Using the Indicators of Hydrologic Alteration Statistical Tool to Analyze the Prescribed Flow Regime for the Saranac River, New York.

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Introduction

The Saranac River drains the Northeast corner of the Adirondack Mountains in upstate New York. Several hydroelectric dams are located on the river. In January of 2006, New York State Electric and Gas received new 40 year licenses for four of these dams (FERC project 2738). The uppermost of these dams, High Falls Dam, diverts up to 851 cfs around a section of the river that is approximately one mile long. Through the federal dam relicensing process, several stakeholders sought to restore flows to this river bypassed reach. To inform these decisions, a delphi study was carried out to determine appropriate continuous base flows for the reach and a whitewater feasibility study was carried out to assess recreational benefits of pulse flows (NYSEG 2003, NYSEG 2004a). Management objectives for the High Falls Bypassed reach stated in the delphi study were: “Brown and resident rainbow trout habitat, Forage fish habitat, Riffle habitat, Fishing opportunity, Riparian Vegetation/Wetlands.” Based on the delphi study a subset of stakeholders[1] reached a settlement calling for continuous water releases of 50 cubic feet per second (cfs) October 1st through April 30th, and 75 cfs May 1st through September 30th (NYSEG 2004b). The settlement prohibited pulse flows of 250 cfs that were requested by other stakeholders, due to environmental concerns including impacts to invertebrate habitat. The settlement resulted in a state 401 water quality certificate and a new 40 year license that requires the Licensee to provide this flow regime for the duration of the license term.

Map 1. Saranac river flowing from left to right through the High Falls Reservoir, High Falls Dam where water is removed, High Falls Gorge bypassed reach, and then past the powerhouse where water is returned to the river.

[1] Settlement parties are New York State Electric and Gas, the United States Fish and Wildlife Service, Adirondack Park Agency, New York State Department of Environmental Conservation, New York Rivers United, Adirondack Council, New York Council of Trout Unlimited

The flow regime is one of the primary determinants of the physical structure and biological assemblage of river ecosystems (Poff et al 1997). Individual elements of flow regimes play specific roles in geomorphology and the lifecycles of many aquatic and riparian organisms. Poff et al 1997 report some of these roles that have been described in the literature in the Table below:

Flow component	Specific alteration	Ecological response	Reference(s)
Magnitude and frequency	Increased variation	Wash-out and/or stranding	Cushman 1985, Petts 1984
		Loss of sensitive species	Gehrke et al. 1995, Kingsolving and Bain 1993, Travnichek et al. 1995
		Increased algal scour and wash-out of organic matter	Petts 1984
		Life cycle disruption	Scheidegger and Bain 1995
		Altered energy flow	Valentin et al. 1995
	Flow stabilization	Invasion or establishment of exotic species, leading to:	
		Local extinction	Kupferberg 1996, Meffe 1984
		Threat to native commercial species	Stanford et al. 1996
		Altered communities	Busch and Smith 1995, Moyle 1986, Ward and Stanford 1979
		Reduced water and nutrients to floodplain plant species, causing:	
		Seedling desiccation	Duncan 1993
		Ineffective seed dispersal	Nilsson 1982
		Loss of scoured habitat patches and secondary channels needed for plant establishment	Fenner et al. 1985, Rood et al. 1995, Scott et al. 1997, Shankman and Drake 1990
		Encroachment of vegetation into channels	Johnson 1994, Nilsson 1982
Timing	Loss of seasonal flow peaks	Disrupt cues for fish:	
		Spawning	Fausch and Bestgen 1997, Montgomery et al. 1993, Nesler et al. 1988
		Egg hatching	Næsje et al. 1995
		Migration	Williams 1996
		Loss of fish access to wetlands or backwaters	Junk et al. 1989, Sparks 1995
		Modification of aquatic food web structure	Power 1992, Wootton et al. 1996
		Reduction or elimination of riparian plant recruitment	Fenner et al. 1985
		Invasion of exotic riparian species	Horton 1977
		Reduced plant growth rates	Reily and Johnson 1982
Duration	Prolonged low flows	Concentration of aquatic organisms	Cushman 1985, Petts 1984
		Reduction or elimination of plant cover	Taylor 1982
		Diminished plant species diversity	Taylor 1982
		Desertification of riparian species composition	Busch and Smith 1995, Stromberg et al. 1996
		Physiological stress leading to reduced plant growth rate, morphological change, or mortality	Kondolf and Curry 1986, Perkins et al. 1984, Reily and Johnson 1982, Rood et al. 1995, Stromberg et al. 1992
	Prolonged baseflow "spikes"	Downstream loss of floating eggs	Robertson 1997
	Altered inundation duration	Altered plant cover types	Auble et al. 1994
	Prolonged inundation	Change in vegetation functional type	Bren 1992, Connor et al. 1981
		Tree mortality	Harms et al. 1980
		Loss of riffle habitat for aquatic species	Bogan 1993
Rate of change	Rapid changes in river stage	Wash-out and stranding of aquatic species	Cushman 1985, Petts 1984
	Accelerated flood recession	Failure of seedling establishment	Rood et al. 1995

[a]Only representative studies are listed here. Additional references are located on the Web at http://lamar.colostate.edu/~poff/natflow.html.
Source of Table: Poff et al 1997.

This analysis uses the Indicators of Hydrologic Alteration tool in concert with basic hydrological statistical analyses to assess the new flow regime dictated for the High Falls Gorge bypassed river reach, on the Saranac River. Hydrologic data are linked with known relationships between flow variables and ecological responses. General ecological effects of the new flow regime are predicted based on these relationships.

Proposed pulse flows are discussed in this hydrological context. An enhanced flow regime is suggested based on the findings of these analyses.

Methods

Daily flow data from USGS Saranac River at Plattsburgh Gage, gage # 02473500, were obtained for the period of 10/1/1949 through 9/30/1999. This 50 year timeframe was the same period used by the Licensee to create mean annual flow duration curves which were subsequently referenced by the Federal Energy Regulatory Commission (FERC) in their environmental assessment of the proposed flow regime. The data were corrected for drainage area by a factor of 0.862: the drainage area at the gage is 608 square miles whereas the drainage area at the dam is 524 square miles. These corrected data represent the approximate inflow to the High Falls Dam, and likewise represent the approximate natural flow regime of the Saranac River through High Falls Gorge prior to diversion. We will refer to this dataset as the "natural flow regime."

A second 50-year dataset was then constructed based on the same 10/1/1949 through 9/30/1999 dataset to represent the flow regime in the bypassed High Falls Gorge under the new license. To accomplish this, 851 cfs was subtracted from the daily flow data to account for the maximum amount of water that the High Falls Dam is capable of diverting (flows above 851 cfs spill over the dam into the High Falls Gorge). Next, all values for October 1st through April 30th period that were less than 50 cfs were replaced with 50 cfs to account for the prescribed continuous base flow. Likewise, all values for the May 1st through September 30th period that were less than 75 cfs were replaced with 75 cfs to account for the prescribed continuous base flow. The resulting dataset describes what the instream flows would have been for the 50 year analysis timeframe had the new license been implemented throughout this timeframe. It also provides insight into what the effects on instream flows will be over the next 40 years during which the license is in effect. We will refer to this dataset as the "managed flow regime."

Annual mean flow for the 50 year analysis period was downloaded from the USGS website. Low, medium, and high water years were selected based on the median, and upper and lower quartile and their representative characteristics. These data were selected to compare the natural and managed flow regimes on simple line graphs.

The datasets were then merged for analysis in the IHA model. IHA analyses compare two time periods of flows representing pre-impact and post-impact conditions. In this analysis the natural flow dataset is considered pre-impact and the managed flow regime is considered post-impact. To compare the two datasets in IHA, they were combined into one continuous 100 year dataset by modifying the dates in the managed flow dataset to begin on 10/1/1999 and end on 9/30/2050. Thus, for example, the 2000 managed flow regime is the 1950 natural flow regime modified to account for the flow provisions in the new license.

This 100 year dataset was loaded into the IHA model in a simple 2-column format. Non-parametric statistics were selected. Two time periods were selected for comparison: 10/1/1949 through 9/30/1999 (natural flow regime) and 10/1/1999 through 9/30/2050 (managed flow regime). While the model considers these as two real timeframes, it should be noted that the purpose of the analysis is to compare natural flows with managed flows.

The High Falls Gorge has not experienced a truly natural flow since prior to dam construction, and has just begun to experience the newly prescribed "managed flows." The flow regime for the interim period in the Gorge itself is not well known but in recent years some flow was provided by flashboard leakage.[2] Currently, the actual instream flows are a combination of the managed flows (50 and 75cfs) plus existing leakage. Since at any point leakage flows could legally and be stopped by improvements to the flashboards, we have not included leakage flows as part of the managed flow regime data set. While the IHA model was designed to analyze a past impact, it is equally well suited to predicting impacts of flow prescriptions in FERC licenses and state 401 permits.

Lastly, the proposed and rejected pulse flows were analyzed in the context of both the natural and managed flow regime. The pulse flow proposal was for 6 days of 250 cfs flows, with 8-hour release periods per day between June 1st and October 31st. These flows were plotted on the selected low, medium, and high water year hydrographs for comparison. Daily flow values of 250 cfs were used in analysis rather than the daily average flow, to better depict the relative magnitude of the pulse flows. Flow dates were randomly selected from the 153 day long release timeframe. Pulse flows were also discussed in the context of the IHA results.

Results

Basic Hydrologic Results

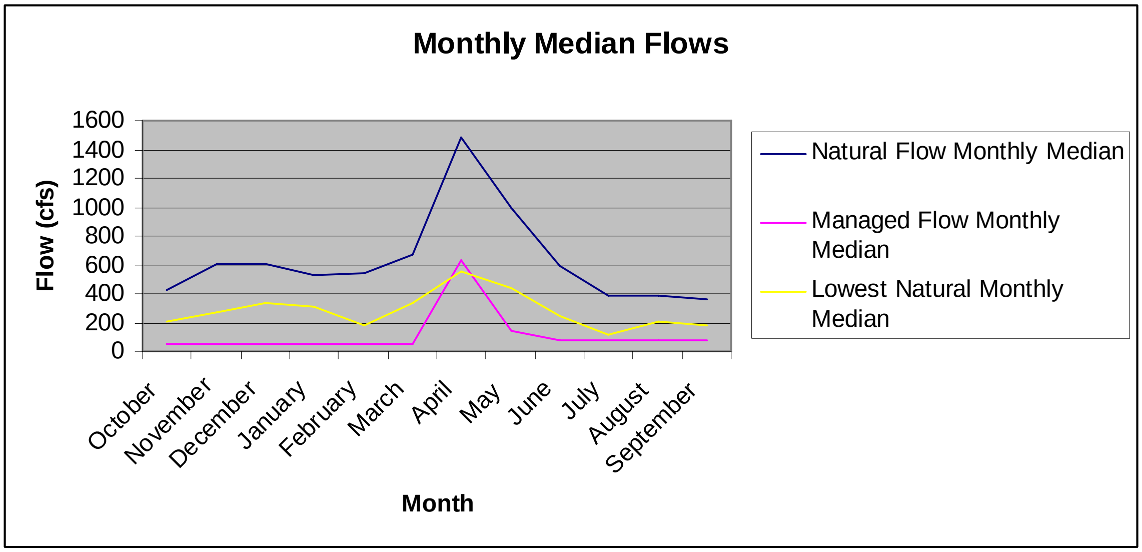
The flow regime of the Saranac River follows a similar pattern to many Adirondack rivers and streams. The flow regime is characterized by a large spring runoff period resulting from snowmelt and rain, a smaller rain driven runoff period in the late fall and early winter, and intervening periods of variable lower flows with frequent rain induced small pulses. Figures 1 and 2 show this basic pattern at the scale of monthly median flows. Figure 1 also shows that managed median monthly flows constitute a 57.3 to 92.6% reduction from natural flows, with the smallest reduction occurring during the spring high water season when the dam typically spills water into the gorge. Lastly, the lowest natural monthly median is noted for comparison. The managed flows are lower than the lowest natural flow in the 50 year record in every month except April.

Figure 1. Median Monthly Flow (cfs) in the Saranac River at High Falls Dam

Month	Natural Flow	Managed Flow	Reduction (%)	Lowest Natural
October	424.1	50	88.2	210.3
November	607.3	50	91.8	268.9
December	605.6	50	91.7	332.7
January	531	50	90.6	310.3
February	544.4	50	90.8	178.9
March	671.9	50	92.6	337.0
April	1485	634.8	57.3	559.4
May	991.3	141.3	85.7	439.6
June	587.2	75	87.2	249.5
July	384.9	75	80.5	122.4
August	392.6	75	80.9	209.5
September	367	75	79.6	185.3

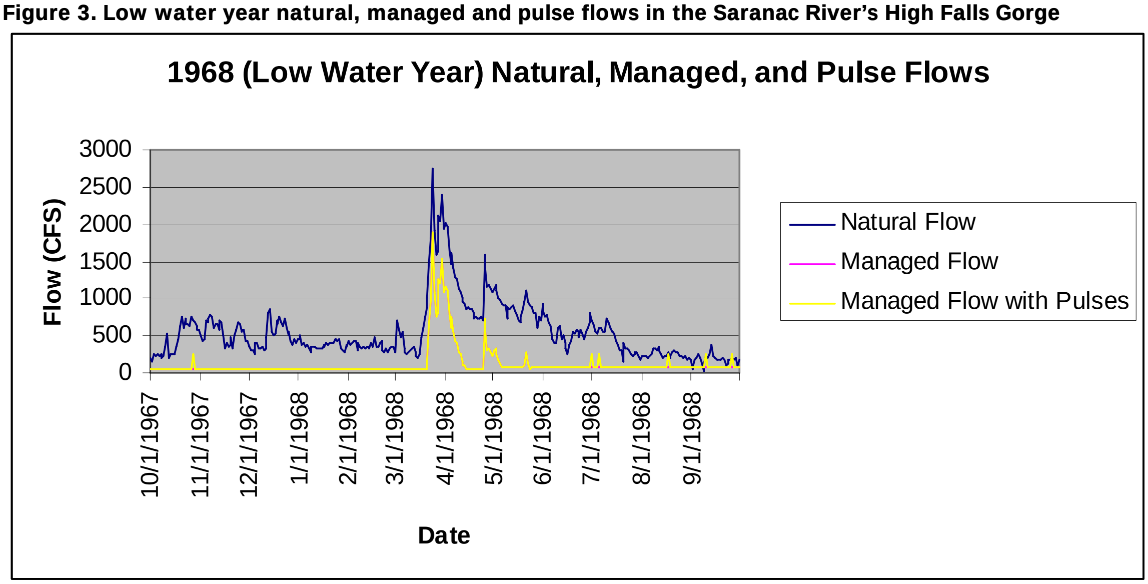
[2] A new gage in the bypassed river reach indicates that August instream flows tend to be around 103 cfs, indicating that leakage at this time is approximately 28cfs. https://ebiz1.nyseg.com/cusweb/flowdata.aspx.

Figure 2. Median Monthly Flow (cfs) in the Saranac River at High Falls Dam



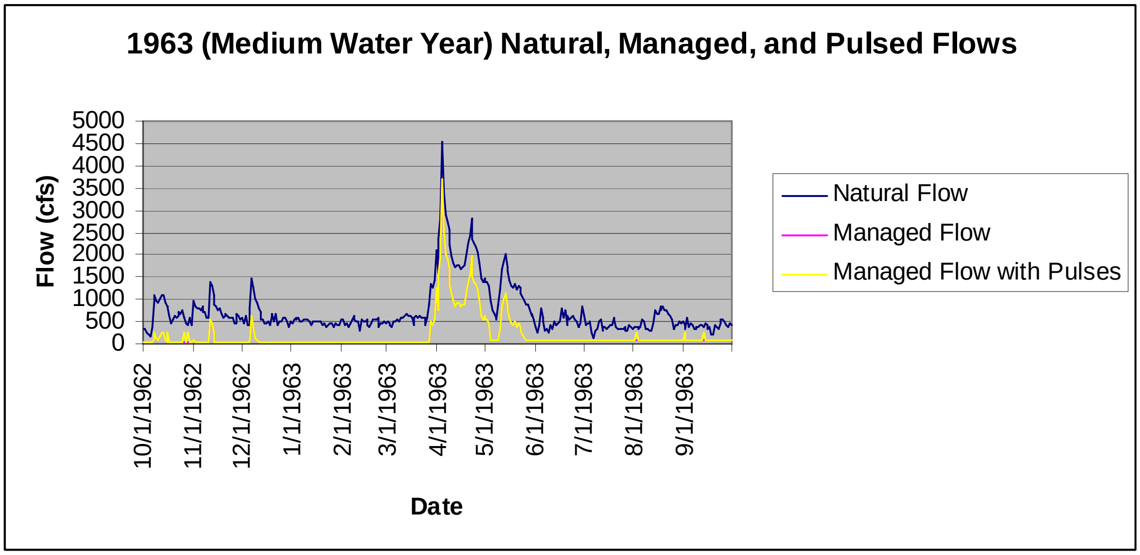
The low water year selected (1968) for analysis exhibits the typical flow pattern for the Saranac River (Figure 3). The differences between the natural and modified flow regimes that are apparent are that under managed flows 1) high pulses are reduced in magnitude, 2) medium and small pulses are virtually eliminated, 3) base flows are radically reduced, and 4) base flows totally lack variability. The six proposed managed 250cfs pulse flows are graphed and clearly visible (a seventh in mid-may is natural). Three of the pulses are significantly lower volume than simultaneous natural flows, and three are similar to natural flows (note also that pulses were graphed at peak flow rather than daily average). The pulse flows restore some variability to the otherwise totally flat-lined hydrograph during the release timeframe.

Figure 3. Low water year natural, managed and pulse flows in the Saranac River's High Falls Gorge



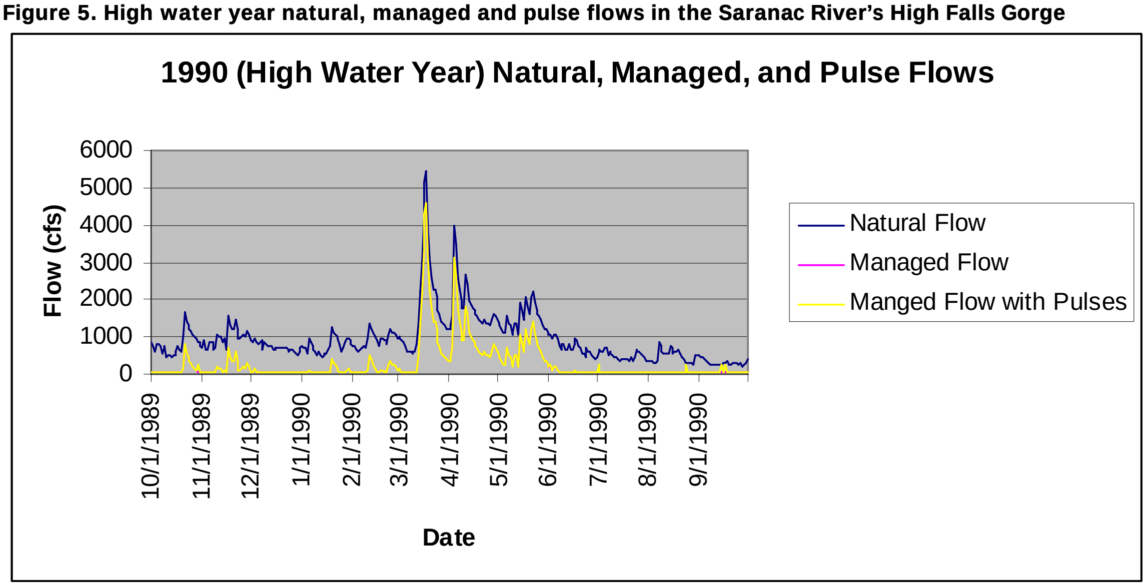
The medium and high water years selected (1963 and 1990 respectively) also exhibit the typical flow regime pattern and the same basic differences between the natural and managed flow regime as the low water year (Figure 4). All managed pulse flows are far lower volume than natural flows, and restore some variability to the otherwise largely flat-lined hydrograph during the release timeframe.

Figure 4. Medium water year natural, managed and pulse flows in the Saranac River's High Falls Gorge



Due to the higher number of flow events that exceeded the diversion capacity of the High Falls Dam, the managed flow regime of the high water year exhibits more variability than the other lower water years (Figure 5). The managed pulse flows are barely visible in the context of the high water year. They do however restore some variability to the otherwise mostly flat-lined hydrograph during the release timeframe.

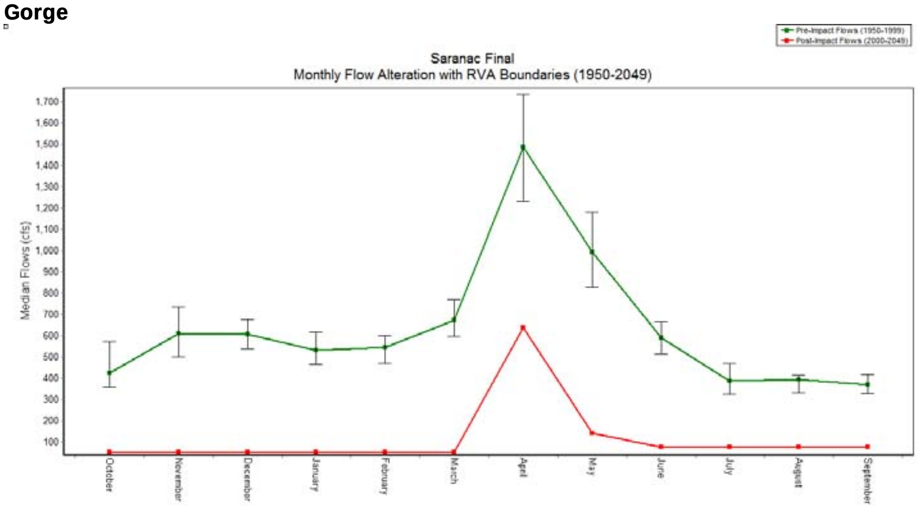
Figure 5. High water year natural, managed and pulse flows in the Saranac River's High Falls Gorge



Indicators of Hydrologic Alteration Results

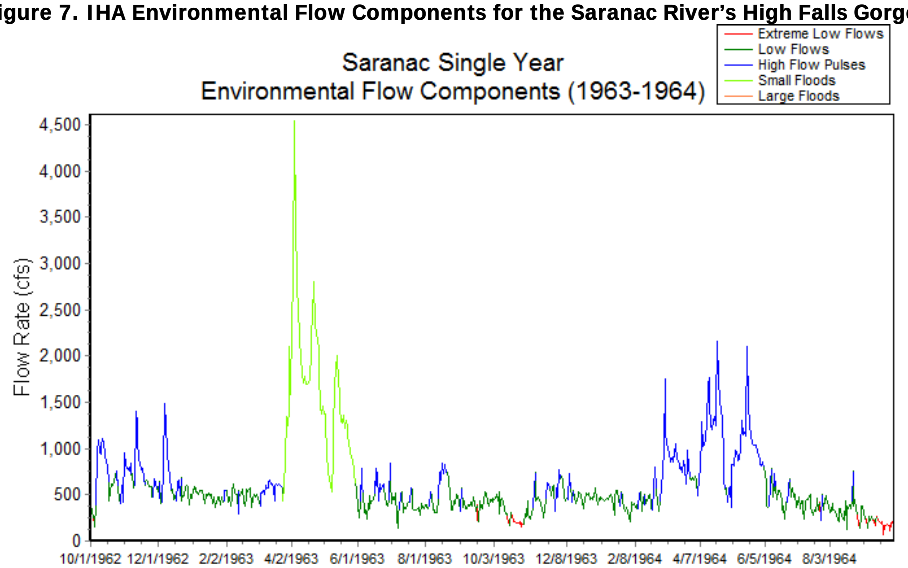
The results of the IHA were highly consistent with the basic hydrological analysis carried out on the flow regimes. They accurately depict and describe the anticipated effects of flow management on the natural flow regime. At the simplest level, the IHA analysis shows the intentional effect of removing 851 cfs from the river and instituting a seasonal flat lined base flow (Figure 6). Range of Variability Analysis (RVA) boundaries show that the managed flow is well outside of the natural flow regime's natural variability. The boundaries represent the 25th and 75th quartile. In addition, IHA offers significant detail on a suite of environmentally relevant elements of the flow regime.

Figure 6. IHA comparison of managed and natural monthly median flows in the Saranac River's High Falls Gorge



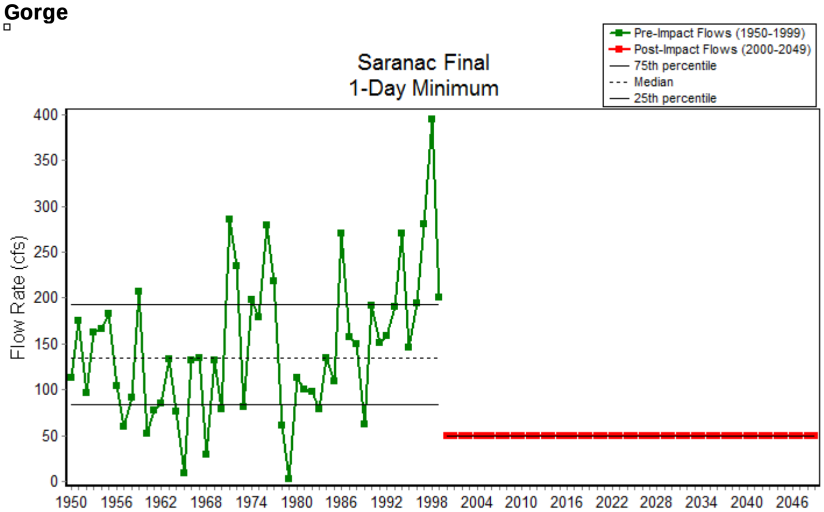
IHA segments the hydrograph into ecologically significant Environmental Flow Components. These components were graphed for the medium water year (1963) and the following relatively low water year (Figure 7). When compared with the managed flow regime it is clear that the managed flow regime virtually eliminates Low Flows and High Flow Pulses. Small Floods are reduced in magnitude but not frequency, and virtually all other flows are replaced with stable Extreme Low Flows.

Figure 7. IHA Environmental Flow Components for the Saranac River's High Falls Gorge



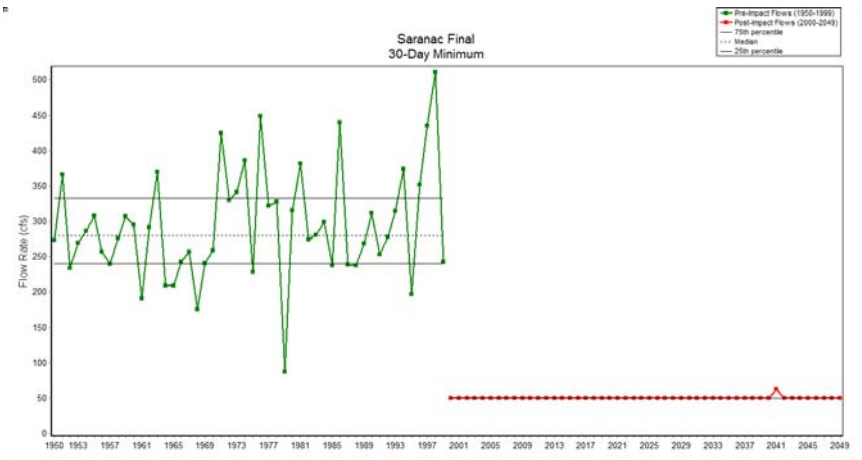
IHA analyses of low flows reveal that the 1-day minimum flow is lower under flow management than it is under the natural flow regime in all but three years of the 50 year period of record (Figure 8). The single lowest day of each year under the natural flow regime was a median of 134 cfs, whereas the managed lowest single day was 50 cfs in every year. In addition, management totally eliminated inter-annual variation of this flow variable.

Figure 8. IHA comparison of natural and managed 1-day minimum flows in the Saranac River's High Falls Gorge



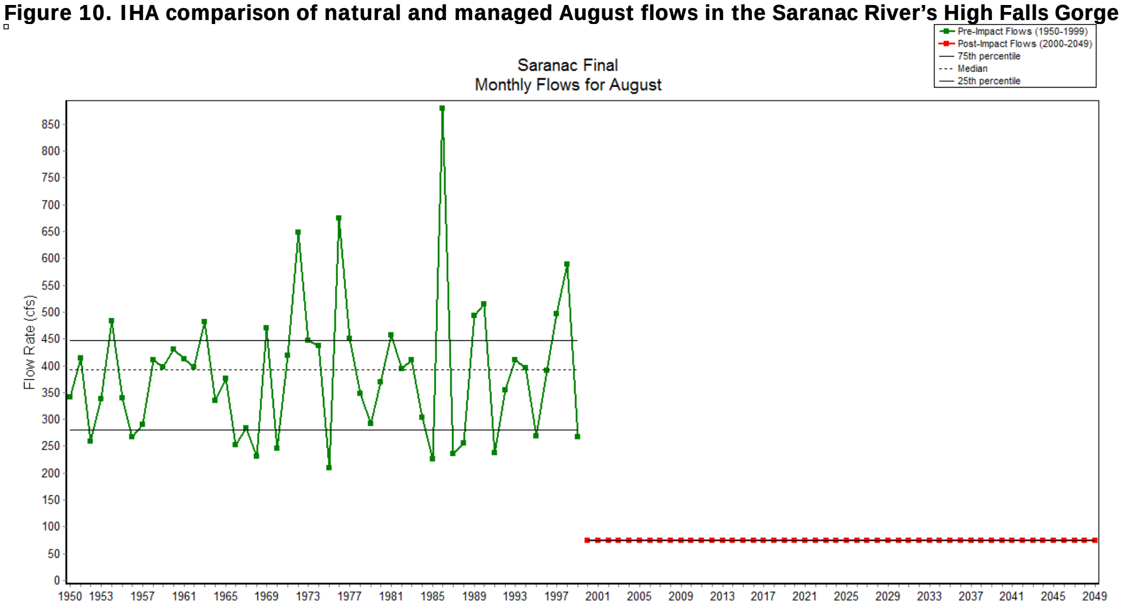
When looked at on a weekly time step, the effect is more dramatic. The 7-day minimum flow in the natural flow regime (based on a moving average) was a median 215 cfs, while the managed 7-day minimum remains at 50 cfs (Figure 9). Only one year in the natural flow regime dataset had a lower 7-day minimum than the managed flow regime. The differences in inter-annual variability remain distinct and absolute. The same relationships are present in analyses of the 30-day minimum and 90-day minimums, for which the managed moving averages are 280 and 365 cfs respectively. At these scales some inter-annual variability occurs. The 30-day minimum is depicted in the graph below.

Figure 9. IHA comparison of natural and managed 7-day minimum flows in the Saranac River's High Falls Gorge



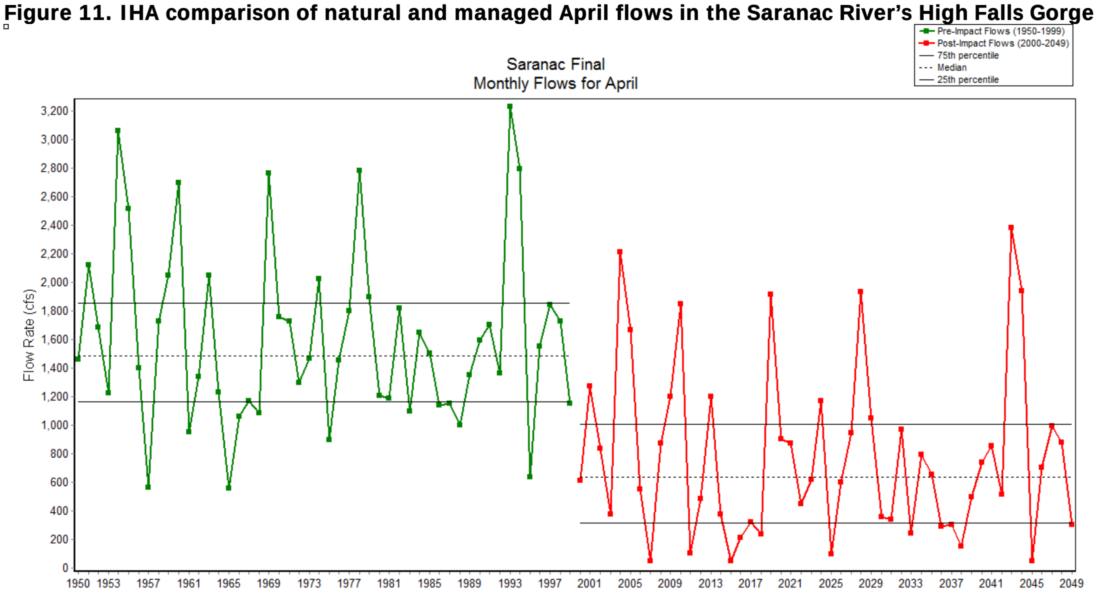
As discussed previously, the effects of flow management differ between seasons. Seasonal distinctions are important based on the seasonal factors of aquatic organisms' life histories. Managed summer base flows and inter-annual variability are noticeable lower than in the natural flow regime. As the graph below depicts, August monthly flows are reduced from a median of 391.3 cfs to 75 cfs, and variability is totally eliminated (Figure 10).

Figure 10. IHA comparison of natural and managed August flows in the Saranac River's High Falls Gorge



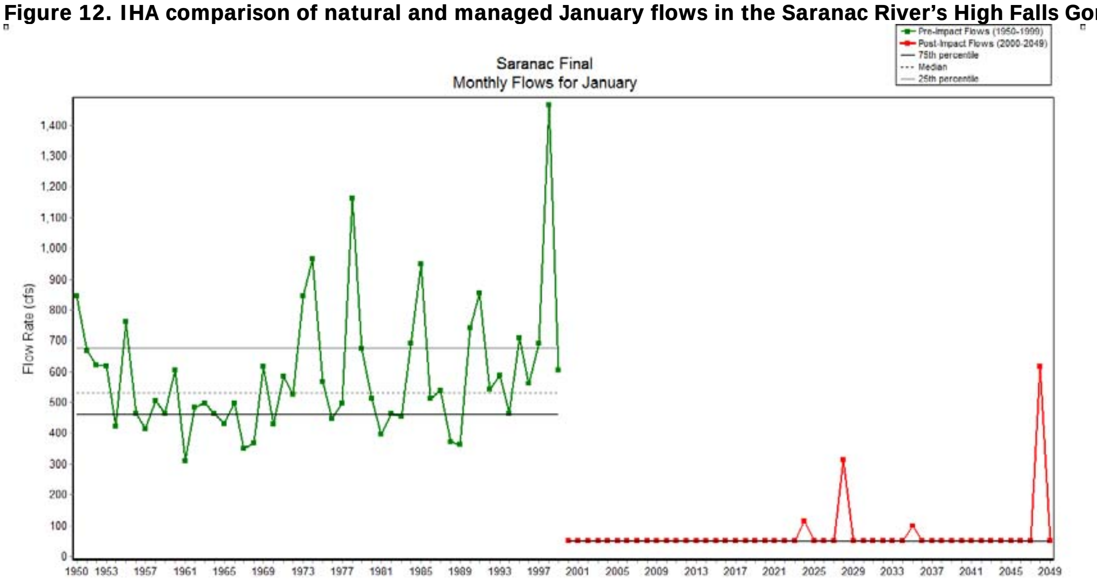
These effects are less pronounced in the spring. The graph of April below shows that the diversion of 851 cfs consistently reduces flows by that volume but does not dramatically affect inter-annual variability (Figure 11).

Figure 11. IHA comparison of natural and managed April flows in the Saranac River's High Falls Gorge



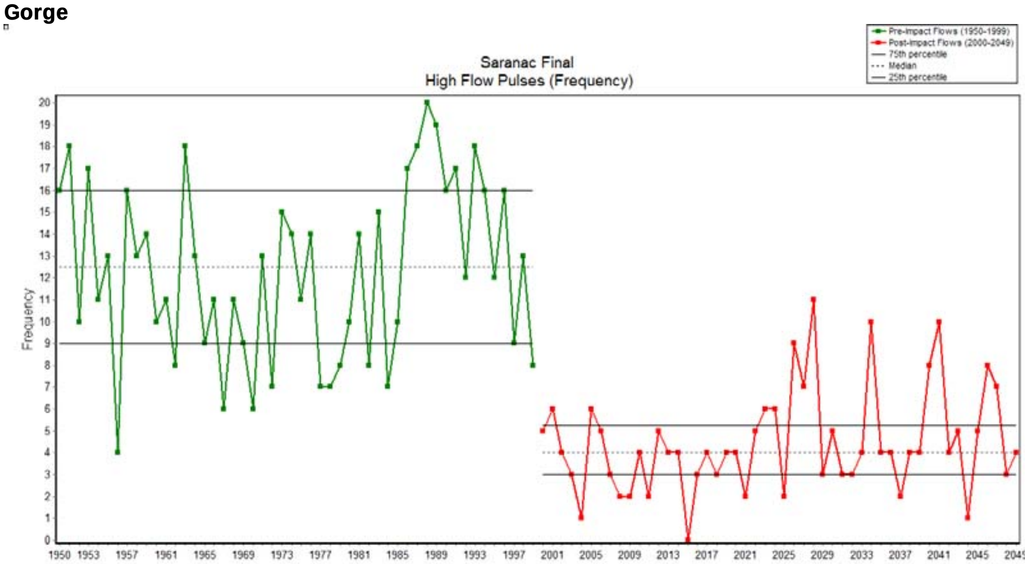
Winter flows, when ice and cold temperatures are an environmental factor organisms must deal with, are reduced through management in a manner similar to summer flows. Flows are reduced from a median flow over 500 cfs down to 50 cfs, and most inter-annual variability is eliminated (Figure 12).

Figure 12. IHA comparison of natural and managed January flows in the Saranac River's High Falls Gorge



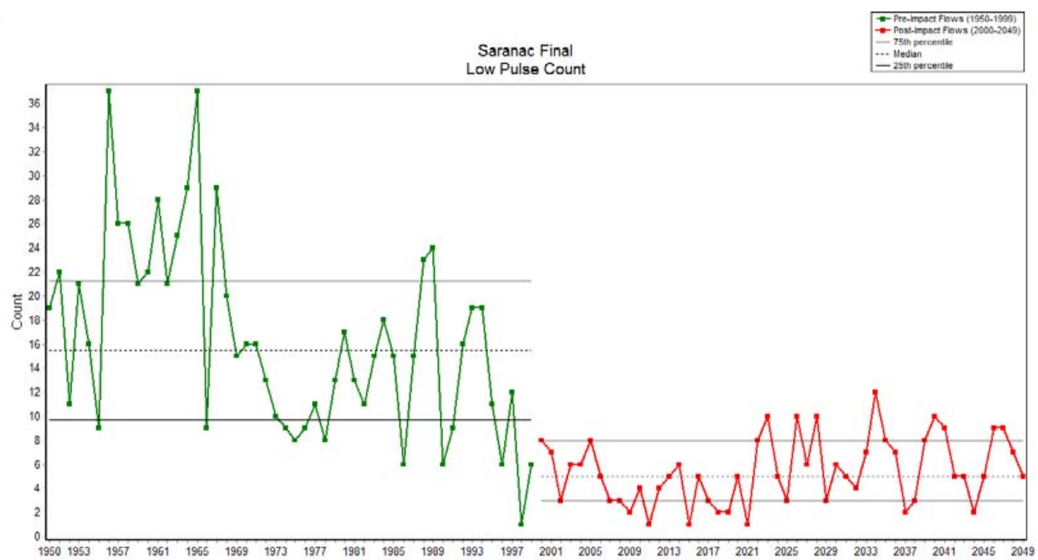
Flow management has reduced the frequency of high flow pulses from medians of around 12 per year to around 4. This reduction has also been accompanied by a reduction in inter-annual variability (Figure 13).

Figure 13. IHA comparison of natural and managed High Flow Pulses in the Saranac River's High Falls Gorge



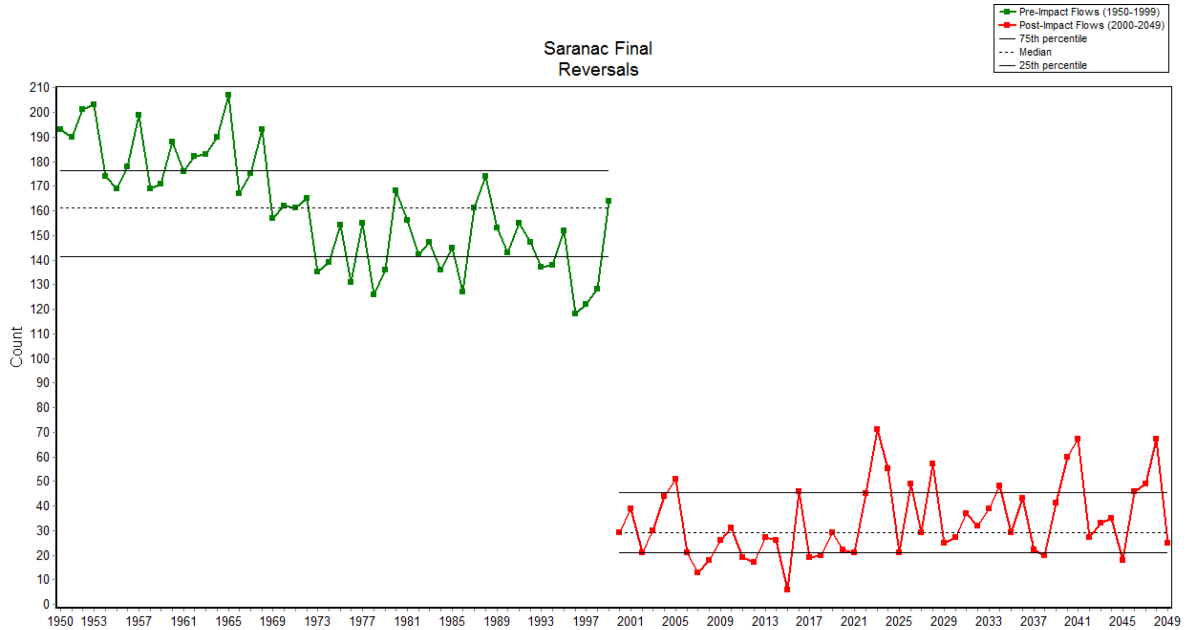
The low pulse count is similarly affected by flow management. Both the annual number and inter-annual variability is reduced though management (Figure 14).

Figure 14. IHA comparison of natural and managed low pulse count in the Saranac River's High Falls Gorge



The IHA analysis revealed a noteworthy difference in the number of reversals of flow per year (Figure 15). The natural flow regime experienced flow reversals on a median of 161 days per year while the managed flow regime only reversed a median of 29 times per year. This difference highlights the simplification of the flow regime through management.

Figure 15. IHA comparison of natural and managed flow reversals in the Saranac River's High Falls Gorge



While management reduces the number of flow fluctuations, it increases the rate at which the river rises and falls (Figures 16 and 17). The managed river rises more than two times faster and falls almost two times faster than the natural flow regime. Managed rise and fall rates are also far more variable than natural ones.

Figure 16. IHA comparison of natural and managed rise rate in the Saranac River's High Falls Gorge

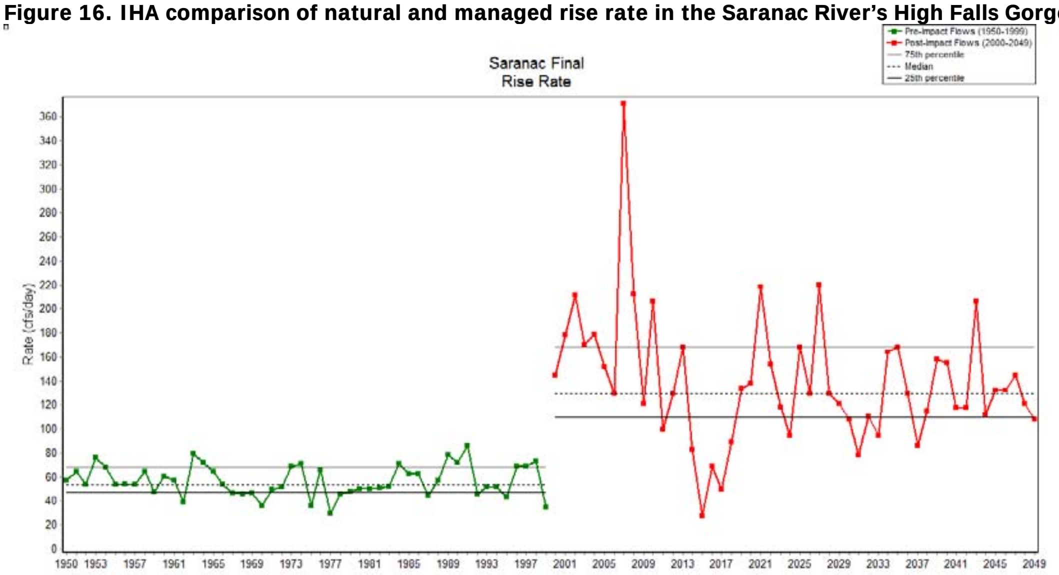
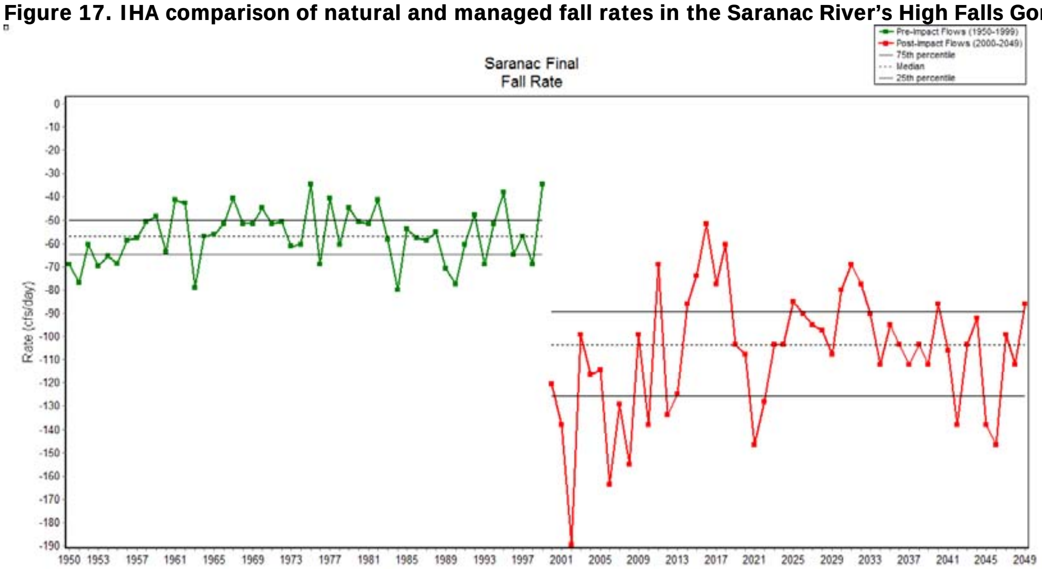
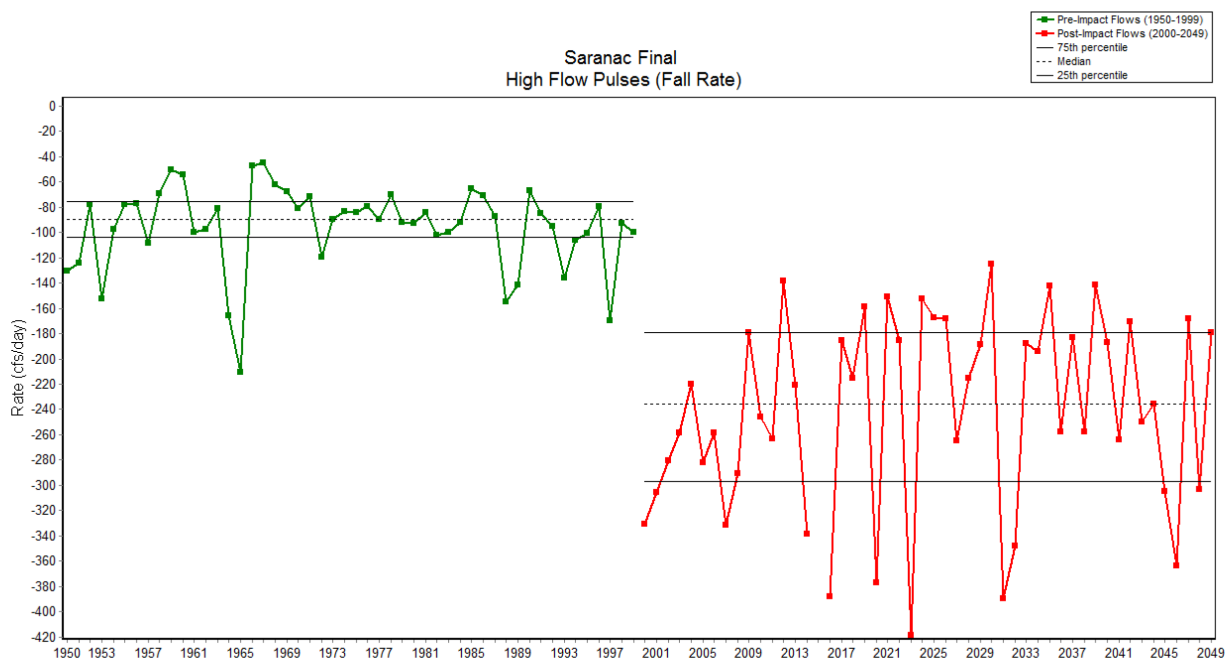


Figure 17. IHA comparison of natural and managed fall rates in the Saranac River's High Falls Gorge



The fall rate of managed high flows is much quicker than the fall rate of natural high flows, and of total managed flows.

Figure 17. IHA comparison of natural and managed high flow pulse fall rates in the Saranac River's High Falls Gorge



Discussion

The High Falls Hydroelectric Project is designed to remove a range of flows up to 851 cfs from a one mile section of the Saranac River. Management decisions were made based on a delphi study that analyzed flows of 3.9, 21.8, 39.7, 71, and 95.2 cfs. Each higher flow was found to provide successively more habitat. This analysis resulted in prescribed flat-lined base flows of 50 and 75 cfs depending on season. The delphi study participants indicated that those flows provided adequate habitat.

The IHA analysis indicates that the prescribed flow regime fails to restore flows that are within the range of natural variability and fails to restore several flow regime components that are ecologically significant. Thus, it can be concluded that the delphi study inadequately informed flow prescription decisions on the Saranac River, and will likely result in limited river restoration or protection. Maintaining a flow regime that lacks key ecological components can be expected to result in ongoing impacts to the Saranac River.

Flow Volumes

On the monthly scale the selected flows fall short of the Range of Variability Analysis boundaries which are based on the 25th and 75th quartile of monthly medians of the natural flow regime. In fact, in every month but April, the median managed flows are markedly lower than the lowest monthly median flow value for the natural flow regime. Thus, the managed flow regime selected by the delphi method is not even within the natural range of monthly median flows for the Saranac River.

At the daily flow scale, the managed flow regime also is outside of the natural flow regime for several variables. On only three out of fifty years did the natural flow regime ever fall below the 50 cfs flow that was selected by the delphi method. It is likely that these outlier one-day "natural" low flows were actually caused by the operations of upstream dams deviating from their normal run-of-river management. The natural river fell to 50 cfs on only one year for a seven day period and never fell to 50 cfs for a 30 or 90 day period. The base flows selected, which regularly span many months without deviation, are thus below not only the RVA values, but most or all of natural variation. IHA characterizes flows below 254.4 cfs as "extreme low flows" on the Saranac River, yet the managed base flows are a mere 50 and 75 cfs.

For most variables, the managed flow regime is at the edge or outside of the range of natural variability. These unnaturally low flows reduce the amount of aquatic habitat, the quality and types of aquatic habitat, and can increase water temperatures and predation of aquatic species (Cushman 1985, Petts 1984). While it is expected that hydro operations will withdraw water, it is strongly recommended that such operations do not limit ecologically significant flow variables greater than 25% from the median (Richter et al 1997). In this case they have been modified greater than 50% from the median and are at times more than 600% less than the lowest natural values.

Figure 18 shows the natural, managed and lowest monthly median flows, and the low RVA values which represent the 25th percentile values. Developers of the IHA model and others recommend maintaining flow variables at or above the low RVA values. Certainly, managers are advised to stay within the natural variability for the river.

In the case of the Saranac, managers have accomplished neither of these goals. In order to restore even the most basic habitat variables to the Saranac River, it is recommended that base flows be increased to at least the lowest natural monthly median values.

Figure 18. IHA comparison of monthly median flow values including Range of Variability Analysis (RVA) values in the Saranac River's High Falls Gorge

Month	Natural Monthly Median	Managed Monthly Median	Lowest Natural Monthly Median	Low RVA Values
October	424.1	50	210.3	359.5
November	607.3	50	268.9	498.9
December	605.6	50	332.7	534
January	531	50	310.3	465.5
February	544.4	50	178.9	465.5
March	671.9	50	337	593.3
April	1485	634.8	559.4	1228
May	991.3	141.3	439.6	825.2
June	587.2	75	249.5	513.7
July	384.9	75	122.4	323.3
August	392.6	75	209.5	329.9
September	367	75	185.3	324.2

Daily Variability

One of the most obvious differences between the natural and managed regimes are the long flat-lined periods present in the managed flow regime and absent in natural flow regime. The stable managed base flows of 50 and 75 cfs are often uninterrupted for months at a time. These same time periods in the natural flow regime are characterized by nearly constant daily and weekly changes in flow. IHA best describes this difference with its analysis of the number of reversals that occur annually. Reversals are essentially a significant change in flow from a rising condition to a falling condition, or from a falling to rising condition. IHA reports that the natural flow regime has a median of 161 reversals per year, while the managed flow regime only has a median of 29 reversals annually. The low RVA value is 147 reversals, and the lowest natural value is 118 reversals. This is one of the most dramatic effects of the flow management.

The impacts of reduced reversals may include vegetative encroachment (Johnson 1994, Nilsson 1982) and alteration of communities through establishment of exotic species (Busch and Smith 1995, Moyle 1986, Ward and Stanford 1979). Elimination of moderate high flows can have impacts on sediment transport, and the composition and relative abundance of species in the river (Leopold et al 1964, Fisher 1983, Meffe and Minckley 1987, Schlosser 1985, Beschta and Jackson 1979).

The delphi study offered no means of analyzing daily variability or regular moderate pulse flows and thus failed to lead to prescription of these important flow variables.

Many bypassed river reaches have a degree of daily variability that is contributed through significant tributaries. The High Falls Gorge does not contain tributaries capable of contributing significant variability. Restoring daily or weekly variability could be accomplished through changes in base flow releases on those timescales or through provision of pulse flows. Restoring this element of the hydrograph would require the restoration of 118 reversals to be within the natural range of variability and 147 to be within one quartile of the median natural value. Doing so would restore an ecologically significant element of the Saranac River that the managed flow regime fails to restore.

Seasonal Factors

Poff et al (1997) report that the high and low flows act as cues for fish spawning, egg hatching, rearing, and migration. IHA highlights several season elements of the flow regime that may be ecologically significant in this regard. While spring flows follow a reduced natural pattern, the moderate pulses have been largely eliminated through management from summer, fall, and winter seasons. Elimination of these cues may impact fish life cycles. In addition, managed flows are lower than the natural range of variability and may expose aquatic organisms to increased risk of predation, higher summer water temperatures, and ice in the winter. Perhaps most importantly, managed flows usually eliminate the early winter pulses that are typical of the natural flow regime and replace them with a radically low flow of 50 cfs.

The delphi study recommended two seasonal variations in flow. These are both so low and similar that it is unlikely that this variability is significant. In addition the managed flow provides higher base flows (75 cfs) in the summer than in the winter (50 cfs), whereas the natural flow regime exhibits the opposite seasonal relationship. Thus, the delphi study and resulting settlement failed to restore seasonal functions of the flow regime.

A managed flow regime that includes moderate pulses in the summer, fall, and winter seasons, in concert with higher base flows and larger early winter pulses would restore natural seasonal functionality to the flow regime.

Inter-annual Variability

Hydrologic variability are key determinants of aquatic community structure and stability (Poff and Ward 1989; Poff et al. 1997; Richter et al. 1996; Bowen et al. 1998; Freeman et al. 2001). A specific flow regime naturally selects for some species and against others. Flow regime elements that differ from year to year can help assure that no one species is selected for or against every year in a manner that is inconsistent with natural processes. For most variables, the managed flow regime of the Saranac River has significantly less inter-annual variability than the natural flow regime. Managers have, in essence, created a simplified system. Periods of spill on the Saranac River maintain some degree of natural variability, but only to some variables and in some months. In general, seasonal analyses in IHA show that under the managed flow regime there are few or no differences in flow volumes or variability for summer, fall, and winter flows. Thus, year after year organisms that flourish under those conditions will be selected for, and those that are impacted by those conditions will be selected against. The delphi study failed to analyze or recommend any inter-annual variability.

A flow regime that featured inter-annual variability in base flows and the timing and magnitude of pulse flows would restore ecological functions associated with this factor. This has been accomplished at other hydropower dams such as the Santeetlah Dam on the Cheoah River in North Carolina (Dilts et al 2005).

Rise and Fall Rates

Rise and fall rates can have ecological effects such as scouring velocity sensitive organisms and stranding of organisms respectively (Cushman 1985, Petts 1984). The managed flow regime exhibits rise and fall rates that are roughly twice the natural rate, far more variable, and outside of the natural range of variability. This divergence from the natural flow regime could cause scouring and stranding.

Dam operators can generally ramp planned and unplanned spills. Instituting up-ramp and down-ramp protocols at the High Falls Dam could protect organisms from these impacts. These impacts may or may not actually occur during spills based on channel morphology, so additional onsite study is likely justified prior to instituting ramping.

Pulse Flows

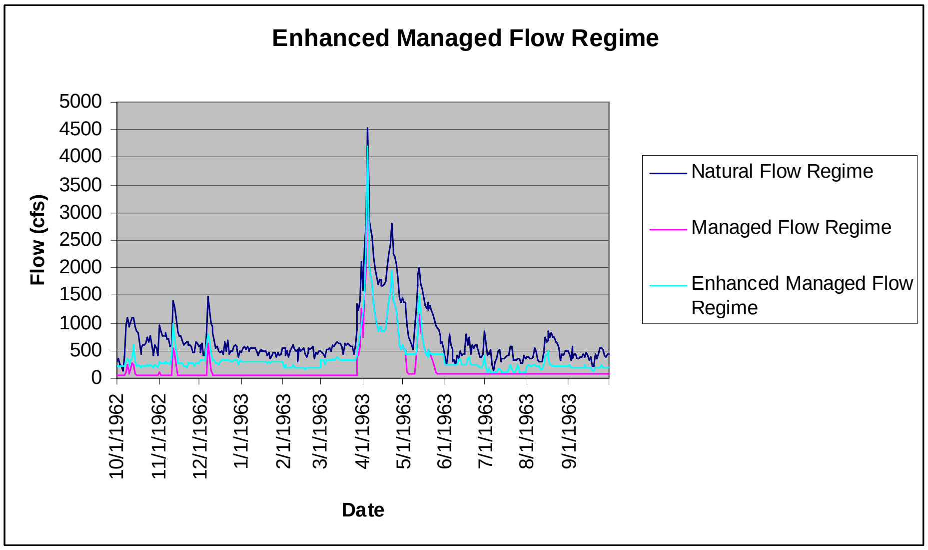
Several stakeholders successfully opposed the inclusion of pulse flows in the managed hydrograph based on environmental concerns. The delphi study offered no basis on which to analyze pulse flows, and thus the decision to exclude pulse flows by state and federal agencies was made outside of the context of the analysis. The IHA model presents strong evidence that pulse flows would result in a more natural hydrograph that could be expected to result in environmental benefits. Pulse flows would restore a percentage of natural daily variability, seasonal variability, and inter-annual variability to the managed flow regime.

The maximum volume of the proposed pulse flows was 250 cfs. The IHA model would characterize that flow volume as an Extreme Low Flow for the Saranac River, the threshold for which is 254.4 cfs. Such flows certainly do not exceed the natural range of variability for the Saranac River, except that they are unusually low. Natural pulse flows that increase by 175-200 cfs are extremely common. The proposed managed pulse flows would have restored a small percentage of these natural pulse flows.

A Better Flow Regime

Based on the IHA analysis it is clear that the flow regime prescribed based on the delphi study lacks critical ecological components. Using the information from IHA an enhanced flow regime can be designed that still allows significant hydropower withdrawals (Figure 19). In the example below, the Lowest Monthly Mean Flow was selected as the base flow for each month. While this value is the outer edge of natural variability, it was selected to maximize the hydropower withdrawal allocation. To these base flows, spills that existed under the managed flow regime were increased in volume to better approximate natural spill volumes, with a special emphasis on the annual peak flow. In addition, daily and weekly variability was added to the base flows by adding low flow periods and pulse flows. The pulse flows were ramped up and down. We would recommend either a) providing flows based on a relationship with inflow to mimic natural flow variations, or b) establish at least five distinct years of flow regime targets to provide inter-annual variability.

Figure 19. Example of an enhanced managed flow regime in the Saranac River's High Falls Gorge.



Regulatory Implications

This analysis casts serious doubt on the delphi method's validity. In this case, it failed to provide river managers with the information needed to design a flow regime that meets the ecological needs of the river ecosystem. It is recommended that the delphi method not be accepted by FERC or state agencies as evidence for flow prescriptions, or that it only be accepted in concert with a supporting IHA analysis. Likewise, it is recommended that other instream flow methodologies that address only *minimum* instream flows be supplemented with an IHA analysis to provide hydrological context. IHA can be effectively used to prescribe flow variability including pulse flows that is hydrologically consistent with the natural hydrograph. It is strongly recommended that IHA be used by FERC and other decision makers to construct and contextualize flow prescriptions.

The flow regime in the High Falls Gorge of the Saranac River itself may be worth revisiting based on these analyses. The current managed flow regime fails to protect or restore the river from significant impacts.

Conclusions

Basic hydrological analysis was paired with an Indicators of Hydrological Alteration (IHA) analysis to critique the newly prescribed flow regime for the Saranac

River's High Falls Gorge. The delphi method was used to select the managed flow for the river. Hydrological analysis, including IHA, showed that the managed flow regime lacks many environmentally significant components of the natural flow regime, and is in fact typically well outside of natural variability. These results indicate that the delphi method in this case provided inadequate information to make environmentally responsible flow prescription decisions. The IHA analysis provided additional information that informed the creation of an enhanced managed flow regime that included pulse flows and other variables that are predicted to maintain environmentally significant flow components.

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