RI01116300	Furnace Hill	4.19	1964-1974
RI01115630	Nooseneck	8.23	1965-1974
RI01115187	Ponagansett at S. Foster	13.70	1994-2002
RI01115100	Mosquitohawk near N. Scituate	3.06	1965-1974
RI01115098	Peeptoad at Elmdale	4.96	1994-2002
RI01114500	Woonasquatucket at Centredale	38.30	1941-2002
RI01114000	Moshassuck at Providence	23.10	1963-2002
RI01112700	Blackstone at Woonsocket	2.31	1965-1974
RI01111500	Branch at Forestdale	91.20	1958-2002
RI01111400	Chepachet	17.40	1964-1973
RI01106000	Adamsville	8.01	1940-1974, 1987
MA01124750	Browns Brook near Webster	0.49	1962-1989
MA01111200	West River at West Hill Dam	27.90	1962-1989
MA01109200	West Branch Palmer	4.35	1962-1974
MA01107000	Dorchester Brook near Brockton	4.67	1963-1974
MA01105730	Indian Head at Hanover	30.30	1963-1974
MA01105600	Old Swamp River	4.50	1966-2002
CT01126600	Blackwell Brook near Brooklyn	17.00	1964-1976
CT01125490	Little River at Harrisville	35.80	1961-1971
CT01123000	Little River near Hanover	30.00	1952-2002
CT01121000	Mount Hope near Warrenville	28.60	1941-2002
CT01120500	Safford Brook	4.15	1950-1981
CT01120000	Hop River near Columbia	73.90	1932-1971
CT01118300	Pendleton Hill Brook	4.02	1959-2002

4.1.2 Intermittent Streams

Further review of the hydrologic record showed that some of the streams had periods of zero flow. While this was not necessarily attributed to regulation of flow, clearly the statistics would be skewed if intermittent streams (or zero flows) were analyzed as part of the statistics. Therefore, any streams that went dry were eliminated as representative streams. Table 4.2 identifies the intermittent streams that were removed from the representative set, and Table 4.3 identifies those continuously flowing streams used to develop the RI-ABF standard.

Table 4.2 – Intermittent gauged streams removed from the representative data set.

USGS Site Number	Gage Site	Drainage Area	Period of Record
RI01116300	Furnace Hill	4.19	1964-1974
RI01115187	Ponagansett at S. Foster	13.70	1994-2002
RI01115100	Mosquitohawk near N. Scituate	3.06	1965-1974
RI01115098	Peeptoad at Elmdale	4.96	1994-2002
RI01112700	Blackstone at Woonsocket	2.31	1965-1974
MA01124750	Browns Brook near Webster	0.49	1962-1989
MA01109200	West Branch Palmer	4.35	1962-1974
CT01120500	Safford Brook	4.15	1950-1981
CT01118300	Pendleton Hill Brook	4.02	1959-2002

Table 4.3 – Continuous flowing gauged streams analyzed for the standard.

USGS Site Number	Gage Site	Drainage Area	Period of Record
RI01126200	Bucks Horn	5.52	1965-1974
RI01118500	Pawcatuck at Westerly	295.00	1963-2002
RI01118000	Wood at Hope Valley	72.40	1953-2002
RI01117800	Wood near Arcadia	35.20	1964-2002
RI01117500	Pawcatuck at Wood	100.00	1940-2002
RI01117468	Beaver near Usquepaug	8.87	1974-2002
RI01115630	Nooseneck	8.23	1965-1974
RI01114500	Woonasquatucket at Centredale	38.30	1941-2002
RI01114000	Moshassuck at Providence	23.10	1963-2002
RI01111500	Branch at Forestdale	91.20	1958-2002
RI01111400	Chepachet	17.40	1964-1973

USGS Site Number (cont.)	Gage Site	Drainage Area	Period of Record
RI01106000	Adamsville	8.01	1940-1974, 1987
MA01111200	West River at West Hill Dam	27.90	1962-1989
MA01107000	Dorchester Brook near Brockton	4.67	1963-1974
MA01105730	Indian Head at Hanover	30.30	1963-1974
MA01105600	Old Swamp River	4.50	1966-2002
CT01126600	Blackwell Brook near Brooklyn	17.00	1964-1976
CT01125490	Little River at Harrisville	35.80	1961-1971
CT01123000	Little River near Hanover	30.00	1952-2002
CT01121000	Mount Hope near Warrenville	28.60	1941-2002
CT01120000	Hop River near Columbia	73.90	1932-1971

4.2. Use of the Monthly Median Flows

Apse 2000[5], presents an argument that when evaluating watersheds with smaller drainage areas (<50 $mi.^2$) as seen in Rhode Island, the median of the monthly medians is a better measure of the natural flow regime. The median is accepted as a better measure of central tendency in cases where data is skewed by extremes as it is in stream flow distribution data where a few large storm events create large flow numbers on very few days. The USFWS ABF development looked at data from 48 streams with a drainage area >50 $mi.^2$. The reason given for this minimum $mi.^2$ criteria is to "insure that a dendritic drainage pattern is included to help smooth out the effects of localized storms and reduce stream flow variability." (Lang, 1990[3]) In Rhode Island, the majority of the streams have watersheds < 50 $mi.^2$, so results using the median of monthly means would likely be skewed upward due to storms. Therefore, it is recommended that any evaluations made to develop a flow standard should include median of monthly medians.

4.2.1 Extending Stream Gage Records

As can be seen from Table 4.3 above, the periods of record for the individual gages vary widely and many comments from the technical advisory committee revolved around this issue. The concern was that staggered records would result in incorrect results because some streams where flow was measured for a few years during the 1960's drought would result in lower streamflow statistics than a stream that was measured for a few years during a wet period. The assumption is that if all of the gages were normalized to the same time period, the statistics would correlate better and be more representative of historical and natural conditions. Therefore, the stream gage records were extended to encompass the period from 1974 to 2002.

In consultation with the USGS[6], DEM selected the Move.1 equation as the methodology to extend the record by applying it to the monthly Median and other low flow statistics (4Q2 and 4Q3). First, the statistics from a short-term station was compared to the statistics from a long-term station for the same period of record. Medians, 4Q2's and 4Q3's and were calculated for each intersecting time period. For example, medians, 4Q2's and 4Q3's were calculated at Buck's Horn Brook (1964–1975) and then the same statistics were calculated for the Wood River at Arcadia for the period of 1964-1975 even though the period of record for the Wood River is 1964-2002. Since the statistics were computed during the same time periods, there is a better chance for good correlations to develop by removing interferences of other dry or wet years. Figure 4.1 is an example of a short-term station (Buck's Horn Brook) compared to a long-term station (Wood River at Arcadia). Each short-term gage was compared to at least 4 long-term gages to determine which gage had the best correlation.

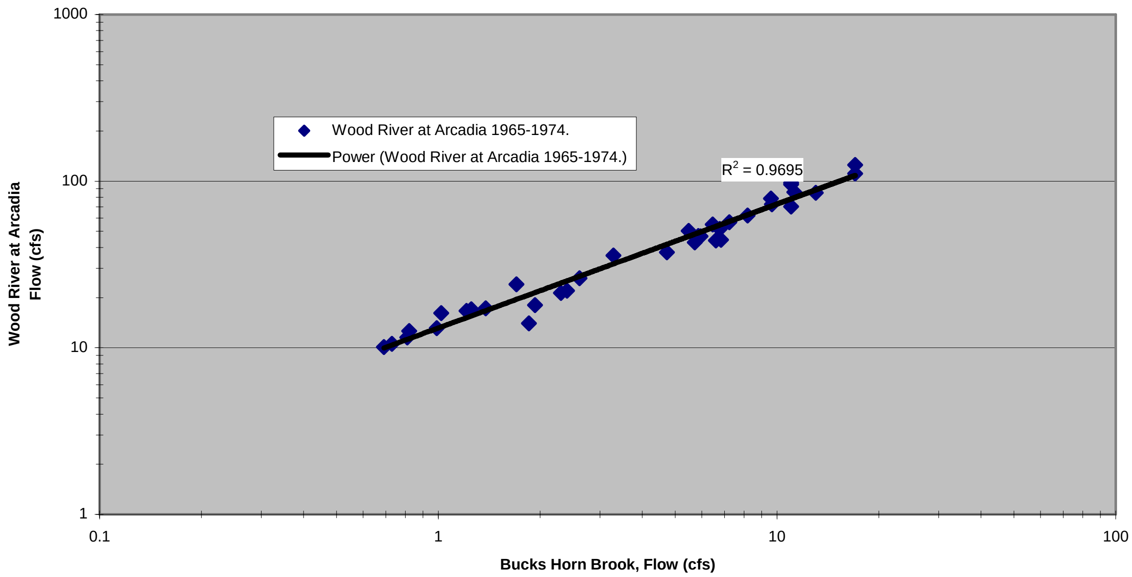


Figure 4.1 - Wood River at Arcadia vs. Bucks Horn Brook 1965-1974
Statistics plotted for monthly Medians, 4Q2's and 4Q3's.

Then the Move.1 line was plotted for the Median, 4Q2 and 4Q3. Figure 4.2 below shows the Move.1 line used to extend the record for the 4Q3 line.

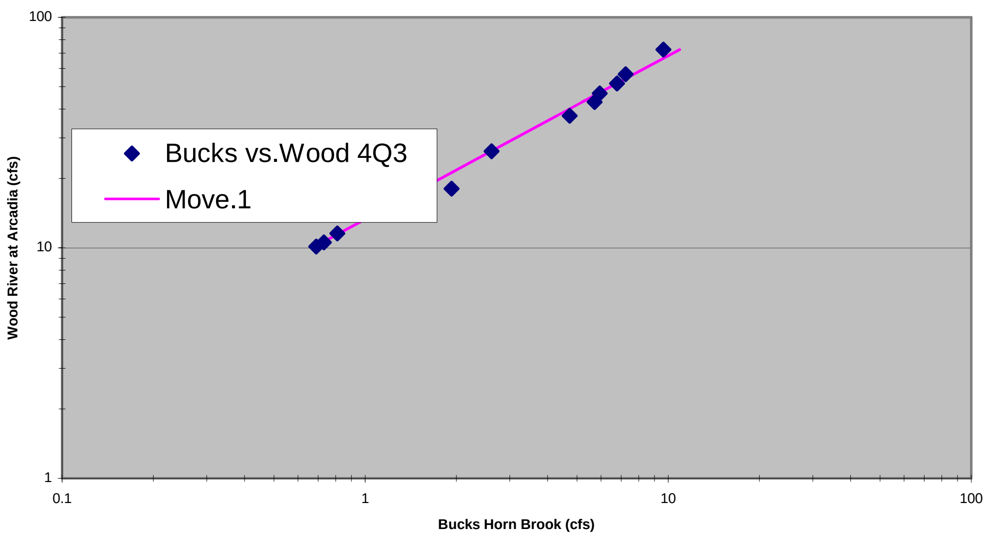


Figure 4.2 - Move.1 line for the 4Q3 of Bucks Horn Brook vs. Wood River at Arcadia

The Move.1 equation in this example was 4Q3 Bucks Horn = $10^{(1.39(\log(4Q3\ Arcadia)-1.43)+.43)}$ and so the last step is to take the monthly values from the 4Q3's at Wood River at Arcadia for the period 1974-2002 and apply the equation to get the resulting 4Q3 at Buck's Horn Brook for the period 1974-2002. This process was completed for the 4Q2, 4Q3 and Median flows for 9 gages (Adamsville, Blackwell Brook, Buck's Horn Brook, Chepatchet River, Dorchester Brook, Hop River, Little River at Harrisville, Nooseneck River and the West River).

4.3 Natural Flow Regime - Monthly vs. Seasonal

An instream flow standard should mimic the natural flow regime as closely as possible in order to adequately represent the five riverine components (hydrology, biology, geomorphology, water quality and connectivity). Movement from a seasonal standard to a monthly standard more closely approximates the natural flow regime. The natural flow regime of virtually all rivers is inherently variable, and this variability is critical to ecosystem function and native biodiversity[1]. For this reason, providing a single flow value (minimum, optimal, or otherwise) cannot meet the life cycle requirements for all riverine species[1].

Unregulated (reference) gages in both the coastal lowlands and the eastern highlands were evaluated to generate the median of the monthly medians for each month of the year.

4.4 Physiographic Regions

Observation of the data, and analysis from the May 2003 white paper showed that the northwestern section of the State did not naturally yield flows as high as the southern part of the state. Conversations with USGS and information from the Apse 2000[1] thesis provided a rationale. USGS stated that the northwestern portion of the State has a more shallow alluvial channel before reaching bedrock and will therefore not yield as much water as a similar area in the southern part of the State. Research done by Patton in 1988[6] showed that a landscape characteristic (geomorphology) evaluation is necessary to determine hydraulic responses to precipitation. Patton reviewed the large-scale factors that define the nature of rivers in New England. The New England physiographic province has been divided into four primary subregions that are considered to be similar in geology, topography and vegetation (Denny, 1982[7]; Patton, 1988[8]). These subregions, from west to east, are the Western Highlands, the Connecticut Valley Lowlands, the Eastern Highlands, and the Coastal Lowlands (Figure 3). Geology is emphasized in defining these regions as the shape and structure of the New England landscape is primarily controlled by its underlying bedrock (Denny, 1982[8]). The two regions in Rhode Island are the Coastal Lowlands and the Eastern Highlands. The eastern highlands contain areas of the greatest elevation, with resistant metamorphic rocks most evident in the area of the White Mountains (granitic intrusions) and resistant igneous rocks best exemplified by Mt. Katadhin in Maine. The coastal lowlands are areas of low relief and Cenozoic sedimentary deposits and deep stratified drift. Streamflow data from the two physiographic regions were tested to determine whether the differences are statistically significant, and as described in detail in section 4.5 of this report, the tests confirmed that the monthly differences in streamflow statistics for the two regions are significantly different.

There is an exception to these physiographic regions. Due to the large resolution that these regions were developed upon (New England to Canada), pockets of isolated differences may occur. The streamflow statistics and the knowledge of the geology (high bedrock) indicate that the streams located on the islands (Jamestown, Prudence, Aquidneck) and in the Towns of Barrington, Warren and Bristol, behave similarly to those in the Eastern Highlands. Therefore, those areas have been incorporated into the Eastern Highland regions.

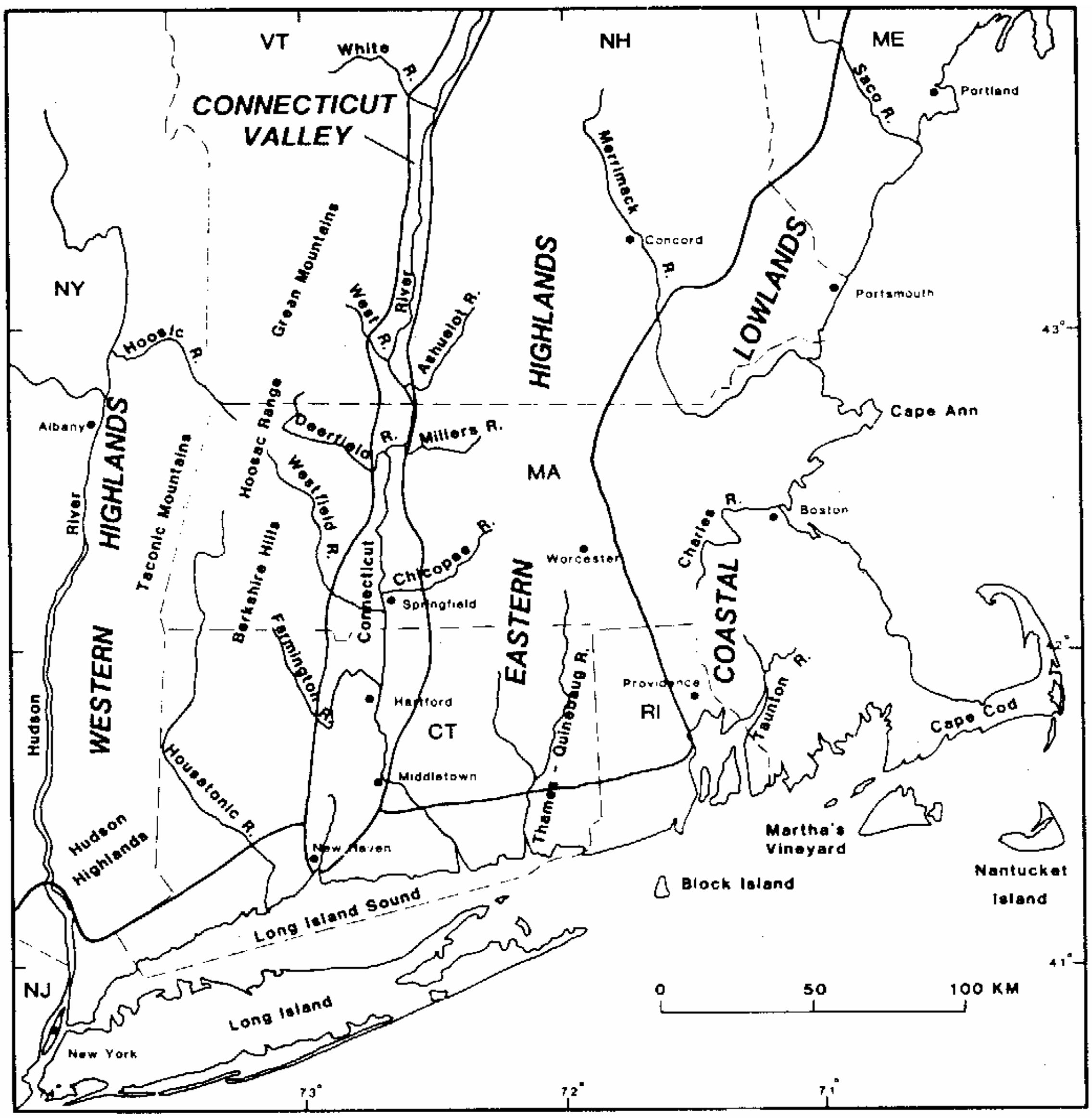


Figure 4.3 - Physiographic map of the New England Region (Denny, 1982[7])

4.5 Statistical Significance

Two types of tests were performed on the monthly medians, 4Q2's and 4Q3's. The Rank-Sum Test developed by Wilcox (1945)[9] and the student's t-test. The Rank-Sum test is a more involved test that compares the differences between two independent groups. In it's most general form, the rank-sum test is a test for whether one group tends to produce different observations than the second group. Usually, however, the test is used for a more specific purpose – to test whether or not the two groups selected by the analyst are statistically different from each other. The rank-sum test evaluates the two groups by evaluating differences between the means and the variances. The student's t-test only evaluates the differences between the means. Both tests were used to analyze these data sets to evaluate the statistical significance of 1) differences in monthly streamflow data for the two physiographic regions and 2) gages with drainage areas less than 5 sq. mi. versus those that are greater than 5 sq. mi.

Early on it was recognized that the student's t-test was more conservative (meaning it resulted in no differences in the two groups more often than the rank-sum test). The t-test was specifically a two-tailed, two-sample unequal variance test. Because of the level of difficulty required to administer the rank-sum test, and because the t-test was consistently more conservative, the student's t-test was performed for the rest of the population analysis instead of the rank-sum test.

Two hypothesis were tested. The first hypothesis was: Are streams with < 5 sq. mi. statistically significantly different from streams with > 5 sq. mi? The second hypothesis tested was: Are there differences in the statistics between the eastern highlands and the coastal lowlands? Because of the noise in the data, meaning, variations between the coastal lowlands and the eastern highlands, the first hypothesis was tested in it's own region. Therefore, in Table 4.4 below, gages with < 5 sq. mi. within the Coastal Lowlands were tested against gages with >5 sq. mi. within the Coastal Lowlands. The same procedure was used for the Eastern Highlands.

Below in Table 4.4 is the result of the t-test to determine if stream gages with < 5 sq. mi. were from a statistically significant independent group. These hypothesis tests require the selection of a probability or α. For these types of analysis, the USGS typically selects 0.05 as the probability. This means that the hypothesis is only true when the probability of independence was 95% or greater.

Table 4.4. - Student T- test to determine if gages with <5 sq. mi. were significantly statistically different from the rest of the population (α=0.05, two-tailed two-sample unequal variance test, statistics normalized for drainage area)

	4Q3 (CFSM)		4Q2(CFSM)		MEDIAN (CFSM)	
	EH	**CL**	**EH**	**CL**	**EH**	**CL**
Jan		yes		yes		yes
Feb		yes		yes		
Mar		yes		yes		
Apr		yes		yes		yes
May		yes		yes		yes
June	yes	yes		yes		yes
July	yes	yes	yes	yes	yes	yes
Aug	yes	yes	yes	yes	yes	yes
Sept	yes	yes	yes	yes	yes	yes
Oct	yes	yes	yes	yes	yes	
Nov	yes					
Dec						

The results of this test show that flows in watersheds of <5 sq. mi in the Coastal Lowlands are almost always lower per sq. mi. of drainage area than flows in the larger watersheds. The test also shows that the population is significantly different throughout most of the year whereas, in the Eastern Highlands, the difference is only apparent in the summer. There are two conclusions from this analysis. First, that gages with <5 sq. mi. of drainage should not be used to calculate the standard and should not be averaged in with the general population. Second, that the standard should not be applied to those watersheds with <5 sq. mi. of watershed.

After eliminating the stream gages with less than 5 sq. miles, the t-test was then performed on the two physiographic region groups to determine if there is a significant statistical difference between the regions.

Table 4.5. - Student T- test to determine if the eastern highlands were significantly statistically different from the coastal lowlands (α=0.05, two-tailed two-sample unequal variance test, statistics normalized for drainage area)

	4Q3	4Q2	Median
Jan			
Feb			
Mar			
Apr			
May	yes		
Jun	yes	yes	yes
Jul	yes	yes	yes
Aug	yes	yes	yes
Sep	yes	yes	yes
Oct	yes	yes	
Nov			
Dec			

The results of this test in Table 4.5 show that the regional differences are only evident in the summer. The conclusion to this analysis is that the physiographic regions are statistically different, but only during low-flows. The recommendation of the RIDEM however, is that to avoid confusion there should be a separate standard for the Eastern Highlands and for the Coastal Lowlands. Table 4.6 lists the stream gages used to determine the RI-ABF standard organized by physiographic region.

Table 4.6. – Stream Gages to used to develop the RI-ABF Organized by Physiographic Region

Gage#	Station Name
Eastern Highlands	
01111500	Branch River at Forestdale, RI
01117800	Wood River at Arcadia, RI
01106000	Adamsville Brook at Adamsville, RI
01115630	Nooseneck River at Nooseneck
01126200	Bucks Horn Brook at Greene, RI
01114000	Chepachet River at Chepachet, RI
01111200	West River at West Hill Dam, MA
01121000	Mnt. Hope River nr Warrenville, CT
01123000	Little River near Hanover, CT
01120000	Hop River near Columbia, CT
01125490	Little River at Harrisville, CT
01126600	Blackwell Brook near Brooklyn, CT

Coastal Lowlands	
01114000	Moshassuck River at Providence, RI
01114000	Woonasquatucket River at Providence, RI
01117468	Beaver River near Usquepaug, RI
01117500	Pawcatuck at Wood River Junction, RI
01118000	Wood River at Hope Valley, RI
01118500	Pawcatuck River at Westerly, RI
01105730	Indian Head at Hanover, MA

The location of these gages are shown in Figure 4.4 below:

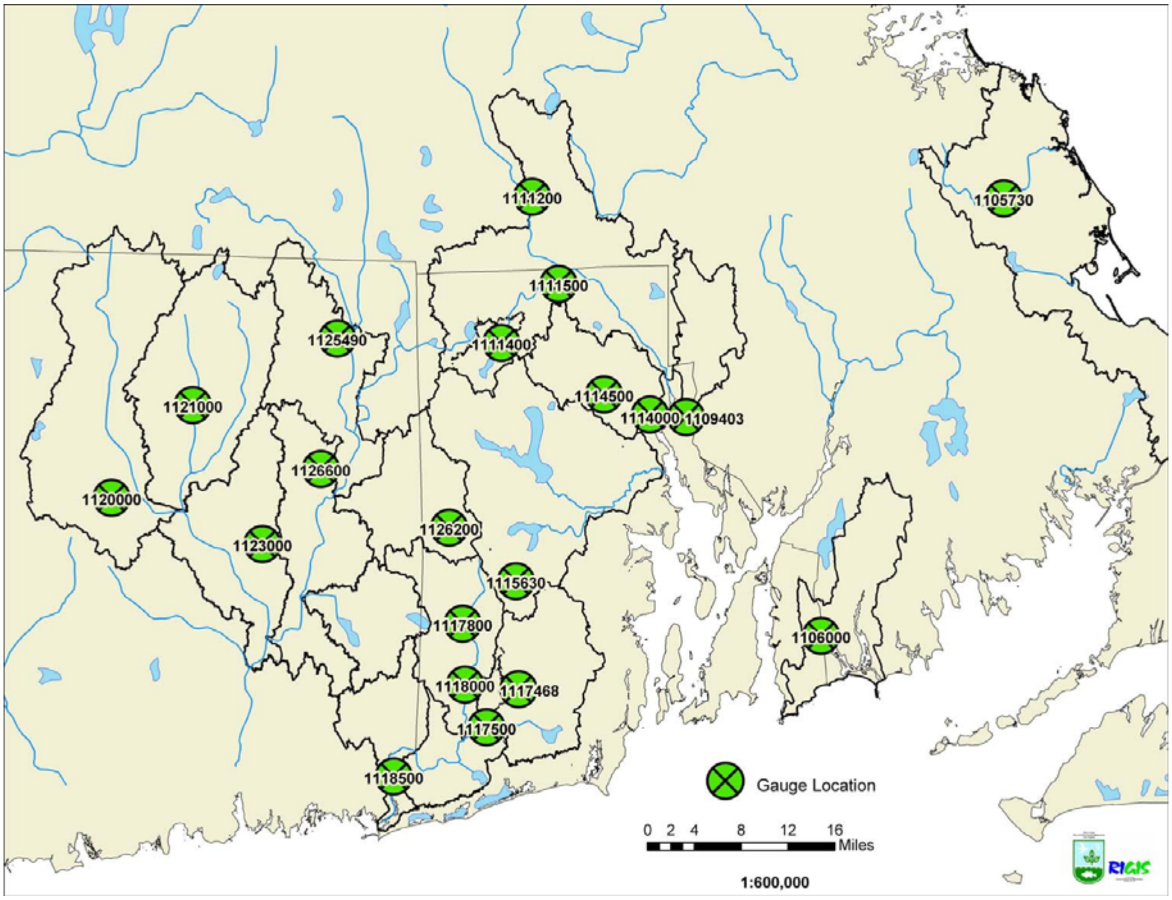


Figure 4.4 Locations of USGS Stream Gages used to develop the streamflow standard.

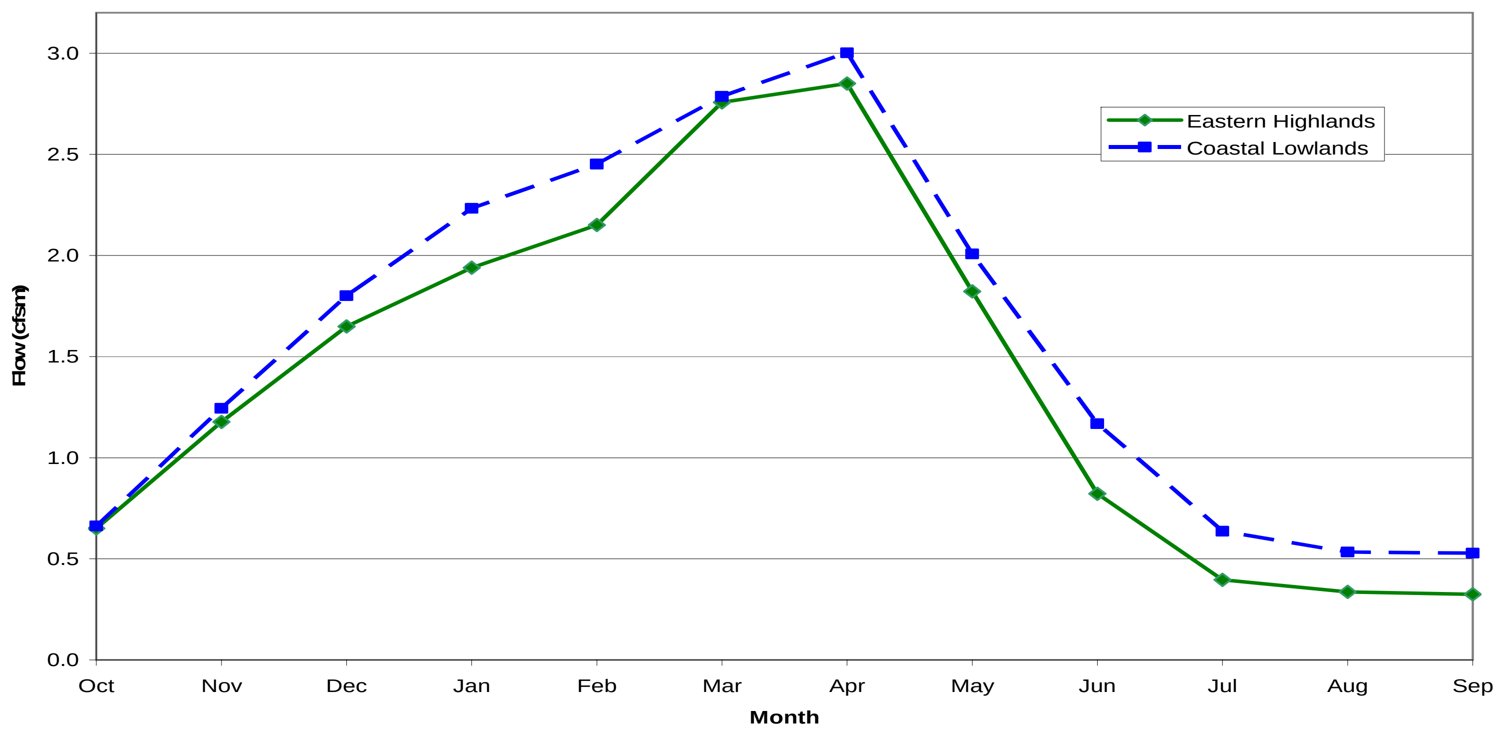
5.0 SUMMARY: Rhode Island Aquatic Base Flow (RI-ABF)

The Rhode Island modified ABF (RI-ABF) monthly instream flow values are presented in Figure 5.1. The standard consists of monthly medians of unregulated streams organized by physiographic regions, as described previously.

Table 5.1 – RI-ABF Monthly Instream Flow Values

Monthly instream flow values in cubic feet per square mile of drainage (cfsm)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Eastern Highlands	0.65	1.18	1.65	1.94	2.15	2.76	2.85	1.82	0.82	0.4	0.34	0.32
Coastal Lowlands	0.66	1.24	1.8	2.23	2.45	2.79	3	2	1.17	0.64	0.54	0.53



6.0 COMPARISONS WITH OTHER STUDIES

6.1 Ipswich River, Massachusetts

The Massachusetts USGS conducted its first study of instream flow methodologies in New England on the Ipswich River in Massachussetts[10]. In this report the USGS conducted fish surveys, habitat assessments, and studied the hydraulics of the stream. They did not provide an extensive analysis between habitats and fish, however they did use several accepted scientific methods to determine instream flow requirements. The results from the Ipswich Study compared with the RI-ABF are presented below in Table 6.1:

Table 6.1 - Comparison of the Ipswich River study and the RI-ABF – Coastal Lowlands

Method	Flow (cfsm)
Mean R2CROSS for altered riffle sites	0.74
Tennant (Good Flow)	0.67
Tennant (Fair or degrading flow)	0.50
RI-ABF (September)	0.53
R2CROSS for a natural Riffle site	0.42
Wetted Perimeter for altered riffle sites	0.41
Tennant (Poor or Minimum)	0.17

6.2 Usquepaug-Queen Rivers, Rhode Island

The USGS study on “Streamflow requirements for habitat protection on the Usquepaug -Queen Rivers”[11], was conducted in a similar fashion to the Ipswich River Study. However, the methodology of the study was expanded by also measuring continuous instream temperatures. The results of this study showed that there was sufficient water in the Usquepaug-Queen River to maintain a viable fishery, however the river was dangerously close to the temperature threshold for maintaining the viable fishery. The report states that although the study did not determine how current water withdrawals and land-use practices may be affecting stream temperatures, "the stream temperatures in the Usquepaug River and Queen River headwaters were marginal for brook trout in the summer of 2000, and cold-water fish communities that may exist in these reaches would appear to have little tolerance for additional temperature changes that could possibly be created by increased water withdrawals." The report presents the results of the different methods for determining instream flow. These along with results from application of RI-ABF are presented in Table 6.2.

Table 6.2 - Comparison of the Queen-Usquepaug Study and RI-ABF- Coastal Lowlands

Method	Flow cfsm
Tennant (Good Flow)	0.85
Tennant (Fair or degrading flow)	0.64
Mean R2CROSS 3/3 unaltered sites	0.53
RI-ABF (September)	0.53
Mean Wetted Perimeter	0.41
Tennant (Poor or Minimum)	0.21

6.3 Quinebaug River, Massachusetts

Another study for comparison and evaluation is the "Ecohydrology Study of the Quinebaug River" by Piotr Parasiewicz and A.S. Gallagher[12]. The information gathered is from an interim report and so the results are not final. This study is unique from the others because it applies a physical habitat model to restoration planning at a whole river scale. "The design proposed here builds upon the Instream Flow Incremental Methodology but is focused at the need for managing large-scale habitats and river systems. It modifies the data acquisition technique and analytical resolution of standard approaches, changing the scale of physical parameters and biological response assessment from micro- to meso-scale. In terms of technological process, a highly detailed microhabitat survey of a few, short sampling sites would be replaced by mesohabitat mapping of whole-river sections. As with more traditional stream habitat models, the variation in the spatial distribution and amount of mesohabitats can provide key information on habitat quality changes corresponding to alterations in flow, channel changes, and stream improvement measures. However, the scale of simulations more closely matches restoration and system analyses, because it provides a solid base for quantitative assessment and simulation of habitat conditions for the whole stream[15]."

Table 6.3 - Comparison of the Preliminary Results from the Quinnebaug River Study and RI-ABF-Eastern Highlands

MesoHabsim	**RI-ABF**
1. Winter Survival Period: **Dec 1 - Feb 28/29** ▪ Minimum: 1.9 cfsm ▪ Critical: 2.0 cfsm ▪ Optimum: 2.2 cfsm	1. **Dec – Feb** ▪ 1.7 – 2.2 cfsm
2. Storage Period: **Mar 1 - April 15** ▪ Minimum: 2.6 cfsm	**2. Mar-April** ▪ 2.8- 2.9 cfsm
3. Spawning Period A: **April 16 - May 25** ▪ Minimum: 1.7 cfsm*	**3. April-May** ▪ 2.9 cfsm - 1.8 cfsm
4. Spawning Period B: **May 26 - July 7** ▪ Minimum: 0.5 cfsm*	**4. May, June, July** ▪ 0.4 – 1.8 cfsm
5. Rearing and Growth: **July 8- Sept. 15** ▪ Minimum: 0.35 cfsm ▪ Critical: 0.4 cfsm ▪ Optimum 0.5 cfsm	**5. July, August, September** ▪ 0.32 – 0.4 cfsm
6. Growth Period: **September. 16 - Oct 31** ▪ Minimum: 0.5 cfsm ▪ Critical: 0.5 cfsm ▪ Optimum: 0.8 cfsm	**6. September - October** ▪ 0.32 – 0.65 cfsm
7. Growth Period2: **November** ▪ Minimum: 1.0 cfsm ▪ Critical: 1.1 cfsm ▪ Optimum: 1.5 cfsm	**7. November** ▪ 1.2 cfsm

* Denotes literature values and not actual results from the MesoHabsim model

The instream flow recommendations for this study are taken from a presentation given by Neil M. Fennessey, Ph.D. The presentation discusses the DSS Model and how it can route flow for habitat needs required by the MesoHabsim model. The results in Table 6.3 above compare results from the MesoHabsim model with the RI-ABF. The RI-ABF standard for Eastern Highlands is used since most of the Quinebaug is located in the Eastern Highlands.

7.0 APPLICABILITY OF THE STANDARD

This standard is presumed to be protective of rivers and streams and is designed to provide a relatively simple approach to determine acceptable instream flow values. However, the methodology does not specifically consider the hydrologic requirements of associated wetland areas. This standard is designed to apply to those points in the stream where the upstream watershed is greater than 5 mi^2 and to those streams that have continuous flow throughout the year. If the watershed of concern is mostly in the eastern highlands, the eastern highland flow regime should be applied, if the watershed of concern is mostly in the coastal lowlands, the coastal lowland standard should be applied. Also, if the standard is to be applied to a river or stream that was used to create the RI-ABF, then the stream statistics specifically from that river or stream should be applied.

Finally, if it can be demonstrated that any of the monthly values presented in the standard are not applicable to a given site, then the Department will consider such requests on a case by case basis, for example when reviewing a permit application. Any such requests must have biologic and other scientific evidence supporting any variations. The RI-ABF standard should not be applied if site-specific criteria are deemed more appropriate because of the environmental sensitivity of a site or the size of the proposed project. In any event, establishment of the RI-ABF standard does not preclude use of site specific studies to determine instream flow values.

8.0 CONCLUSION

This paper presents the methodology used to develop an instream flow standard that better defines the narrative “water quantity” standard contained in the Department’s Water Quality Regulations however, it does not prescribe specific implementation requirements.. The RIABF is a modification of the US Fish and Wildlife Aquatic Base Flow standard designed to be more applicable to Rhode Island rivers and streams. Four main criteria were followed in developing the state standard: 1) the reference streams selected to develop the standard should not be significantly influenced by current pumping or dams, 2) the standard must flexible (meaning that it allows for site specific studies and may be applied to varying sized watersheds), 3) the standard must recognize Rhode Island's hydrogeologic features, and 4) the standard must be simple to apply.

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The RI-ABF standard builds upon the time-tested USFWS ABF methodology, applying the "best science" available to Rhode Island's specific conditions. The Instream Flow Council's position is that an effective instream flow prescription should mimic the natural flow regime as closely as possible. To that end, the RI-ABF contains monthly flow values instead of the three seasonal values of the USFWS ABF. Variations of the physiographic regions within the state are also accounted for in this methodology. The eastern highlands have shallower alluvial channels producing less water than the deeper stratified drift found in the coastal lowlands. In addition, this standard is based on data from gages located in Rhode Island and within 20 miles of the border and includes the smaller watersheds as opposed to the USFWS ABF. This standard is based on the median of the monthly medians, rather than the median of the monthly averages as is done in the development of the USFWS ABF.

A review of other studies conducted in Rhode Island and geologically similar areas in Massachusetts resulted in protective low flows that are consistent with the values produced with the RI-ABF methodology Studies on the Ipswich River in MA, using the wetted perimeter and R2CROSS methods, resulted in flows ranging from 0.41-0.74 cfsm. A similar study on the Usquepaug-Queen Rivers in RI presented flow results ranging from 0.41-0.53 cfsm. The Assabet and Charles Rivers study in MA produced results ranging from 0.14-1.05 cfsm. Whereas, the RI-ABF results were an August median of 0.32 – 0.54 cfsm, within the ranges of these three studies. The flow values generated using the RI-ABF are slightly lower than the range of numbers generated using other time-tested methods. However, this may have to do with the small watersheds and low percentages of stratified drift in Rhode Island and especially in the Eastern Highlands.

The RI-ABF standard is a presumptive standard, designed to be representative of natural stream flow regimes and therefore presumed to be protective of aquatic habitat. The RI-ABF method presented is relatively simple to apply, however site-specific methods for evaluating impacts are always an allowable option.

9.0 Acknowledgements

I would just like to thank several people who were instrumental in moving this project forward. Colin Apse who first had the idea to modify the USFWS ABF, Alicia Good for providing the resources to keep this project moving forward, Elizabeth Scott for her excellent linguistic skills and ideas to polish up the report, Carlene Newman who was my job sharing partner at the beginning of this project and assisted so well with the first draft, and Deb Merrill for her programming skills that allowed me to run many of the calculations presented. A special thanks to all on the streamflow committee and the technical advisory committee who reviewed the documents, listened to presentations, and provided such valuable feedback. Thanks Everyone!

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APPENDIX A

Median of Monthly Median

Varied Record Periods

Flow in Cubic feet per second per square mile

Eastern Highlands		**Period of Record**	**Drainage Area mi²**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
RI01111500	Branch at Forestdale	1958-2002	91.20	1.75	1.93	2.68	2.82	1.80	0.87	0.44	0.39	0.38	0.80	1.18	1.61
RI01117800	Wood near Arcadia	1964-2002	35.20	2.24	2.67	3.05	3.39	2.33	1.32	0.68	0.51	0.53	0.71	1.42	2.05
RI01106000	Adamsville	1940-1974,1987	8.01	1.87	2.18	2.75	2.12	1.50	0.57	0.16	0.08	0.06	0.26	1.16	1.44
RI01115630	Nooseneck	1965-1974	8.23	1.76	2.61	3.34	3.43	2.31	1.37	0.69	0.47	0.50	0.77	1.46	2.31
RI01126200	Bucks Horn	1965-1974	5.52	1.99	1.99	3.08	3.08	2.36	0.99	0.31	0.23	0.25	0.43	1.20	1.99
RI01111400	Chepachet	1965-1973	17.40	1.61	1.98	2.87	2.74	1.81	0.79	0.43	0.31	0.26	0.89	1.24	1.95
MA01111200	West River at West Hill Dam	1962-1989	27.90	1.33	1.76	2.71	2.97	1.79	0.68	0.27	0.23	0.19	0.34	0.81	1.36
CT01121000	Mount Hope near Warrenville	1941-2002	28.60	1.45	1.59	2.59	2.49	1.63	0.69	0.26	0.21	0.20	0.45	0.87	1.29
CT01123000	Little River near Hanover	1952-2002	30.00	1.50	1.82	2.53	2.53	1.80	0.85	0.47	0.33	0.33	0.50	0.92	1.50
CT01120000	Hop River near Columbia	1932-1971	73.90	1.31	1.45	2.90	2.19	1.57	0.64	0.26	0.19	0.22	0.42	0.91	1.42
CT01125490	Little River at Harrisville	1961-1971	35.80	0.92	1.23	2.77	2.23	1.08	0.57	0.18	0.12	0.10	0.25	0.69	0.77
CT01126600	Blackwell Brook near Brooklyn	1964-1976	17.00	1.53	1.85	2.59	2.53	1.65	0.65	0.24	0.18	0.18	0.28	0.82	2.12
Coastal Lowlands															
RI01114000	Moshassuck at Providence	1963-2002	23.10	1.52	1.73	2.12	2.23	1.47	0.84	0.52	0.43	0.43	0.56	0.97	1.26
RI01114500	Woonasquatucket at Centredale	1941-2002	38.30	1.85	2.17	2.92	2.75	1.80	1.12	0.76	0.65	0.63	0.68	1.10	1.75
RI01117468	Beaver near Usquepaug	1974-2002	8.87	2.71	3.07	3.38	3.69	2.71	1.61	0.89	0.62	0.57	0.63	1.13	2.09
RI01117500	Pawcatuck at Wood	1972-2002	100.00	2.21	2.76	2.88	3.25	2.24	1.43	0.86	0.76	0.64	0.68	1.06	1.80
RI01118000	Wood at Hope Valley	1953-2002	72.40	2.24	2.67	3.29	3.39	2.24	1.29	0.73	0.55	0.56	0.70	1.30	2.09
RI01118500	Pawcatuck at Westerly	1963-2002	295.00	2.07	2.52	2.84	3.09	2.05	1.25	0.72	0.52	0.54	0.58	0.99	1.77
MA01105730	Indian Head at Hanover	1966-2002	30.30	1.91	2.13	2.94	2.56	1.57	0.84	0.29	0.36	0.36	0.54	1.39	1.82

Median of Monthly Median

1974-2002 Record

Flow in cubic feet per second per square mile

Eastern Highlands		Drainage Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RI01111500	Branch at Forestdale	91.20	1.85	2.17	2.63	2.65	1.84	0.83	0.43	0.45	0.39	0.86	1.20	1.51
RI01117800	Wood near Arcadia	35.20	2.66	2.60	3.17	3.28	2.24	1.24	0.70	0.57	0.58	0.77	1.51	2.05
RI01106000	Adamsville	8.01	1.92	2.37	3.44	3.51	1.81	0.52	0.14	0.11	0.09	0.42	0.98	1.61
RI01115630	Nooseneck	8.23	2.33	2.67	3.15	3.18	2.32	1.17	0.66	0.69	0.62	1.21	1.60	1.96
RI01126200	Bucks Horn	5.52	2.34	2.28	2.95	3.09	1.88	0.87	0.41	0.32	0.33	0.47	1.12	1.67
RI01111400	Chepachet	17.40	2.13	2.33	2.96	3.18	2.09	1.03	0.54	0.38	0.40	0.72	1.40	1.98
MA01111200	West River at West Hill Dam	27.90	1.73	1.92	2.58	2.81	1.68	0.71	0.32	0.21	0.22	0.46	1.03	1.58
CT01121000	Mount Hope near Warrenville	28.60	1.64	1.91	2.48	2.52	1.57	0.65	0.26	0.23	0.22	0.56	1.02	1.45
CT01123000	Little River near Hanover	30.00	1.73	1.88	2.37	2.53	1.70	0.87	0.47	0.33	0.35	0.62	1.16	1.62
CT01120000	Hop River near Columbia	73.90	1.68	1.93	2.47	2.50	1.62	0.71	0.31	0.28	0.25	0.62	1.08	1.50
CT01125490	Little River at Harrisville	35.80	1.53	1.77	2.30	2.34	1.47	0.61	0.25	0.22	0.20	0.52	0.96	1.35
CT01126600	Blackwell Brook near Brooklyn	17.00	1.71	1.98	2.58	2.62	1.64	0.68	0.28	0.25	0.23	0.59	1.07	1.51
Coastal Lowlands														
RI01114000	Moshassuck at Providence	23.10	1.65	1.71	2.03	2.23	1.47	0.84	0.52	0.48	0.43	0.56	0.96	1.23
RI01114500	Woonasquatucket at Centredale	38.30	2.19	2.35	2.58	2.90	1.85	1.08	0.57	0.50	0.55	0.81	1.72	2.01
RI01117468	Beaver near Usquepaug	8.87	2.71	3.07	3.38	3.69	2.71	1.61	0.89	0.62	0.57	0.63	1.13	2.09
RI01117500	Pawcatuck at Wood	100.00	2.21	2.75	2.84	3.10	2.22	1.39	0.79	0.65	0.63	0.66	1.06	1.75
RI01118000	Wood at Hope Valley	72.40	2.53	2.67	3.18	3.36	2.20	1.22	0.72	0.54	0.55	0.74	1.37	2.04
RI01118500	Pawcatuck at Westerly	295.00	2.30	2.66	2.78	3.16	2.05	1.21	0.67	0.53	0.58	0.60	1.07	1.78
MA01105730	Indian Head at Hanover	30.30	2.05	1.95	2.71	2.57	1.55	0.83	0.29	0.43	0.40	0.64	1.39	1.70
Average Eastern Highlands		**31.56**	**1.94**	**2.15**	**2.76**	**2.85**	**1.82**	**0.82**	**0.40**	**0.34**	**0.32**	**0.65**	**1.18**	**1.65**
Average Coastal Lowlands		**64.13**	**2.06**	**2.26**	**2.67**	**2.80**	**1.85**	**1.03**	**0.54**	**0.46**	**0.46**	**0.62**	**1.25**	**1.72**