Case Study in Practical Approaches for Water Supply versus Aquatic Base Flow Needs

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ABSTRACT

A Flow Release and Operational Plan balancing the needs of human and aquatic water users was developed in support of the Town of Cohasset's intention to supply 306,000 gallons per day of water to a neighboring community. As the sale of water involved a transfer between two of the Commonwealth of Massachusetts' regulatory watershed basins, an Interbasin Transfer Act (ITA) review was required. The plan was developed to address the regulatory issues posed by the ITA process. The plan was accepted and the water sale was authorized by the Massachusetts Water Resources Commission.

INTRODUCTION

The Town of Cohasset, Massachusetts in the "South Coastal Basin" proposed the sale of water to address the water supply needs of a development in the neighboring Town of Hingham in the potentially stressed "Weir River Basin." This proposal triggered the regulatory review associated with the Massachusetts Interbasin Transfer Act (ITA). The ITA regulatory process was expected to create additional requirements for Cohasset Water for the operation of its water supply system, which generally consists of two surface water bodies: Aaron River Reservoir and Lily Pond. As part of the regulatory process for the ITA Determination of Insignificance, the Massachusetts Water Resources Commission (WRC) established environmental parameters that required additional stream flow releases relative to existing practice. The means to provide these releases and the associated

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impacts to water supply safe yield was addressed in the plan. A key component in the preparation of the plan was the development and use of a Reservoir Model.

SOURCE WATER SYSTEM DESCRIPTION

Lily Pond is the lower of the two reservoirs in the Cohasset system. Lily Pond's water level can be raised or lowered by the manual operation of weir gates at the Bound Brook Control Structure (BBCS). The BBCS creates a backwater effect, which alters upstream hydraulics and creates impoundment-like conditions in Bound Brook, in Herring Brook up to Lily Pond, and in Aaron River up to the Aaron River Reservoir Dam. The primary purpose of the BBCS is to direct waters released from the upper Aaron River Reservoir to Lily Pond, in order to help maintain water levels and increase the storage volume in Lily Pond. A fishway is a key part of the BBCS.

The Aaron River Reservoir is the upper and larger of the two reservoirs. At normal water surface level, the reservoir has a storage capacity of approximately 480 million gallons of water with a water surface area of about 150 acres. The normal water level of the reservoir is at elevation 63 ft. with the elevations of the overflow spillway, emergency spillway, and top of dam at 65 ft., 67 ft., and 69 ft., respectively. The reservoir water level and releases to Lily Pond are normally controlled by a manually adjustable weir gate located at the entrance of the dam's fishway.

While the primary purpose of these structures is to store water for treatment, distribution, and consumption as potable water, both structures have controls which allow the release of water to provide for fish passage and stream flow maintenance. The original Environmental Impact Report, completed prior to construction of the Aaron River Reservoir Dam and BBCS in the 1960s, called for maintaining a minimum flow in Bound Brook, downstream of the BBCS, of 1 cubic foot per second (CFS). As part of the ITA process, the WRC was anticipated to require higher release rates for purposes of maintaining flow for anadromous fish passage and in-stream aquatic habitat.

IN-STREAM FLOW TARGETS

No long term stream flow data from the U.S. Geological Survey or other sources exists. In such cases, generic stream flow targets are often set using the U.S. Fish & Wildlife Service's "New England Aquatic Baseflow Policy (ABF)." The ABF was developed using stream gage information from watersheds throughout New England with contributory watershed areas of greater than 50 square-miles. The ABF flow goals are seasonal and as follows:

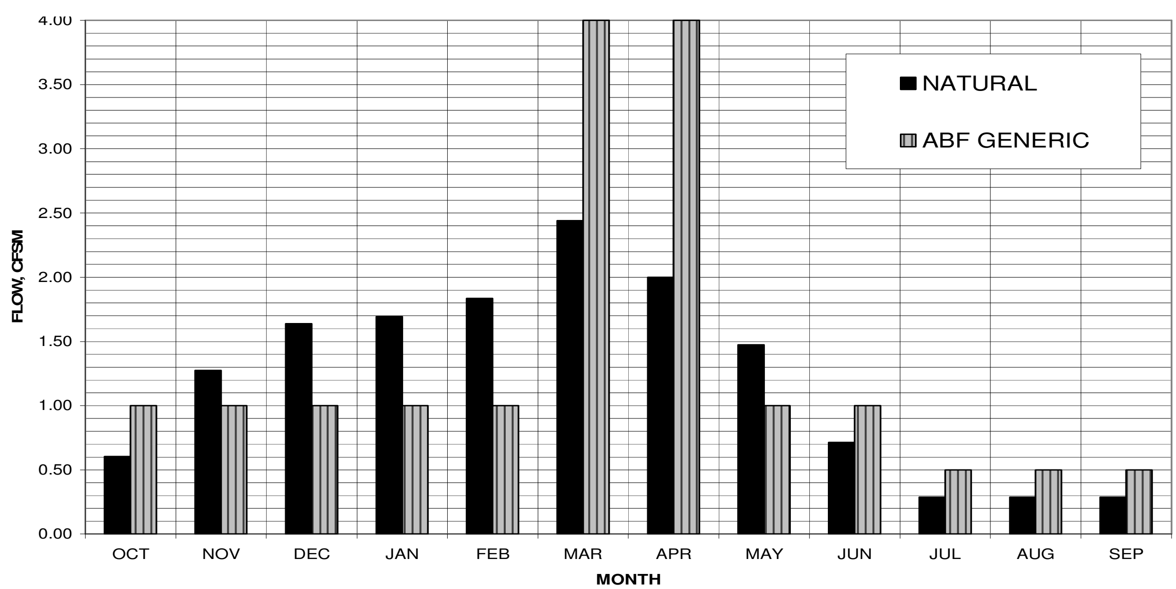
- 0.5 cfs per square mile (4.6 cfs) for July to September
- 1.0 cfs per square mile (9.1 cfs) for October to February
- 4.0 cfs per square mile (36.4 cfs) for March to April
- 1.0 cfs per square mile (9.1 cfs) for May and June

The contributory watershed area for the BBCS at Bound Brook is about 9.1 square-miles. This fact, combined with our understanding of the site-specific hydrology of the area, resulted in concern that application of the ABF to the BBCS watershed would require greater releases than would naturally occur in the watershed. A simple drainage-area ratio of a similar watershed's stream gage data (referred to as the free-flowing "natural" condition) reinforced this concern as shown below in **Figure 1**.

Such unrealistic downstream releases would be unsustainable and may adversely affect the availability of potable water supply in the Cohasset system, as well as the flow regime in the downstream brook. Thus, the purpose of the Reservoir Modeling was to pro-actively set the downstream flow targets to balance the water supply needs of the Cohasset Water Department with the environmental needs for anadromous fish passage and in-stream aquatic habitat.

RESERVOIR MODELING

A computerized, spreadsheet-based Reservoir Model was developed for the reservoir system by GZA GeoEnvironmental, Inc. and Tutela Engineering Associates, Inc. to evaluate the stream flows under various operating conditions, the water surface levels of both reservoirs, and the ability for the Cohasset Water System to provide potable water, The model addressed the operation of the two reservoirs in series, using a water budget methodology which accounts for environmental (e.g., stream flow, precipitation, evaporation, etc.) and physical (e.g., reservoir capacity, spillway size, etc.) factors that impact the operation of the reservoirs. The model was used to simulate and compare the existing and proposed conditions and further as an analytical tool to evaluate and compare relative impacts to stream flow. Comparison of stream flow statistics allowed a quantitative assessment of the significance of the water transfer as per the Interbasin Transfer Regulations.



Methodology and Data Sources

A simple model was developed to simulate the daily water surface elevations and resultant flows from Aaron River Reservoir and Lily Pond. Aaron River Reservoir (contributory drainage area of 5.1 square miles) feeds into Lily Pond (contributory drainage area of 4.0 square miles) via discharge to the Aaron River. Pertinent data for the source system is provided in **Table 1** below:

Table 1. Pertinent data for the Cohasset water system.

	Aaron River Reservoir	Lily Pond	Combined
Watershed Area	5.1 sq. mi.	4.0 sq. mi.	9.1 sq. mi.
Outflow Stream	Aaron River	Herring Brook	Bound Brook
Normal Water Surface Elevation	63.0 ft.	43.0 ft.	---
Normal Storage Capacity	479 Mgal	117 Mgal	596 Mgal

Climatology, hydrology, water supply operations procedures, and structural/engineering data were gathered from the Town of Cohasset, the National Climatic Data Center (NCDC), the U.S. Geologic Survey (USGS), and MassGIS. This information provided the means to estimate the water budget of: a) Aaron River Reservoir and b) Lily Pond, including the impoundment along Bound Brook created by the BBCS. A water budget, an accounting of the inflows and outflows of each water body, was built upon the relationships described in the hydrologic cycle which can be presented as a simple equation relating precipitation, evapotranspiration, stream flow, diversions/withdrawals/ outflows over weirs or spillways, and changes in storage volume:

Change in Storage = Inflows - Outflows

Where:

Inflows = Stream flow + Direct Precipitation + Diversions (in)

Outflows = Evaporation + Spillway / Fishway / Other Discharge + Water Withdrawals (out)

From this relationship, a detailed spreadsheet-based model, using a daily time-step, was developed for application to each water body (i.e., Aaron River Reservoir and Lily Pond / Bound Brook). Resultant reservoir water surface elevations were computed by comparing the total storage at the end of each time step to a storage/depth relationship function based on reservoir bathymetry.

Since the Bound Brook watershed does not contain a continuous USGS stream gage, a similar gaged watershed was utilized as a surrogate to provide inflow characteristics for the water budget model. The Old Swamp River at Weymouth USGS gage (Gage ID

01105600, contributory drainage area of 4.5 square miles) was selected as this surrogate based on the characteristics of the Aaron River Reservoir/Lily Pond watershed (surficial geology/percent stratified drift, geographic location, relative watershed area, no significant groundwater withdrawals). Data from the gage for its period of record beginning in May 1966, was proportioned for the difference in drainage areas and incorporated into the water budget model. To simulate the incoming stream flow for the years prior to the Old Swamp River data set, from 1960 to 1966, data from the USGS stream gage at the East Branch of the Neponset River in Canton (Gage ID 01105500) was used.

The overall period of record used by the model spanned over forty (40) years from August 1960 to October 2001.

Operating procedures for the low level outlet at Aaron River Reservoir were established. A conditional outflow from Aaron River Reservoir to Lily Pond was incorporated into the model such that low level outlet flows from Aaron River Reservoir would occur if Lily Pond fell below its normal operating elevation of 43 ft. This conditional outflow is based on the Town's operational strategy to keep Lily Pond at a relatively constant elevation (about 43 ft.) through releases from Aaron River Reservoir.

Model Calibration

The Water Budget/Reservoir Storage Model was assembled using existing data as described above and calibrated to observed water surface elevations in Aaron River Reservoir and Lily Pond as supplied by the Town of Cohasset. Limited weekly observed water surface elevations at Aaron River Reservoir and Lily Pond were available, typically for the spring and summer months, since 1997. The calibration process involved adjusting flow routing model characteristics and weir coefficients at the Aaron River Reservoir and BBCS hydraulic structures such that the model adequately estimated observed water surface elevations from 1997 to 2001. A more thorough calibration procedure, based upon either estimated and observed flows downstream of the BBCS or daily, year-round water surface elevations, could not be undertaken due to a lack of data.

Model Application

The model was developed to estimate baseline (existing) conditions and to investigate the impacts of various withdrawal volumes and flow targets upon stream flows in Bound Brook. Uncontrolled, "natural" conditions were first estimated using a simple drainage area ratio transformed from the Old Swamp River at Weymouth (USGS Gage ID 01105600, contributory drainage area of 4.5 square miles). The average daily flows from this gage were unitized by contributory watershed areas and transposed to the watershed areas of Aaron River Reservoir and the BBCS, respectively. Separate stream flows were generated for each of the study watersheds. The stream flows generated from the natural condition were used as reference stream flows in the Water Budget/Reservoir Storage Model.

Using the Water Budget/Reservoir Storage Model, four water resource development scenarios to estimate resultant stream flows under different levels of control and withdrawal were simulated:

a) Existing: This condition represents water level controls and withdrawals currently in place in the watershed. Current Average Daily Demand (ADD) was set at 0.73 million gallons per day (MGD) as per the most recent Department of Conservation and Recreation (DCR) water demand projections for the year 2020. Current monthly water withdrawal patterns were seasonally varied based on averaging Cohasset monthly withdrawal data contained in the DEP water supply annual reports for the five year period of 1997 to 2001 (see Average Monthly Demand Factors below). A minimum instantaneous flow target of 1 cfs was applied to both Aaron River Reservoir and the BBCS.

b) Existing + Proposed Development Water Demand: This potential scenario assumes seasonal current withdrawals described above plus an additional year-round, steady withdrawal of 0.306 MGD, or a total ADD of 1.04 MGD. It was estimated the resultant flows in Bound Brook based on no-change in the operating rules at the Aaron River Reservoir or the BBCS.

c) Division of Marine Fisheries (DMF) Generic: Based upon feedback from the Divison of Marine Fisheries (DMF), this potential scenario assumes an ADD of 1.04 MGD and attempts to maintain the flow targets suggested by DMF:

MAR 1 - JUN 15	6.0 cfs	SEP 15-NOV 15	6.0 cfs
JUN 15-SEP 15	0.5 CFSM	NOV 16-MAR 1	1.0 CFSM

The flow of 6.0 cfs for periods of possible fish runs (from March 1 to June 15 and September 15 to November 15) was established by DMF as being necessary for the Denil-type fishways at Aaron River Reservoir and the BBCS to function. No technical explanation for the development of the 6.0 cfs flow target was made available. The summer (June 15 to September 15) and winter (November 16 to March 1) flow target is based upon the U.S. Fish and Wildlife Service New England Aquatic Baseflow Policy (ABF Policy).

Basis of Proposed Flow Targets

Based upon analyses of: 1) the assumed natural, uncontrolled flows; 2) the existing condition; and 3) our independent fishway hydraulic analysis described hereafter, an alternative set of flow targets were developed:

MAY (typ.)	6.0 cfs	OCT (typ.)	6.0 cfs
JUN 1 – SEP 30	2.2 cfs	NOV 1 – APR 31	2.2 cfs

The proposed minimum flow target is 2.2 cfs, or about 0.24 cfs per square mile (cfsm) at the Bound Brook control structure, on a year-round basis. The proposal includes monitoring for the periods where anadromous fish are present at the fishways at the Bound Brook Control Structure and Aaron River Reservoir Dam. During these periods, which usually occur around May and October each year, minimum target flows would be increased to 6.0 cfs to facilitate fish passage at the respective fishways.

Seasonal Fish Run Flow Target (May and October, typical)

Based on a memorandum from the Massachusetts Division of Marine Fisheries, 6 cfs was selected as the minimum flow target during periods of anadromous fish movement. The typical duration of the fish runs is estimated to be about one month. The fish runs in the area typically occur during May (spawning adults moving downstream to upstream) and October (juveniles moving upstream to downstream), depending upon water temperatures. Since the target species, alewife and blueback herring, do not travel during hours of darkness, the target flow rate will be maintained only during daylight hours. This means that for about 16 hours (a conservative estimate of the amount of daylight hours during the months of anadromous fish migration) the target flow rate will be 6 cfs. Each night (for the remaining 8 hours) the Town has the option to reduce the target flow to 2.2 cfs. Therefore, the time-weighted average of the daily target flow used in the Reservoir Model is estimated as 4.8 cfs (16 hours times 6 cfs plus 8 hours times 2.2 cfs divided by 24 hours). The reductions in target flow are envisioned to be accomplished using an automated gate system, to be installed at Aaron River Reservoir Dam and at the Bound Brook Control Structure. The changes in target flow will occur gradually by lowering and/or raising the gates in a controlled manner.

Year Round Flow Target (June through September; November through April)

The year-round minimum flow target of 2.2 cfs (or 0.24 cfsm at the BBCS) is based upon the minimum flow and depth at which the fishways will support anadromous and other fish passage (see fishway hydraulic analysis). The 2.2 cfs flow target corresponds to 1-foot of water flowing above the fishway baffle. At a depth of 1-ft, the velocity within the fishway is estimated to be about 1.7 ft/sec, less than the typical cruising swim speed of juvenile and adult alewife (and most other fish, including trout, white sucker, etc.). Since increasing depths at the fishway result in higher velocities, the 2.2 cfs target represents a balance between flow rate, water depth, and fishway velocity.

The year-round flow target of 2.2 cfs represents an annual exceedence value of about 80 percent (compared to the flow duration statistics derived from modeling existing conditions). This means that the proposed target flow is currently met or exceeded about 80 percent of the time. This minimum flow goal also produces an average August monthly median flow which is in excess of that which results under both natural and existing conditions (**Table 1**). It should also be noted that the flow target exceeds the estimated 1.7

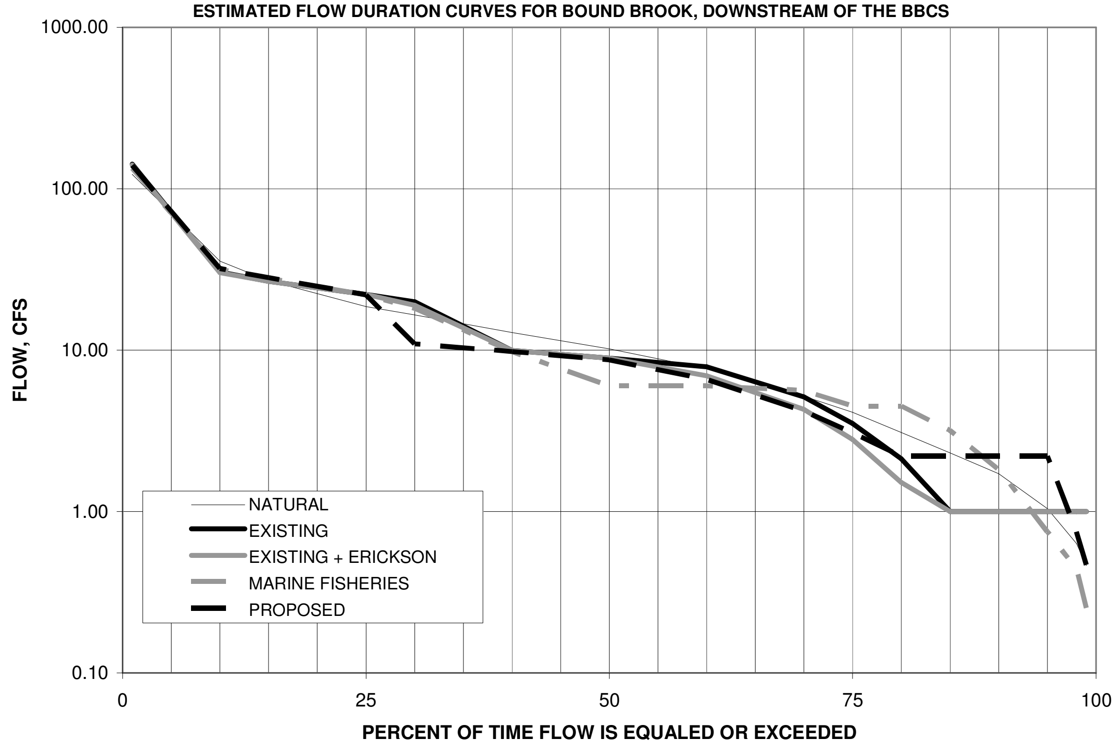
cfs (0.20 cfsm) median August flow generated by the USGS/MADCR StreamStats computer application.

While the flow target of 2.2 cfs is lower for non-summer seasons in comparison to generic New England aquatic baseflow values developed by the U.S. Fish and Wildlife Service, it is important to note that the target is a minimum, not a median, value. Appropriate seasonal variation in and magnitude of flows is anticipated to continue under proposed conditions, due to the limited surcharge storage in the reservoirs. Typical winter and spring inflows from the 9.1 square-mile contributory watershed are anticipated to often exceed the limited available surcharge storage in the system and result in flows over the fishway weirs and other spillways. These uncontrolled releases produce average median flows in excess of the minimum target flow during non-summer months.

DISCUSSION OF MODELING RESULTS

The proposed operations strategy increases the 95 percent exceedence flow (2.2 cfs) as compared to existing conditions (1.0 cfs) (**Figure 2**). The increase is attributed to the higher summer target flow adopted as part of the proposed operations plan.

FIGURE 2
ESTIMATED FLOW DURATION CURVES FOR BOUND BROOK, DOWNSTREAM OF THE BBCS



However, the higher the target flow, the less likely it is to be sustainable for extended periods of time. For example, the existing condition, which uses 1 cfs as the instantaneous target flow, has a 99 percent and a 98 percent exceedence flow of 1 cfs. The proposed operations would result in a 99 percent exceedence flow of about 0.5 cfs and a 98 percent exceedence flow of about 0.8 cfs. The DMF-suggested operations plan would result in a 99 percent exceedence flow of about 0.3 cfs and a 98 percent exceedence flow of about 0.4 cfs. Note that under estimated "natural" conditions, the 99 percent and 98 percent exceedence flows are 0.5 cfs and 0.6 cfs, respectively.

These results indicate that high target flow rates result in a more rapid evacuation of the volume of water available to release. As a result, the reservoirs are lowered and unable to sustain higher flow releases, particularly during low-flow periods. For example, the DMF summer target flow of 0.5 cfsm, or 4.5 cfs at the BBCS, exceeds the natural August median flow of 2.6 cfs by about 73 percent. Therefore, the "gap" in the two daily flowrates must be made up by releasing the volume from available reservoir storage above the controlling fishway weir. Since this volume is finite, it only lasts for a limited period of time, after which releases are limited to the rate of inflow into the reservoir, after it is subject to losses such as evaporation or withdrawal. The situation is exacerbated during drier years, as the median flow of 2.6 cfs is by definition not met 50 percent of the time.

<u>Seasonal Variation and Proposed Target Flows</u>

To investigate the affect of target flows upon the seasonal variation in outflows from the BBCS, the reservoir model was used to examine typical dry and normal years. **Table 2** provides a comparison of estimated monthly median flows for the dry year (water year 1981) and the normal year (water year 1988) using both proposed and DMF modified generic target flows[4].

The results indicate that the higher DMF modified generic flows, when used as minimum target flows, can be met during typical years, but are not sustainable during a dry year. Monthly median flows are below the generic minimum target values for seven of the twelve months during the dry year (water year 1981). In comparison, the proposed target flows can be sustained for most of the dry year, with the exception of October; the first month of the water year in which the system is still recovering from an extreme dry year, 1980. Note that low flows correlate with relatively low storage in the reservoirs, which is detrimental not only for aquatic flora and fauna, but also from a water supply standpoint. During normal years, estimated median outflows from the BBCS under proposed operating conditions are similar, and in some cases exceed flows under the DMF modified generic target flow operating conditions.

[4] DMF modified generic flows utilize much of the generic New England Aquatic Baseflow Policy, while suggesting a value of 6 cfs to facilitate the passage of anadromous fish via fishways during typical periods of anadromous fish migration.

Table 2. Estimated Monthly Median Outflows from The BBCS for Representative Dry and Normal Years Given Proposed and Generic Minimum Target Flows.

MONTH	WY 1981 (DRY YEAR)						
	RAINFALL	PROPOSED			DMF GENERIC		
	INCHES	TARGET	ESTIMATED FLOW		TARGET	ESTIMATED FLOW	
		CFS	CFS	CFSM	CFS	CFS	CFSM
OCTOBER	4.95	6.0	0.4	0.05	6.0	0.4	0.05
NOVEMBER	2.98	2.2	2.2	0.24	6.0 / 9.0	2.2	0.25
DECEMBER	1.31	2.2	2.2	0.24	9.0	2.7	0.30
JANUARY	1.31	2.2	3.1	0.34	9.0	2.7	0.30
FEBRUARY	7.73	2.2	9.8	1.08	9.0	9.0	0.99
MARCH	0.64	2.2	9.8	1.08	6.0	6.0	0.66
APRIL	3.44	2.2	10.9	1.20	6.0	12.1	1.33
MAY	1.63	6.0	7.6	0.84	6.0	6.0	0.66
JUNE	1.96	2.2	2.2	0.24	6.0 / 4.5	5.8	0.64
JULY	5.92	2.2	2.2	0.24	4.5	2.2	0.25
AUGUST	1.6	2.2	2.2	0.24	4.5	1.4	0.16
SEPTEMBER	4.09	2.2	2.2	0.24	4.5 / 6.0	0.8	0.08
MONTH	WY 1988 (NORMAL YEAR)						
	RAINFALL	PROPOSED			DMF GENERIC		
	INCHES	TARGET	ESTIMATED FLOW		TARGET	ESTIMATED FLOW	
		CFS	CFS	CFSM	CFS	CFS	CFSM
OCTOBER	3.82	6.0	7.6	0.84	6.0	6.0	0.66
NOVEMBER	4.81	2.2	15.9	1.75	6.0 / 9.0	18.7	2.06
DECEMBER	2.97	2.2	22.0	2.42	9.0	22.1	2.42
JANUARY	3.13	2.2	9.8	1.08	9.0	9.8	1.08
FEBRUARY	5.92	2.2	33.4	3.67	9.0	32.9	3.61
MARCH	4.11	2.2	10.9	1.20	6.0	22.1	2.43
APRIL	1.9	2.2	10.9	1.20	6.0	6.0	0.66
MAY	3.74	6.0	9.8	1.08	6.0	6.0	0.66
JUNE	2.2	2.2	5.6	0.62	6.0 / 4.5	6.0	0.66
JULY	10.38	2.2	2.2	0.24	4.5	4.5	0.49
AUGUST	2.42	2.2	6.6	0.73	4.5	6.6	0.73
SEPTEMBER	1.49	2.2	2.2	0.24	4.5 / 6.0	4.6	0.51

SUMMARY

The impact of water supply on the environment is likely to be a continuing focus of resource management agencies. One of the keys to successful water resources management is to proactively develop a thorough understanding of site-specific conditions and appropriate stream flows. The management of water supply sources for both human consumption and aquatic habitat maintenance requires a multi-disciplined engineering, scientific and planning approach.

Frequently, estimated "natural" average or median generic flows are recommended as flow targets by resource management agencies. These flow targets are then often suggested as instantaneous, minimum flows. Attempting to provide minimum downstream flows equal to or in excess of naturally occurring median flows, which by definition are met only 50 percent of the time, can result in steep declines in reservoir elevations (from which water is released to meet the targets) and also may have unintended negative consequences on extreme low flows in a reservoir-controlled system. Application of generic ABF flow targets to small watersheds may result in similar difficulties. Proactive setting of appropriate, site-specific stream flow targets enable a smoother regulatory review and may benefit human and non-human water users.

REFERENCES

GZA GeoEnvironmental, Inc., "Status of and Potential Impacts on Water Budget for the Weir River Watershed," Final Draft Report, December 2000.

Instream Flow Council. 2002. Instream flows for riverine resource stewardship. Thomas Annear, *et al*. editors. Instream Flow Council. ISBN No. 0-9716743-0-2. 411 p.

U.S. Fish and Wildlife Service. Interim Regional Policy for New England Stream Flow Recommendations. Newton Corner, MA. 1981.

U.S. Fish and Wildlife Service. 1994. Memorandum from Vern Lang, USFWS Region 5. Considerations for instream flow studies. US Fish and Wild. Serv. 22 Bridge Street, Concord, NH. September 13, 1994.

U.S. Fish and Wildlife Service. Questions and Answers on the New England Flow Policy. Vernon Lang. Concord, NH. May 11, 1999.