Strategy for Sustainable Management of the Upper Delaware River Basin

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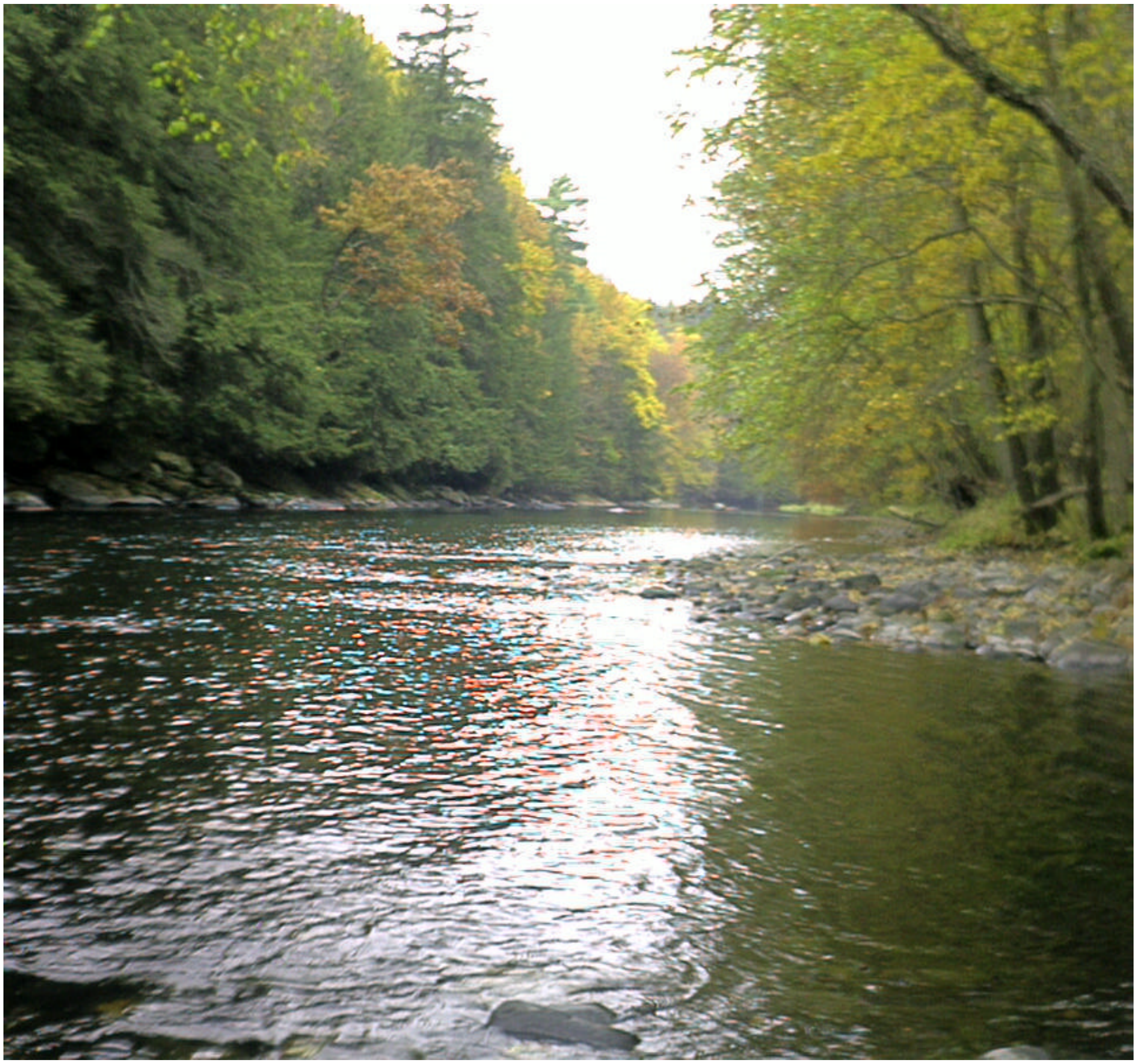
For Trout Unlimited



> “The forests and their deep duff, with topsoil intact, covered surrounding mountains like deep sponge. Even the heaviest rain seldom raised the river’s level appreciably or even clouded its waters. Flash floods were practically unknown. If they did occur, it was only in the late winter or very early spring, with the break up of river ice or when frozen ground couldn’t absorb snowmelt. The river was narrower because the banks were squared and closer together, not eroded by floods. They were well defined, sharp and steep, not lensing gradually up the valley sides. The Delaware was a classic example of a freestone river, its bottom filled with glacial boulders, graded stones, and gravel. (…) Silt was unheard of. The water was cooler. Dense conifer forests interspersed with hardwoods kept tributary streams cool and helped keep water temperatures low in the main stream. Even the main river was better sheltered, because trees grew down to the banks and overhung the river. Brook trout prospered.”
>
> Nick Karas “Brook Trout”

Summary

The Upper Delaware River represents a valuable ecological resource of New York and Pennsylvania. Recognized as one of the most scenic rivers in the country, it is highly appreciated for high quality trout fisheries and outdoor experience. The river also serves as a water supply for local communities and New York City. The three New York City water supply reservoirs (Cannonsville, Pepacton and Neversink) are designed to withdraw more than 70% of the average annual volume available at the top of the basin at three stems of the Delaware: West Branch, East Branch and Neversink River). The severe flow reductions, together with channel alterations and landscape modification, result in dramatic changes of water temperature in the river. As a consequence of these alterations to water flow and temperature, Delaware aquatic fauna is strongly impaired.

The complex ecological impact caused by unnatural flow conditions and past environmental degradation conflict with local and regional development and necessitates a well-defined management scheme to optimize use of the river as a resource and secure its long-term sustainability. Detailed hydrologic and biological information is needed to determine factors that control the functioning of the system and help to define a long-term management plan. However, the highly degraded fishery requires immediate action. Consequently, a two-phase program is proposed to address the problems. In the first phase acute deficits will be addressed by prescribing permanent increases of base flow, and reducing ramping rates and peak amplitudes. These measures are expected to stop further damage and are compatible with current water withdrawals. In the second phase, a broad multidisciplinary study will provide a solid base for type specific restoration options and an integrative, long-term management plan for the whole basin.

Introduction

With 22 million inhabitants and numerous industrial enterprises, the Delaware River Basin is an example of an intensively used resource with conflicting demands. The sparsely populated upper portion of the basin represents a valuable ecological resource for both New York and Pennsylvania. Heralded as one of the most scenic rivers in the country and highly regarded for its fisheries and outdoor experience, the river serves as a local and regional (New York City) water supply. Multiple withdrawals of water for domestic supplies dramatically alter the flow of the river and consequently the river character. Three New York City reservoirs (Cannonsville, Pepacton and Neversink) are designed to withdraw more than 70% of the average available annual volume at the top of the basin. The effects of flow manipulation can be observed throughout the West Branch, East Branch and Neversink watersheds and the main stem (Sheppard 1983, Hulbert 1987). Negative consequences like thermal fish kills are evident, but many are rarely or hardly recognized. Information pertaining to the consequences of water withdrawals, such as alteration of fauna composition, sediment transport, surface-ground water interaction, thalweg elevation and substrate composition are commonly available for other watersheds, but sparse data exist for this area. Furthermore, limited knowledge of this ecosystem in its pristine form hampers the process of assessing human induced alterations. Hence, a deficit analysis can only be inferred from empirical knowledge of the system and theoretical assumptions. In the long run, a comprehensive multidisciplinary study is needed to establish an explicit management plan with long-term objectives.

Ecological perspective - Anticipated natural conditions

The Upper Delaware (West Branch, East Branch, and Neversink) is an alluvial upland river system of straightened-confined meandering character (B according to Rosgen 1985) with a pluvio-nivial flow regime (i.e. high flows related to rain and snow melt in the fall and spring, and low flow in the summer (Parde 1968)). The gradient is relatively low compared to headwater rivers, and multiple wetlands accompany its course. The river flows over unstable glacial deposits in a U-shaped valley that was heavily forested in pre-colonial times. The high capacity of the forest and wetlands to store water suggests that the historical hydrological regime of East and West Branch differed from the present by having lower fall and spring peaks, and higher summer flows. Consequently, thermal conditions would have been more stable in the past due to higher summer flows (i.e. increased thermal capacity), shading, and high groundwater input (i.e. spring discharges). Historical evidence of coldwater fish species in the upper Delaware also suggests lower summer temperatures and/or wide availability of thermal refuges in the main stem or tributaries (Karas 1997, Van Put 1996).

The estimated native fish community can be classified as either a cold or mixed cold and warm water assemblage. Early nineteenth century evidence suggests only an abundance of large brook trout year-round and American shad seasonally (Karas 1997). NY DEC records show the presence of fallfish, pickerel, golden shiner, pumpkinseed, minnow and sculpin (Elliot pers. comm.) after the river was already heavily modified. The comprehensive list of fauna composition from pre-colonial times does not exist and could only be reconstructed from river morphological characteristics.

Management perspective – economic potential

As a resource, the Upper Delaware offers high quality potable water for local communities and for export to New York City. The groundwater body provides higher quality and a more stable source of potable water because Catskill forests have a high water storage capacity.

Commercial use of the river is also important. Numerous industries can make use of the water resources, including the tourism and recreation industries. The scenic, mountainous landscape is rich with flora and fauna and offers extraordinary recreational opportunities for nearby urban populations like the New York City metropolitan area. The world famous brown and rainbow trout fishery is a traditional attraction and plays a vital economic role in the region.

Large trout rivers on the east coast are rare. Large rivers like the Delaware with high abundance of brook trout were rare even in the past. This exquisite fishing is now limited to a few northern, unsettled regions like Labrador or Manitoba. While restoration of the native brook trout fishery that once existed faces numerous obstacles, it is still a potential option that could open a highly exclusive fisheries resource.

Deficit analysis

Ecological deficits

The river's current condition is the result of two hundred years of human alterations to the original system, not merely the construction of the three upper-basin reservoirs. As a result of massive deforestation in the nineteenth century, the hydrological regime has been modified in the entire basin. Runoff was destabilized, changing annual amplitudes of flow. Average spring and winter flows increased, and summer/early fall flows decreased. With the loss of retention capacity, fluctuations of flow became more frequent and intense. An unstable riverbed was altered by a higher occurrence of flushing flows and massive logging operations, resulting in a wider and shallower channel. These morphological changes, together with reduced canopy cover and lowered ground water discharges, modified annual fluctuations of water temperature, leading to much warmer summer flows. Increased catchment sediment yield and bank erosion changed substrate composition in the river and covered spawning grounds and hyporheic refugia with silt. In response to all these factors, the faunal composition has shifted from a coldwater community towards a more generalist and warm water assemblage. Heavy angling pressure as well as stocking of domesticated brook trout and exotic species also share the blame for loss of a regional treasure: native, long living brook trout (Karas 1997). Tanneries and acid factories contributed to the complete destruction of the aquatic community. These industries vacated the Catskills in early twentieth century, but the physical damages remained.

In the more recent past, the construction of Neversink, Pepacton and Cannonsville water reservoirs for New York City has also contributed to various deficits in the Delaware River system.

- ➢ With regard to flow:

  - ✓ **Reduction of average annual volume by 50%** (from nearly 400 Billion Gallons per Year (BGY) to 200 BGY)**.** The highest flow decreases have occurred on the East Branch and Neversink (70% and 80%, respectively). As a result, chronic low flows occur throughout the year and water flow is severely curtailed in the lower portions of the rivers. Critical physical attributes (velocity, depth etc.) are altered making habitat unsuitable to the original fish community, as well as nonnative cold-water fish including brown and rainbow trout, promoting a generalist and lentic assemblage.

  - ✓ **Change of seasonal and spatial flow pattern.** The magnitude of high flows is only a fraction of the pre-dam peaks (Figure 1). Average discharges over the winter and

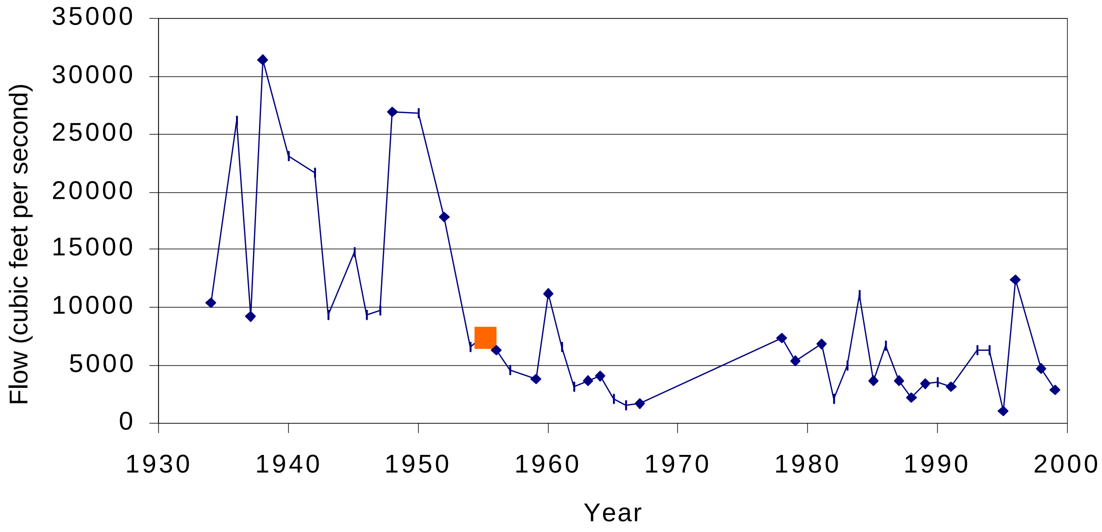


Figure 1: Historical annual peak flows at East Branch of the Delaware River, Harvard gage. The red square indicate the time of construction of Pepacton reservoir (courtesy of Nat Gilespie)

spring periods are dramatically reduced (Figure 2). Summer flows in the West Branch are unusually high, but in contrast are very low in the East Branch and Neversink. Frequently droughts occur in fall instead of summer as a result of sudden increase of reservoir storage (Elliot pers. comm.).

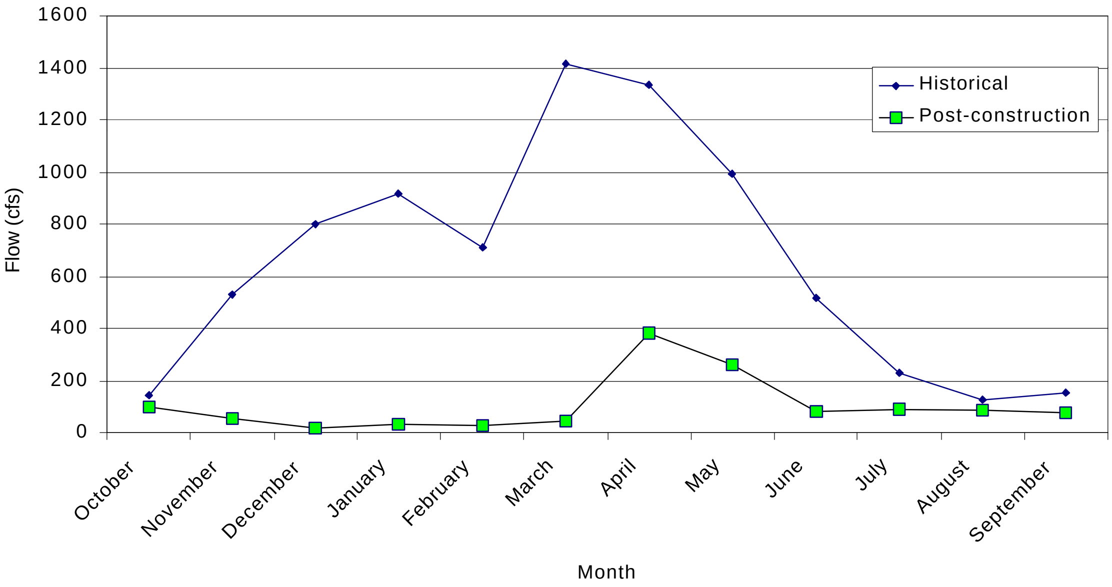


Figure 2: Median monthly flows at East Branch of Delaware River, Downsville NY

- ✓ **Modification of daily flow pattern** (increase of amplitude and ramping rate).[1] Figure 3 compares the Walton (above Cannonsville reservoir) and Stilesvile (right below the dam) hydrographs. In the tailwater, rapid flow changes occur more frequently and with higher intensity. Such frequent spates can result in the impoverishment of aquatic biota (Parasiewicz 1998). Contrary to natural systems, the artificial flow increases are not associated with increased ground water levels that have been identified as “warning signals” for benthic fauna in alluvial rivers (Bretschko and

Moog 1990). Also, the falling limb of the hydrograph fundamentally differs from a natural scenario. Such conditions can lead to the stranding of organisms and increased deposition of fine particles within the channel instead of on adjacent floodplain areas.

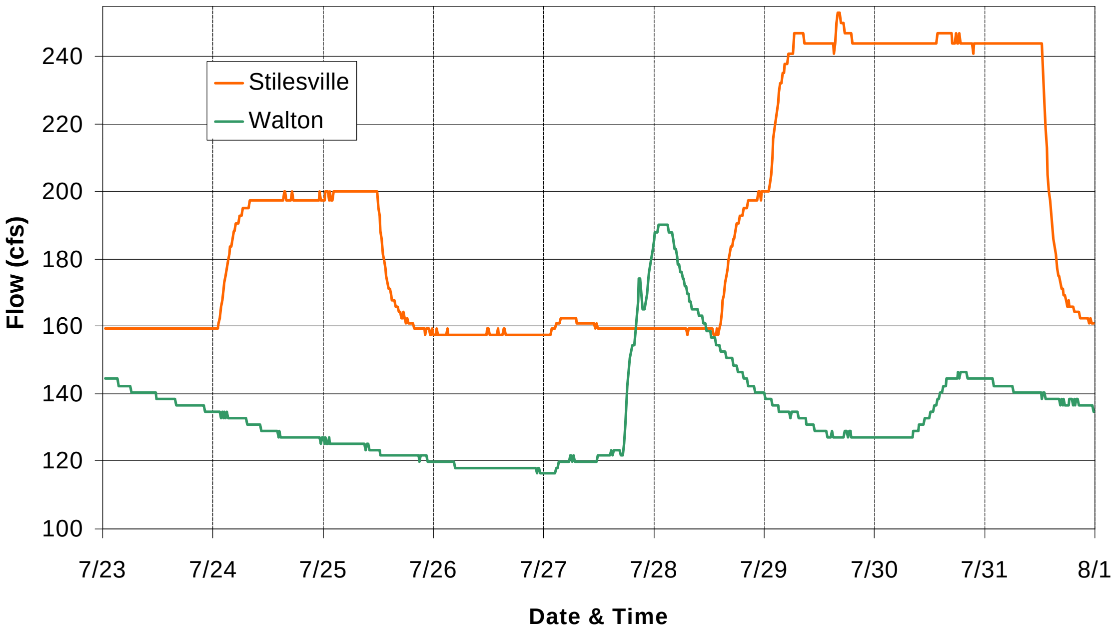


Figure 3: Comparison of daily hydrograph on the West Branch in Walton and Stylesville between 23-31 of July 2000.

- ✓ **Critically low flows during drought and winter seasons**. During droughts, releases are reduced to almost nothing, reducing habitat and thermal refugia in both seasons. In winter higher volumes needed for over-wintering habitat (most frequently deep pools for adult fish and riffles for juvenile fish and fry) do not exist. These periods are detrimental to fish.

- ➢ The thermal regime is also dramatically altered:

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[1] Rate of change during flow increase or decrease

- ✓ **Higher annual amplitudes of temperature**. Low flows, widened riverbeds, and reduced ground water discharge lead to high water temperatures in the summer and cold temperatures in the winter that did not occur in the past. The summer “warm ups” have already caused multiple fish kills in the Delaware River. The increased formation of ice cover with lowered water temperatures in winter (Figure 4) reduces habitat availability in the most critical stage of the annual life cycle, and particularly impacts the survival of young fish. Anchor ice in riffle areas may damage the riverbed and impact juvenile fish and benthic fauna (Gillespie pers. comm.).

Figure 4: Ice on the West Branch of Delaware River at Hancock on 21 January 2001

- ✓ **Extreme daily fluctuations and thermal plunges**. Shallow water bodies are susceptible to highly variable water temperatures even under normal weather conditions (Figure 5). Water temperature can change by many degrees centigrade during hot summer days. Drastic changes in release of water Cannonsville (e.g. 200 cfs to 1200 cfs) regularly introduce a coldwater plume that causes thermal shock to downstream fauna.

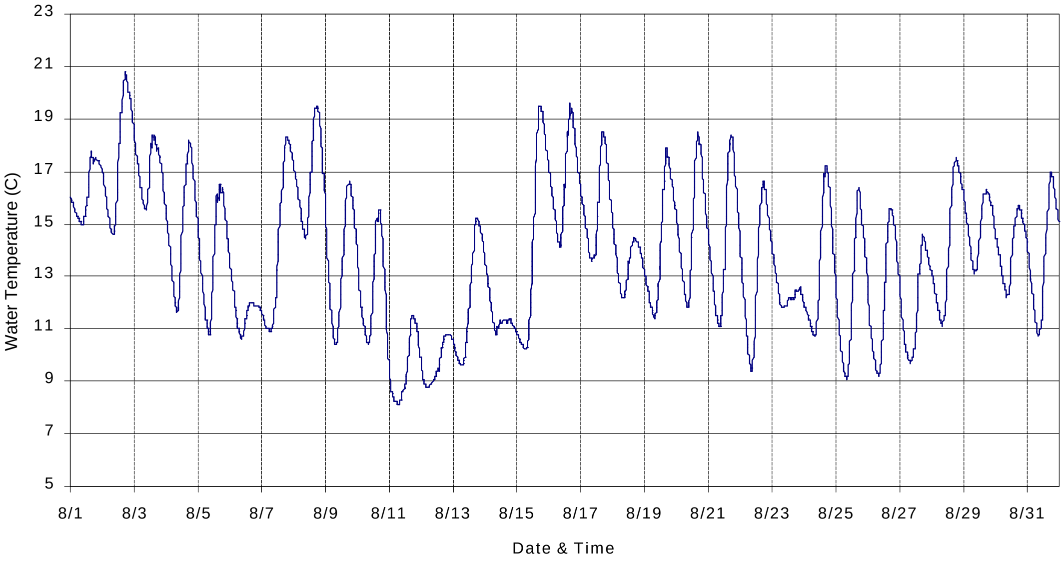

Figure 5: Water temperature on the West Branch of Delaware at Hale Eddy during August. 2000 (cold and wet summer).

- ✓ **Thermal discontinuity.** The temperature continuum along the river course is disrupted by the reservoirs compared to the original system. A natural distribution of the flora and fauna assemblages (as described in River Continuum Concept, Vannote et al. 1980) is disrupted.

- ➢ Longitudinal connectivity is affected by a lack of fish passage facilities at the dams. The resulting habitat fragmentation impairs the migratory cycle of species and limits the access to upstream thermal refugia.

- Substrate recruitment is disrupted by the impoundments and could possibly lead to the downcutting of the riverbed in the tailwaters.

- Channel modifications that took place due to logging and construction of roads, bank stabilization, levees and floodwalls are much more evident than potential morphological changes caused by the alteration of flow regime and substrate deficits. Armoring of the riverbed together with sedimentation of hyporheic zone could reduce vertical connectivity and affect benthic organisms. Potential downcutting might have an influence on longitudinal and lateral connectivity of the ecosystem, affecting life cycles of dependent organisms (e.g. access to spawning grounds).

Other ecological deficits exist that are not attributable entirely or in part to New York City reservoirs and water withdrawals:

- In the Upper Delaware little is known regarding the discharge from the aquifer to the river (USGS pers. comm.). Loss of wetlands and floodplains, increased paved surfaces, and infiltration limited by road surfaces together with low river flows could significantly reduce ground water contributions. Changes in water table levels could have a strong influence on the flow and temperature of the river as well as riparian areas.

- Exotic fish species have been introduced, but their influence on the native population is not clearly known. Brown and rainbow trout compete very successfully with native brook trout. Many unlikely species (e.g. small mouth bass, carp, and walleye) are also abundant. Additionally, many exotic plants compete with native flora.

Resource use deficits

In many cases the different resource uses have opposing interests:

- The water supply industry must deal with increased pressure from local communities and a requirement for water in the stream. On the other hand, water suppliers need to be prepared for an increased frequency of droughts and a growing demand for potable water (see also UNEP report on Global Warming, January 2001).

- Sustained reductions in the recharge of water to groundwater aquifers might cause serious problems for the region in the future. This issue needs to be studied more intensively. The resource has not been used very actively at present, but demands could increase significantly in the near future.

- Non-point source pollution threatens water quality and potable water supplies. Current farming practices (e.g. diaries in the flood plain) are not compatible with a catchment that is intensively used as a drinking water supply. Specifically, the Cannonsville reservoir has been often used to maintain River-Master-prescribed target flow levels due to its low water quality caused by poor upstream land-use practices.

- Recent flood damage made clear that current flood protection measures are not effective or sustainable. More extensive flood damages can be expected because of loss of wetlands and floodplains, expanding storm drainage and road systems, and increased urbanization. Comprehensive, long-term flood protection solutions are needed.

- The tourism and trout fishing industry require high quality instream and riparian habitat. Present flows and thermal conditions are not satisfying and lead to a reduction of fish populations. There is a widespread belief shared by fisheries managers, guides, and other river users that the trout fishery is not achieving its full potential due to flow management. The trout fisheries can be maintained only with the help of cold water releases. The large releases from the Cannonsville reservoir are intended to fulfill flow targets and help to alleviate the need for cold water. However, the East Branch and the Neversink are apparently sacrificed for the sake of the West Branch.

- ➢ A tremendous recreational resource is largely under-utilized. The region is economically depressed, but the unrealized potential of recreational activities of natural resources represents a possibly vast commercial resource.

Objectives for sustainable management

The ultimate goal of basin wide management could be to optimize resource use while maintaining sustainability by implementing the following multidisciplinary objectives:

- Preserve the original character of the river (as a coldwater system) to maintain a dynamic equilibrium and consequently long-term sustainability.

- Maintain ecological integrity (allow only slight changes in species composition and abundance from the type specific communities).

- Focus on the recreational industry and traditional trout fisheries.

- Preserve a potable water supply for present and future generations.

- Allocate water for industry and local uses in the lower part of the basin.

- Provide appropriate flood protection for communities in the upper and lower river basin.

Proposed target system

To fulfill management objectives the following characteristics can be envisioned as a management target:

- To allow for water withdrawals and maintain ecological integrity, the characteristics of the tailwaters of all three reservoirs should correspond to those of the natural system (but on a smaller scale). With some restrictions, higher-quality “reference” streams can be found in the Catskill Mountains (for example the West Branch of Delaware above Walton).

- The flow and temperature regime (timing, frequencies, amplitude, ramping rate) of the Delaware should correspond with the reference conditions (e.g. Walton hydrograph corrected for land cover). To mitigate the impact of increased thermal uptake (a consequence of reduced water body and increased surface area) the temperature should continue to be lowered by releases of cold bottom waters from reservoirs.

- The high ground water level should be maintained by increased infiltration and storage (wetlands, backwaters etc.).

- Riparian vegetation should offer extensive shading and a source of woody debris, which in turn improves channel diversity.

- The substrate deficits should be controlled and minimized by adequate flow management.

- Ice damages should be of little significance and controlled by additional releases and higher ground water levels.

- The habitat diversity and connectivity should be restored.

- To support cold water fisheries low temperatures should maintained, but only to the extent that the tolerance of accompanying fauna is not exceeded.

- Within the limits of ecosystem resilience and sustainability, the water withdrawals can be continued at the same level and the efficiency of water use is maximized.

- Flood protection should assured on long-term basis.

Proposed measures

Implementation of the described target system will take time and additional research without conclusive historical records. However, immediate action is required to rescue the fishery and the ecosystem. Frequent thermal stress causes long-lasting damages to the fish fauna despite mitigation efforts utilizing a thermal stress bank. Unpredictability of weather conditions and a time lag of flow over long distances make precise temperature control difficult (just one catastrophic event could undo a multi-year effort). The damages to the West Branch are the most obvious. Trout are relatively abundant (a result of higher flow release practices), but lethal temperatures lead to fish kills, creating a fishery that is very inconsistent from year-to-year. Low winter flows and anchor ice create a long-term habitat bottleneck for fish and benthic fauna. The situation of the East Branch is also severe, with very low flows and consequent rapid warming. Although the water released from Pepacton reservoir is cold, the channel is wide and shallow, and the volume of warm water entering from the Beaverkill (also warmed due to an unnaturally wide and shallow channel), largely exceeds the downstream thermal capacity. The Neversink as a whole seems to be more resilient, probably due to a dense canopy cover and higher morphological diversity. The present flow regime in the Neversink and East Branch makes flow deficits during winter periods particularly apparent (see

Figure 2). Low flows and ice cover limit fish fauna in both rivers. On all three branches, rapid flow changes may cause serious damage to the fauna (through stranding, drift, thermal shock, and sedimentation).

For these reasons a two-step approach is proposed. First, preliminary measures should be undertaken to solve the most urgent problems and avoid further damages. The deficits that must be addressed in the short term are:

1. Chronic low flows on the East Branch and the Neversink Rivers.
2. Reduction of peak flows in the annual hydrograph with associated impacts. While it has been speculated that the East Branch and Neversink Rivers may suffer from the lack of higher flows since reservoir establishment, more data are needed concerning substrate composition, embeddedness and channel morphology.
3. Temperature bottlenecks in summer resulting from low flow releases.
4. Winter habitat bottlenecks and anchor ice damage resulting from low winter releases.

Second, a long-term management plan should be developed following a focused, multidisciplinary study of the entire system.

Immediate measures

The simplest and most assured way to solve the issues listed above is to provide a constant and adequate base flow in all three branches. It is necessary to prescribe minimum flows based on the general scientific and empirical knowledge of ecosystem mechanisms while adding an adequate margin of safety. As we gain a better understanding of the complex ecosystem, the flow regime can be optimized.

The following factors are integrated to develop a potential flow regime:

- New York City's ability to withdraw the same total amount of water for water supply needs.
- Present and historical flow regime at the reservoir locations.
- Need for reduction of temperature amplitude.
- Need for riparian succession to improve the channel.
- Coldwater fisheries.

Analyses of the water budget over the period of record (early twentieth century until now) have shown that since construction of the reservoirs on average 50% of the annual volume has been withdrawn from the Upper Delaware basin. Consequently, the other 50% of water flowing into reservoirs could be used for impact mitigation without affecting current supply. The key question is how to distribute it across the year most efficiently.

As mentioned before, the upper portion of the West Branch is a good template. The monthly mean flow at Walton or the historical monthly means at stations directly below the reservoirs can be used to determine minimum flow distributions (Figure 6 red and purple line). To accommodate water withdrawals the monthly values need to be reduced by 50% (Figure 6 dashed line). In order to provide the necessary thermal regime, it is proposed to redistribute the available spring and fall volume across the summer and winter months. Reduction of high flows would allow for more succession of riparian vegetation and, in the long run, decrease thermal amplitudes. Figure 6 shows how during an average flow year the flow releases could possibly be distributed on all three tributaries (green line) to meet the short-term management goals.

Furthermore, it should be realized that the flow releases from Cannonsville reservoir more effectively reduce the temperature of the main stem because the distance to the confluence is shorter and the temperature of the East Branch is elevated by inflowing Beaverkill waters. For this reason and also to accommodate the trout fisheries (mostly utilizing the West Branch and the main stem), an alternative approach would be to increase the Cannonsville releases to 300 cfs in winter and 600 cfs in summer. A small portion of 50% of the East Branch mean annual flow would therefore be transferred to the West Branch from November through May. Compared to the scheme presented above it requires only a slight reduction of the minimum flows in the East Branch (Figure 6 blue line). This pragmatic solution would also simplify the operation of reservoirs and compliance control. The proposed releases are summarized in Table 1.

Table 1: Proposed flow releases in cfs.

	oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep
West Branch	300	300	300	300	300	300	300	425	600	600	600	450
East Branch	150	200	250	250	200	200	300	400	500	500	500	400
Neversink	70	100	150	150	150	200	228	200	150	100	100	100
Total	520	600	700	700	650	700	828	1025	1250	1200	1200	950

Because of the high vulnerability of the system to sudden temperature increase at low flows, the releases during the drought periods should be reduced to a ratio lower than for the other users and never go below 50% of the identified minimum flows.

Another important issue is to avoid sudden flow and thermal fluctuations due to excessive ramping rates. The maximum amplitude of changes should be identified based on the Walton hydrograph. Ideally, the ramping rate should be more gradual than extreme values occurring at the Walton gage. The shape of the Walton hydrograph is narrowed due to the location of the gage higher up in the drainage and because the watershed suffers from lack of forest cover. For a

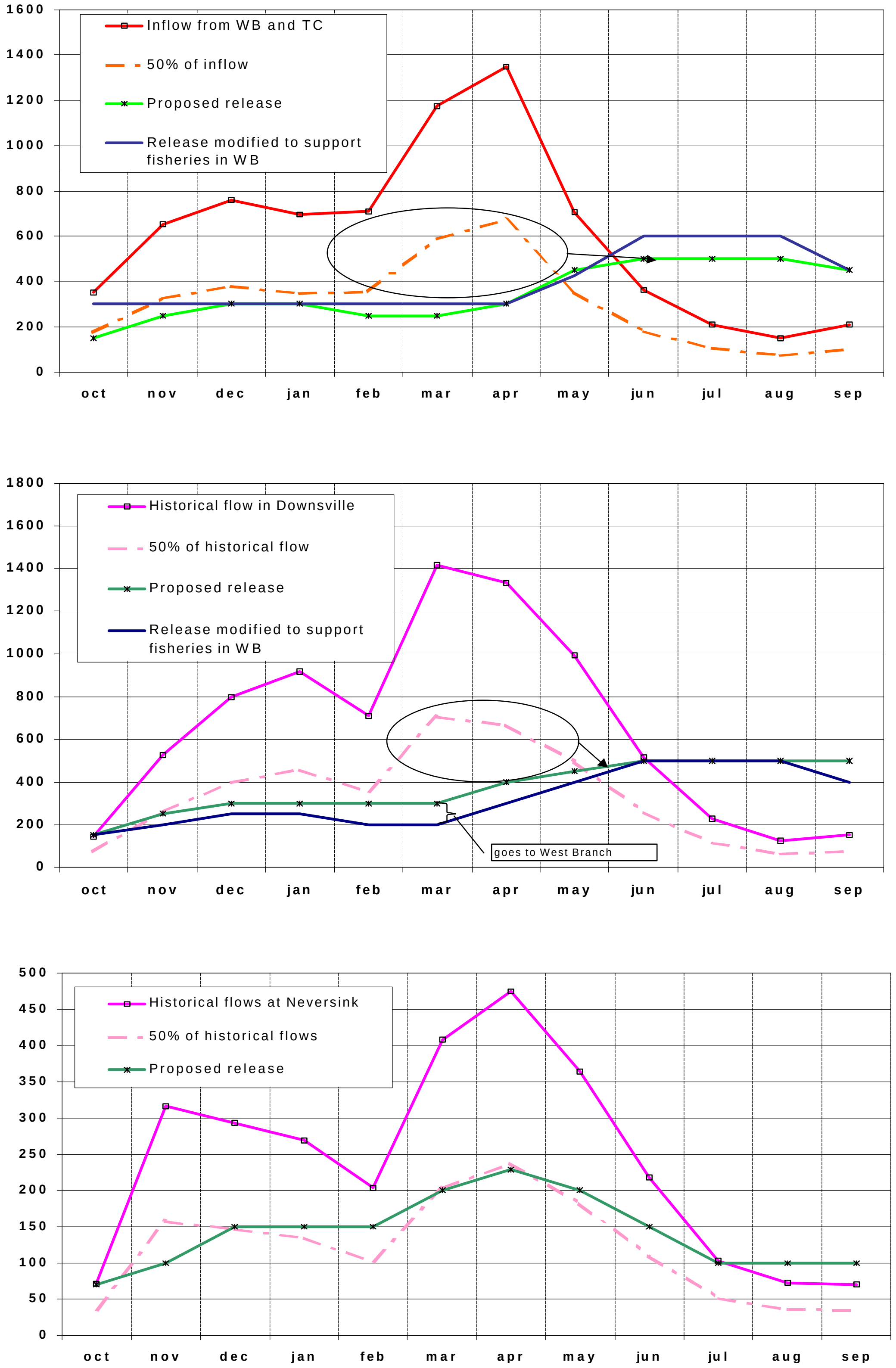

Figure 6: Calculation process of proposed flow releases based on historical flow regime for West Branch (up), East Branch (middle) and Neversink (down).

variety of biologic and geomorphic reasons mentioned earlier in the text, flow reductions should mimic the recessional limb illustrated in Figure 3, rather than being reduced at its current rate. Hence, special attention should be drawn to slow reductions of flow peaks.

Long term measures

This preliminary flow regime is still very artificial and needs to be intensively monitored to identify potential shortcomings. The monitoring results will support the planning process and help to define the most economically and ecologically effective measures. It should be conducted as part of a long-term management and research program. Intensive investigation by a multidisciplinary team of scientists and managers will provide an ecologically based foundation. Predictive models of hydrological and thermal regimes, ground water flow, sediment transport and target-fish-community habitat should be developed for the whole Upper Delaware, using a reference river for calibration and validation of measures. Based on comprehensive deficit analysis and model predictions, the dynamic flow management scheme can be determined. This and other measures, such as restored connectivity, improved channel diversity, or enhanced water quality in Cannonsville reservoir through reduction of non-point source pollution should be integrated to maximize ecological benefits of flow releases.

Conclusion

The Upper Delaware River Basin has a high potential to be an extraordinary example of applied sustainable management. We have an unprecedented opportunity to show that a devastated river system such as the Delaware can “bounce back” and create a definitive example for the entire country and world.

There are enough resources available to achieve this goal and allow for the coexistence of intensive human uses and an intact ecosystem. The costs of these measures are not high when compared to the long-lasting benefits for the users in and outside of the region. Even the short-term measures can be achieved at very low cost and are mostly flow management issues. Assuming that reservoirs are big enough to store adequate water volume, **the proposed flow scenario can be achieved without changing the volume of water withdrawn for New York City**. Moreover, the goals of uses could go hand in hand with restoration objectives (e.g. reduction of high flows).

These immediate measures are not optimal and even with them the system will remain heavily impacted. Therefore, in the long run it requires a well defined, scientifically sound, long term management concept that will consider the basin in its entirety. The intensive study to quantify limiting ecosystem factors, to better understand groundwater and surface water interactions, and to determine restoration options is a foundation of such plan. The majority of the necessary information is available, although it is widely distributed among research institutions. The “pieces of the puzzle” need to be collectively analysed and advanced through additional investigations and modelling exercises as prescribed in this study.

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