An environmental perspective on the water management policies of the Upper Delaware River Basin

Arun Ravindranatha,*, Naresh Devinenia and Peter Kolesarb

aDepartment of Civil Engineering, Center for Water Resources and Environmental Research, NOAA-Cooperative Remote Sensing Science and Technology Center, City University of New York (City College), New York, NY 10031, USA

*Corresponding author. E-mail: aravind000@citymail.cuny.edu

bColumbia Business School, Columbia Water Center, Columbia University, New York, NY 10025, USA

Abstract

Since 1954, the Delaware River has been managed under the framework of a Supreme Court decree and the subsequent concomitant intergovernmental collaboration between New York State, New Jersey, Pennsylvania, Delaware, New York City (NYC) and the US federal government. Taking an environmental perspective, we review the evolution of water release policies for three NYC reservoirs from the issuance of the 1954 decree through the implementation of the Flexible Flow Management Program (FFMP) of 2007–2015 and examine the policies’ impact on the upper Delaware River. We describe governmental and institutional constraints on the development of Delaware water policy and show how modifications of release policies have enhanced aquatic habitat and ecological health in the upper Delaware while reliably delivering water to NYC and the Delaware’s other principal stakeholders. We describe the development of the FFMP in 2006, its subsequent modification, and its augmentation by NYC’s Operations Support Tool in 2012. Finally, we discuss the negative ecological consequences of the 2010–2016 stalemate on Delaware water policy resulting from conflicts between the decree parties about current and future water rights, and how the stalemate derives partially from the decision structure imposed by the 1954 decree and the Good Faith Agreement of 1983.

Keywords: Delaware River; DRBC; FFMP; Inter-state compacts; New York City water supply; Reservoir release policies; Water management

1. Introduction

Interstate water disputes in the United States are resolved via litigation filed in the US Supreme Court, interstate water compacts, or congressional allocation via legislation (Bennett et al., 2000). Interstate water compacts, which are negotiated agreements that, if approved by Congress, become federal law and are binding contracts between the signatory parties, are the preferred method (Bennett et al., 2000).
There are currently 38 interstate water compacts in the United States (National Center for Interstate Compact [NCIC], 2016), and they have largely been characteristic of water policy in the western United States. Notable examples include the Colorado River Compact of 1922, the Rio Grande Compact of 1939 and the Red River Compact of 1978.

In the eastern United States, the Delaware River Basin Compact of 1961, and its predecessors, US Supreme Court decrees of 1931 and 1954, which apportion the waters of the Delaware River among its adjacent states, are interesting case studies of the strengths and weaknesses of the interstate water compact approach. The Delaware River, originating in the Catskill Mountains of New York State, is the longest undammed river in the United States east of the Mississippi (Delaware River Basin Commission [DRBC], 2013). It flows through the states of Pennsylvania, New Jersey, and Delaware, emptying into the Atlantic Ocean in the Delaware Bay after running 330 miles from the confluence of its east and west branches at Hancock, New York (DRBC, 2013). Consequently, all four states have claims to Delaware water. The Delaware River Basin (DRB) (Figure 1) drains roughly 13,000 square miles and supplies more than 15 million people with water for drinking, agricultural and industrial use. The river is also an important recreational boating and fishing resource. A 2011 socioeconomic study estimated that the DRB contributes roughly $25 billion ($10^9) in annual economic value from recreational, water quality, water supply, ecotourism, agricultural, and port benefits and is responsible for more than 600,000 jobs and $10 billion ($10^9) in wages (Kauffman, 2011). The Delaware contributes to the water supplies of New York City and Philadelphia, and to parts of central New Jersey that are outside the basin. It provides aquatic habitats that are crucial for wildlife throughout its reaches, ranging from the trout of the upper river to the oysters of Delaware Bay.

While water policy very directly impacts cold-water fish species that reside in the upper Delaware region, the river also supports migratory fish, including the American shad, blueback herring, alewife, sea lamprey, American eel and shortnose sturgeon (National Park Service, 2012). It is home to aquatic invertebrate and freshwater mussel species including the federally endangered dwarf wedge mussel (National Park Service, 2012). The trout of the upper Delaware, in particular, feed on various species of aquatic insects, the survival of which is highly dependent on sufficient water flows (Elliott, 1998). Moreover, the Delaware indirectly supports non-aquatic fauna, such as black bears, bald eagles, and ospreys (National Park Service, 2012). Water storage reservoirs built by New York City on the headwaters upstream of these habitats divert water out of the basin, thereby modifying upper river flows and directly impacting the aquatic insects and cold-water marine life, and potentially affecting other wildlife as well.

In the New York City metropolitan area, more than 9 million people (about one-half of the population of New York State) are served by the City’s upstate reservoirs in Westchester County, the Catskill Mountains (Hudson River drainage) and the Delaware drainage of the Catskills. Roughly 50% of the inflow to the City’s three upper Delaware reservoirs (Pepacton, Cannonsville, and Neversink, which are frequently referred to in official documents as the PCN reservoirs) is diverted out of the Delaware Basin to the City, and these diversions constitute about 50% of the City’s needs. Mandated releases into the river from the PCN reservoirs are intended to meet multiple downstream objectives, including notably protecting the water supply well downstream for Trenton, Philadelphia and much of central New Jersey, and supporting the cold-water fisheries below the dams. Since 1932, the primary water policy/water management issue on the Delaware has been and remains today, how to balance the diversion needs of New York City, the interests of down-basin stakeholders and the needs of the aquatic ecology downstream of the reservoirs. It is worth noting that to a large extent, the internationally
renowned ‘tail water’ trout fishery below the PCN reservoirs is the direct result of the cold-water bottom releases from the dams (Sheppard & Karat, 1978; Caucci, 1998).

We review and discuss, largely from the viewpoint of the impact on upper river aquatic ecology, the evolution of PCN reservoir release policies. Our analysis starts with the framework set out by the 1954 Supreme Court decree (347 U.S. 995 (1954)) that governs much of Delaware water policy and continues to the
signing of the Interstate Delaware Compact of 1961, which established the Delaware River Basin Commission (DRBC) as a regulatory and supervisory body. We then move on to discuss the ‘Good Faith Agreement’ of 1983, a release policy modification among the decree parties that was motivated primarily by the 1960s drought of record. We follow this with a discussion of the development of DRB’s current Flexible Flow Management Program (FFMP), which incorporates the technology of New York City’s recently developed computer-based Operations Support Tool (OST) algorithm. Kolesar & Serio (2011) presented a thorough description of the development of the initial 2007 version of the FFMP and the improvements that it was designed to make, including the details of the underlying model. The Joint Fisheries White Paper (official title: ‘Recommended Improvements to the FFMP for Coldwater Ecosystem Protection in the Delaware River Tailwaters’) of 2010 assessed the impacts and shortcomings of the 2007 FFMP and made recommendations that led to its subsequent 2012 revision (New York State Conservation Department [NYSDEC] & Pennsylvania Fish & Boat Commission [PAF&BC], 2010). Amplifying these works, and adding a broad policy context, our review goes back to examine the history of the Delaware release policies prior to the FFMP, and then extends the picture to include the modifications to the FFMP made since 2007, most notably the incorporation thereto of the City’s OST algorithm in 2011 (NYCDEP, 2011). We then statistically assess the trends in the annual reservoir storage levels, releases, spills into the river, water diversions to New York City and a system risk metric, the number of ‘drought days’ for the PCN reservoir system, using the Mann–Kendall non-parametric trend test (Mann, 1945; Helsel & Hirsch, 2002). We also conducted a non-parametric rank sum test to verify whether the differences (before and after the FFMP) in the 7-day low flows (a measure of the ecological health of the river) below the dams are statistically significant. We conclude with a discussion of open issues on the River including the current Delaware water policy stalemate among parties to the 1954 Supreme Court Decree, who collectively hold the decision rights on Delaware water allocations.

Section 2 is a brief overview of the DRB and the evolution of New York City’s water supply system. Section 3 discusses consequences of the 1954 Decree and the nine subsequent DRBC-administered revisions to the Delaware release policies, along with modifications via the Good Faith Agreement of 1983, focusing on the impact that these policies have had on the aquatic habitat of the upper Delaware. Section 4 discusses the evolution of the FFMP from 2007 to 2015 and its impacts. Section 5 presents a quantitative analysis of the reservoir storage levels, releases and spills, the number of drought days and the 7-day low flows below the reservoirs. Finally, in Section 6, we present the summary, conclusions, and future directions, including a discussion of the 2011–2016 policy stalemate.

2. Some background and early history

Before 1830, the residents of New York City relied on local water sources. By 1830, faced with declining water quality and a growing population, the City turned beyond its local resources to the Croton River of Westchester County for additional supply, and when in the early 20th century it needed more water, it then turned to New York State’s Catskill mountains (Endreny, 2001). The City’s original Catskill reservoirs were in the Hudson River drainage basin, as is the City itself. By the 1920s, the City, though itself not in the DRB, looked to the Delaware to quench the thirst of its rapidly growing population. However, in 1929, New Jersey brought suit in the US Supreme Court to prevent New York City from using the waters of the Delaware (Endreny, 2001). In resolving this case, entitled State of New Jersey vs. State of New York and New York City, (283 U.S. 336 (1931))
the court permitted the City to build two dams (Pepacton and Neversink), and to divert an average of 19.3 m$^3$/s from the basin (stated as 440 million gallons of water per day (MGD) in the order) with the provision that it maintains a minimum discharge of 43.47 m$^3$/s (stated as 1,535 cubic feet per second (CFS) in the decree) at the United States Geological Survey (USGS) gage on the Delaware at Montague, New Jersey (283 U.S. 336 (1931), DRBC, 2013). There was no representation of the environmental interests during the 1931 case, nor were there any specified provisions for ecological flows in the decree. There is little documentation concerning the environmental impacts of the dams in the interim until the 1960s (New Jersey Department of Environmental Protection (NJDEP), personal communication).

Disputes over water rights on the Delaware go back to colonial times and their continuance since then in no small part explains why the Delaware remains undammed along the 330 miles of its main-stem to this day (Weston, 1989; Albert, 2005). Motivated in part by a severe Delaware flood in 1955, the federal government in 1965 proposed an ambitious multipurpose *Tocks Island Dam Project* to be located between the Delaware Water Gap and Port Jervis, New York. The dam and the resulting reservoir would, in addition to flood control and recreation, be used to generate hydroelectric power, and some of the water in the reservoir would be pumped to supply water to New York City and Philadelphia. A formidable environmental coalition soon opposed the project. A re-analysis of the local geology questioned the soundness of the proposed structure, and its economic rationale was questioned as well. With Congressional support evaporating, the DRBC, in 1975, voted to disapprove the Tocks Island Project and hence the constraints on water supply on the Delaware would remain essentially fixed into the foreseeable future, leaving the Delaware to run free from the PCN dams on its headwaters to the sea to this day (Felverson et al., 1976; Albert, 2005).

3. The Supreme Court Decrees of 1954, the Delaware Compact of 1961 and the Good Faith Agreement of 1983

The 1931 decree stood until 1952 when New York City, intending to build a third Delaware dam, petitioned the Court to increase its diversion of DRB water. New Jersey objected again and, with Pennsylvania and Delaware now joining the case, the Decree Parties – the States of Delaware, New Jersey, New York, and Pennsylvania, along with New York City – returned to Court. An amended decree, issued on June 7, 1954 and consented to by all of the Decree Parties, permitted the City to increase its diversions to 35.05 m$^3$/s (stated as 800 MGD in the decree), contingent upon the construction of the Cannonsville reservoir on the Delaware’s West Branch, and on the City’s maintaining a minimum discharge of 49.55 m$^3$/s (stated as 1,750 CFS in the decree) at Montague, N.J. This latter provision was meant to ensure adequate streamflow downstream and control Delaware estuary salinity (NJDEP, personal communication). The decree also permitted an out-of-basin diversion by New Jersey of 4.38 m$^3$/s (stated as 100 MGD in the decree) to central New Jersey via its Delaware and Raritan Canals. A River Master designated by the U.S. Geological Survey was appointed by the Supreme Court to administer the flow and diversion provisions of the amended decree. In addition to the River Master’s ‘directed releases’ which maintain the Montague flow target, the decree required that the City release into the Delaware an ‘excess release quantity’ (ERQ) of 83% of the volumetric difference between New York City’s total combined system safe yield and its expected coming year’s water usage – the release being made according to a complex seasonal pattern. A noteworthy provision of the 1954 decree enabled the
parties to petition the court for modification of the decree’s provisions at any time, notwithstanding their unanimous subscription to the decree itself (347 U.S. 995 (1954); Delaware River Basin Interstate Flood Mitigation Task Force, 2007; NJDEP, personal communication; Kolesar & Serio, 2011). While the 1954 decree laid out a broad framework for water allocation on the Delaware, many problems remained unaddressed, notably flood protection and down-basin water pollution. The interstate and the interjurisdictional setting was complicated and cumbersome. When the DRBC was created, some 43 state agencies, 14 interstate agencies, and 19 federal agencies had exercised a multiplicity of splintered powers and duties within the watershed (DRBC, 2010). These open issues and the severe flooding from two 1955 hurricanes led to the Delaware Compact of 1961, which was established by joint action of the legislatures of the four Decree Party states and the U.S. Congress (Albert, 2005). The Compact created the DRBC as an intergovernmental regulatory and supervisory body for the Delaware.

Although the DRBC nominally has authority over water allocation, its active powers are enormously curtailed by a provision in the Compact stating that no modifications of the water rights set out in the 1954 decree could be made without the unanimous consent of the Decree Parties. Moreover, the signatories to the Compact abrogated their rights under the 1954 decree to petition the court for modification of its provisions. Thus, while creating an instrumentality for interstate collaboration, the stage was set in the 1961 agreement for the water policy stalemate of 2010 to 2016 – a dilemma that shall be discussed subsequently. In effect, the Compact granted to each of the decree parties an ironclad veto on any modifications to water release policy.

The diversion allocations, flow targets and release rules of the 1954 decree proved deficient during the historical drought of 1961–1967, the so-called ‘drought of record’, during which it was impossible for New York City to divert its 35.1 m$^3$/s (800 MGD) guarantee from the PCN reservoirs and simultaneously satisfy the flow requirement at Montague (DRBC, 2013). Additionally, it became obvious that the Supreme Court ruling had not considered the need for ‘conservation releases’ (DRBC, 2013) to ensure that aquatic life would not be endangered by low flows or excessive water temperatures. As there was not a strong environmental movement in the upper Delaware at the time, it is not surprising that no consideration was given in the 1954 decree to maintaining adequate ecological flows in the upper River. Recall that the main motivation for the Montague flow target constraint was salinity protection for Trenton. A shortcoming of the decrees’ target was that maintenance of a 49.55 m$^3$/s (1,750 CFS) flow some 100 km (60 miles) downriver from the dams at Montague was not itself sufficient to protect the upper River since inflows between the dams and Montague could meet the target even while the upper stretches of the river were starved of water. Although minimum conservation flows were not prescribed in the Decree, an informal ‘gentleman’s agreement’ between the City and New York State Conservation Department (NYSDEC) specified conservation flows equal to the minimum flow of record prior to the construction of the reservoirs. Such small conservation releases were paltry in comparison to the Montague guarantee and severely restricted the suitable aquatic habitat to very short reaches below the dams (Elliott, 1998). The inadequacy of these releases, together with the observation that the concomitant ‘hoarding’ of water behind the reservoirs resulted in predictably extensive and wasteful spilling each spring, led in 1976 to the passage of Article 15 Title 8 of New York State’s Environmental Conservation Law that included ‘augmented conservation releases’ for the PCN reservoirs, the so-called Part 671 releases (Elliott, 1998). Thereby, New York State unilaterally imposed a conservation policy on the City and, in effect, on the other Decree Parties as well. This law also established temperature targets of 23.9 °C (75 °F) as a daily maximum and 22.2 °C (72 °F) as a
daily average at the Callicoon, Harvard, Woodbourne and Hale Eddy USGS gages downstream of the PCN dams (see Figure 1), and further specified that these targets would be met by cold-water releases from a ‘thermal stress bank’ of 6,000 CFS-days of water to be administered by NYSDEC. Such ‘banks’ were not actual water, but rather ‘paper accounts’ to be called on when needed, provided that enough water was actually in the reservoirs. Over time, it would prove to be impossible to meet these targets with the amount of water thus allocated (NYSDEC & PAF&BC, 2010; Kolesar & Serio, 2011).

Since the New York State law’s higher conservation releases would reduce the amount of water stored behind the dams, the City and other Decree Parties objected, and New York City brought suit to block them. When follow-on studies by the NYSDEC and experience showed the beneficial ecological impacts and low risk of the new release rules, they were codified in the first DRBC official release policy following negotiations (DRBC Docket D-77-20 CP) and went into effect initially on an ‘experimental’ basis in May 1977 (Weston, 1989). NYSDEC had taken over from the City the responsibility of administering the conservation releases, and this continued until the June 1980 ‘stipulation of discontinuance’ of the lawsuit that the City had brought (NYS Supreme Court Index N. 5840/80). The implementation of these augmented release rules continued unmodified with annual extensions until the first major release rule revision; the so-called Revision 1 of November 1983 (DRBC, D-77-20 CP Revised). The negotiations that led to Revision 1 were closely linked to and happened in parallel with the Decree Party discussions that resulted in the ‘Good Faith Agreement’ of 1983.

Notwithstanding its mission to act as stewards of the basin’s water resources, and despite having specific responsibilities for instream flow management and integration of environmental and economic needs in the basin, the DRBC took no action with respect to the ecology of the upper River from the signing of the Compact in 1961 until compelled to act by New York State’s initiatives in 1977. In fairness, it must be stated that shortly after the signing of the Compact, the Decree Parties, and the DRBC were confronted with the severe drought of the early 1960s – a stress for which their systems were prepared.

In 1978, motivated by the inadequacy of the 1954 Decree framework to handle the 1960s drought of record, Decree Parties began negotiations that culminated in the unanimous ‘Good Faith Agreement’ of 1983 (Albert, 2005; DRBC, 2013). This Agreement, recognizing that the sustained yield of the PCN system was considerably less than had been calculated in the 1954 decree, recomputed the yield using the 1960s drought data and specified a staged set of diversion and release reductions based on reservoir storage conditions as specified by a set of seasonal ‘Operational Curves’ (p. 4 of the Agreement). For example, the standard New York City (NYC) diversion of 35.1 m$^3$/s (800 MGD), the standard NJ diversion of 4.38 m$^3$/s (100 MGD) and the standard Montague discharge target of 49.6 m$^3$/s (1,750 CFS) now only applied while reservoir storage was above the drought warning curve. If the storage fell below the drought warning condition, the NYC diversion would drop to 22.8 m$^3$/s (520 MGD), the Montague target to 31.2 m$^3$/s (1,100 CFS) and the NJ diversion to 2.85 m$^3$/s (65 MGD) (NJDEP, personal communication).

However, just as the protocols of the 1954 Decree were unprepared to deal with droughts, the Good Faith Agreement was unequipped to deal with the major floods of September 2004, April 2005 and June 2006 (DRBC, 2013). Moreover, from the viewpoint of the conservation community on the upper Delaware, even the Good Faith Agreement’s ‘augmented’ conservation releases were judged insufficient and decades of dispute would follow. For example, Kolesar & Serio (2011) document that on July 25, 2005, shortly after a major flood in April of that year, while the reservoirs were nearly full, and air temperatures were in the 30 °C range (86 °F), the conservation releases from the critical Cannonsville Reservoir were only 3.54 m$^3$/s (125 CFS), which led to lethal water temperatures for the trout in the upper Delaware.
The 1983 Good Faith Agreement also adopted the location-specific thermal targets that had been recommended by NYSDEC in 1977, and the thermal cold water bank to be used to achieve them was increased to 48,831,822 m$^3$ (12,900 million gallons) of water. Still, the thermal targets were often violated either because the banks were depleted early in the season or conservative water management, faced with uncertain weather over the remainder of the summer, would hesitate to make needed releases and the ‘thermal bank’ would go unused only to be wastefully spilled in the following spring (NYSDEC & PAF&BC, 2010; Kolesar & Serio, 2011). Years later, in 2010, the NYSDEC and Pennsylvania Fish and Boat Commission (PAF&BC) would cite the following reasons for the failure of the thermal bank method: (i) meeting temperature and/or flow targets involves combining weather forecasts, current stream conditions, models and experience to predict how much water must be released in advance to maintain targets; (ii) various interested parties have different ideas about when and how water should be released from a bank; and (iii) the thermal banks were too small.

In the interval from the DRBC’s first release policy, Docket D-77-20 CP of May 1977, through the adoption of the FFMP in September 2007, there were nine revisions of D-77-20. Except Revision 1 in November 1983, Revision 7 in May of 2004 and Revision 9 of September 2006, the changes were relatively minor adjustments of the conservation releases, thermal targets, and thermal/habitat protection banks. (An overview of the modifications, and the detailed modifications themselves are posted on the DRBC website and available for download at http://www.nj.gov/drbc/programs/flow/resolutions.html).

As detailed above, Revision 1 of 1983, implementing the recommendations of the Good Faith Agreement, made substantial modifications by lowering conservation releases if the basin moved into a drought warning or drought emergency condition. The important point is that Revision 1 was the last revision to be approved without an expiration date, and hence, could become the fallback release policy should the Decree Parties in the future fail to reach agreement on subsequent revisions or extensions, such as to the FFMP. This threat was implicit in DRBC release policy negotiations in 2010 and undoubtedly plays a role in the current 2012–2016 Decree Party release policy stalemate.

Revision 7 of 2004, the next significant change, made a number of substantial modifications in addition to its tweaking of the several Habitat Protection ‘banks’. There was now an Excess Release Quantity Bank, a Thermal Release Bank, a Supplemental Release Bank, and an Amelioration Bank, all of which were interrelated in a complex fashion with each other and with the ERQ that had been established in the 1954 decree. Revision 7 also established, subject to water availability in the Habitat Protection Bank, a new concept by setting minimum flow targets at Hale Eddy on the West branch, at Harvard on the East branch and at Bridgeville on the Neversink. This led to an adjustment of the reservoir Rule Curves that define the several drought conditions (Figure 1 of Revision 7). The Revision went on to recognize the impact on the upper Delaware of the City’s strong propensity to make almost of all the River Master’s directed releases with low-quality water from Cannonsville into the West branch while starving Neversink of releases. The Revision went on to take an explicit account of the impact of water releases from Lake Wallenpaupack into the Delaware during times of drought. The conservation release rules were becoming increasingly complex and gave an observer the impression of being held together with ‘chewing gum and baling wire’. The Decree Parties themselves recognized the unsatisfactory edifice they had evolved into, and in the preamble to Revision 7, stated their intention to develop a long-term program that ‘would be based upon sustainable sources of water, while considering overall needs in the tail waters below the city Delaware reservoirs and in the main-stem and in the bay’. NYSDEC was commissioned to conduct an evaluation and monitoring plan and provide the DRBC with
a number of scientific reports. The need to ultimately deal with the issue of the federally endangered
dwarf wedge mussel’s requirements was explicitly recognized, as was the intention to fund an update
of the so-called OASIS model, a computer simulation of Delaware River flows, (Phillips, 2004) (Despite
its ‘endangered’ status, the dwarf mussel issue had not been addressed at the time of writing in 2016.)

Although Revision 7 was intended to endure until May 31, 2007, nature intervened when the Dela-
ware suffered severe floods in 2005 and 2006 (Delaware River Basin Interstate Flood Mitigation Task
Force, 2007). Political pressure from the public and the governors of Pennsylvania and New Jersey led
to Revision 9 in 2006, which patched a ‘spill mitigation program’ onto the structure of Revision 7. This
was a program of increased releases from the PCN reservoirs whose goal was to achieve an 80% reser-
voir void from September 1 to February 1. (See Figure 1 of Revision 9.) The spill mitigation discharges
would be curtailed if River reaches were already flooded. Because the PCN reservoirs were not designed
for flood mitigation, the DRBC employed the euphemism ‘spill mitigation’ rather than ‘flood mitiga-
tion’. Naturally, flood mitigation is what the public desired.

Given the Rube Goldberg complexity of its release policy, the ongoing tension between the eco-

cological, New York City, and down-basin needs, and the now prominent issue of downstream flooding, the
DRBC recognized, as it stated in Revision 7, the need for a sustainable long-term solution to the water
allocation of the Delaware. Despite their commitment to developing a fundamentally new solution by
May 2007, between the signing of Revision 7 in April 2004, and the spring of 2006, no new analyses
or design activities had been undertaken by any of the Decree Parties. The official system was in paraly-
sis, and it was into this policy development gap that an outside fishery-oriented conservation coalition
would insert itself.

4. The FFMP of 2007–2011: design principles, PROS, and CONS

Frustrated with the inadequate conservation releases and the mind-boggling complexity of Revision 7,
the fishing voices continued to express deep dissatisfaction with the status quo during the decade of the
1990s and into 2004, complaining that base releases were too low and destructively variable. One very
vocal group, the Friends of the Upper Delaware, called for a simple parochial solution: ‘Just establish a
summertime minimum release of 600 cfs, [16.99 m³/s] from Cannonsville, with a winter minimum of
300 cfs’. That this proposal would put the PCN system into drought condition more than 30% of the
time and that reservoirs would seldom refill by spring was not recognized nor was it their concern (Full-
erton, 2004; Kolesar & Serio, 2011). In January 2006, recognizing the flaws of the current release
policies and realizing that a window of opportunity had been opened by the Decree Parties by their set-
ting a goal for a fundamental revision by May 2007, and intending to take advantage of the newly
available technical models of the Delaware, a coalition of four conservation organizations (The
Nature Conservancy, Trout Unlimited, The Delaware River Foundation and Theodore Gordon Fly-
fishers), with technical support from the Water Center of Columbia University, undertook a research
and advocacy project that culminated in the adoption of the FFMP by the Decree Parties. The develop-
ment of the FFMP, which relied heavily on collaboration between the conservation coalition and staff
from the NYSDEC, is detailed in Kolesar & Serio (2011).

The FFMP has gone through several revisions since its inception in 2007. In this section, omitting
details, we discuss the motivation behind the initial policy design choices made by the coalition in
2007, its actual performance since implementation and the modifications subsequently made. The
FFMP was developed from an operations research-based inventory management approach and the original model, known within the coalition and in presentations to the DRBC as the *Adaptive Release Framework*, was developed at Columbia University by Kolesar & Serio (2011) and Friends of the Upper Delaware River (2007). The designers’ goal was to provide maximal benefit to the aquatic habitats downstream of the NYC reservoirs without increasing drought risk to the City or the down-basin stakeholders. Detailed and extensive quantitative research was made possible by the prior existence of the aforementioned OASIS simulation model of Delaware flows and by the timely completion in 2006, while the project was already well underway of a USGS-developed model which converted OASIS-simulated Delaware River flows to estimates of aquatic habitat by species, by season and by river reach (Bovee et al., 2007). Having quantitative estimates of drought days (risk) and habitat areas (benefit) permitted the coalition to present specific cost-benefit trade-offs to the Decree Parties. They were thus able to demonstrate that the proposed FFMP rules could produce substantial benefit at little risk. Moreover, the recommended FFMP structure, by being substantially simpler than its predecessors, would be easier and more economical to manage. In a time of considerable budgetary stress on the agencies managing the Delaware, this was a strong selling point – perhaps the most telling one.

The FFMP model that was ultimately adopted by the DRBC in September 2007 utilized the *Adaptive Release Framework* in almost all particulars except that the Decree Parties, being more risk-averse, reduced the coalition’s recommended summer and spring Cannonsville releases. When implemented, the Decree Parties’ reductions in releases led to predicted habitat shortfalls and unnecessary spills, as compared to what could have been (NYSDEC & PAF&BC, 2010). However, even in its initial form, the FFMP proved an improvement over its predecessor’s release policies – though not without complaints from some in the fishing community (Fullerton, 2004).

We briefly describe the policy thinking behind the FFMP design. The FFMP, similar to its predecessors, aimed to follow the DRBC charge to:

*address[es] competing needs and uses, including safe and reliable water supplies to serve the needs of over 17 million people; drought management; flood mitigation; protection of the cold water fishery; a diverse array of habitat needs in the main stem river, estuary, and bay; and salinity repulsion (USGS, 2012).*

The FFMP design was based on two core principles and one major constraint. The primary design principle, one that was derived from industrial inventory theory and feedback control concepts, was that conservation releases should be tightly linked to the amount of water actually in storage, and consequently, FFMP releases would be larger when there was abundant water and smaller when reservoir storage levels were below a set of prescribed reservoir levels, the lowest of which was ‘drought emergency’. To avoid confronting the Decree Parties with too much change at one time, and to enhance the chances of approval of the FFMP, the FFMP’s rule curves were built on and amplified the familiar curves of Revision 7 – even though they were clearly suboptimal.

The second FFMP design principle, in recognition of the inefficacy and complexity of Revision 7’s cumbersome system of banks, temperatures and flow targets, was to eliminate them! The designers knew that this provocative choice could expose the upper river to some risk, but their analytically-informed view was that the risk was not significant and could be managed, though not entirely avoided. The coalition’s mantra, frequently touted to the fishing community to gain their support, was ‘We’ll do our best with the base releases, but then let’s let the River be a river’.
The FFMP’s release parameters were constrained by the Decree Parties’ dictate for ‘drought-risk neutrality’. That is, the Parties required that the predicted number of days during which the reservoir storage would be at or below ‘drought watch’ under the FFMP could not exceed the drought days under Revision 7. These risk metrics were to be estimated by OASIS-generated daily hindcasts over the historical period of record from 1/1/28 to 9/30/00. This was a telling constraint: The research team and their NYSDEC collaborators recognized that it was not possible to adhere to this constraint and provide thermal protection on the main-stem Delaware under all conditions. A priority was placed on maintaining suitable summertime water temperatures and year-round habitat in the West Branch, in the upper sections of the East Branch and the upper sections of Neversink River. This point is treated extensively in the Joint Fisheries White Paper (NYSDEC & PAF&BC, 2010; The Joint Fisheries White Paper, 2010). Additionally, to reduce the likelihood of reservoir spilling during major storms or sudden thaws, the discharge mitigation component of Revision 9 was continued in the FFMP (USGS, 2012).

The FFMP was implemented on October 1, 2007, and two minor modifications were made before its expiration on May 31, 2011. In assessing its performance and impacts, two aspects must be considered: the overall statistical metrics of flows, temperatures and the like as evaluated by scientists and river managers on the one hand, and the on-the-river informed views of fishermen, boaters, homeowners and other interested parties. Overall, scientists were pleased with the performance of the FFMP in some regions of the upper Delaware. The NYSDEC and PAF&BC in their 2010 White Paper state that water temperatures in the West Branch down to Hancock, NY and in the upper sections of the East Branch and the Neversink (the areas of priority mentioned above) remained suitable for cold-water species and organisms, even when summer air temperatures exceeded 32.2 °C (90 °F) in June of 2008. However, they also pointed out that summer water temperatures rose enough to stress the main-stem’s trout severely. Furthermore, precipitation patterns along the upper Delaware played a role: during August and early September of 2008, there were no River Master directed releases, and the late summer flows on the West Branch were the lowest that had been recorded in 30 years. Over the rest of the year, flows were marginally better in the West Branch than they were under Revision 7 (NYSDEC & PAF&BC, 2010). Both Kolesar & Serio (2011) and the NYSDEC and PAF&BC in their 2010 White Paper agree that year-round releases were below where they needed to be to support healthy aquatic habitats in the upper River, and both advocated that base releases be revised upward. The White Paper specifically states that ‘the FFMP release schedule does not provide acceptable year-round flows for habitat protection, and temperature in certain segments of the main-stem will frequently exceed desirable levels’. They go on to assert that the maintenance of good flow is necessary for fish spawning, egg incubation and fry hatching.

Kolesar & Serio (2011), who were the program’s founding fathers, had campaigned from the outset for higher releases than those in the 2007 FFMP. Their recommended release schedule, called the CP2 model, differed from those of the 2007 FFMP framework as follows: (i) whereas the FFMP called for a 7.08 m³/s (250 CFS) summer release from Cannonsville, CP2 called for 9.91 m³/s (350 CFS), and (ii) whereas the FFMP called for a Cannonsville spring release of 5.09 m³/s (180 CFS), CP2 called for 7.08 m³/s (250 CFS)). Indeed, OASIS simulations and the USGS habitat model estimated that trout and American shad habitat would increase by roughly 150% in the main-stem Delaware under CP2 while the drought-risk to New York City would increase by barely 4% (Kolesar & Serio, 2011).

In June 2009, the DRBC increased the reservoir releases to nearly match those recommended by the CP2 model and by the White Paper. FFMP performance improved during its second year of implementation. During the summer of 2009, due to the flood-mitigation component of the FFMP, there was no
flooding along the Delaware despite excessive precipitation. However, flooding was widespread in waterways neighboring the Delaware in the northeastern US.

We will now examine some additional expected benefits of the FFMP. The information in the following paragraphs summarizes the assessment found in Kolesar & Serio (2011).

**Economic benefits.** Extrapolations from a 1996 study for Delaware County, New York (home of the Cannonsville dam and the West Branch of the Delaware) to the larger upper Delaware region in the year 2010 imply an important increase in economic activity on the local economy, namely, an overall increase in economic activity due to improved fishing conditions by $84 million. The improved fishing results since the higher releases yield: a better quality of, and an increased number of fishable days during the prime two-month spring fishing season, an extension of the fishing season into the summer, and an extension of the trout habitat further downstream.

**Flood mitigation.** The FFMP higher base releases result in lower average reservoir levels, with particular efficacy at the end of the summer season. This reduction is amplified by the spill mitigation component. As mentioned above, the Delaware did not flood in 2009, a year during which neighboring waterways suffered badly from flooding.

**Recreational benefits.** With fewer low-flow days, recreational boating/kayaking/canoeing, etc., becomes a more pleasant and enjoyable experience, benefiting the local economy and local canoe and rafting liveries.

Finally, as mentioned above, the FFMP decreases administrative complexity and has allowed for a modest reduction of administrative staff—at least within NYSDEC.

With minor revisions, the FFMP has been extended on a provisional year-by-year basis since 2007, the latest extension being due in 2016, at the time of writing this paper. A substantial revision in 2011 addressed a fundamental shortcoming of the FFMP that stemmed from another design constraint that had been imposed by the Decree Parties; namely that all design modeling must assume that New York City would always divert its full allowable 35.1 m³/s (800 MGD) diversion, even though it was well known that actual diversions over the prior decade had averaged about 25.1 m³/s (550 MGD) and were not projected to increase over the foreseeable future. By imposing this worst-case scenario constraint, the Decree Parties effectively forced the wasting of water. By assuming that water would be diverted even though it would not be, and thereby holding it behind the reservoirs in summer, that water would spill in the following spring to no one’s benefit. The Decree Parties even refused to permit a presentation of any analyses based on more realistic diversion scenarios.

Extending the analysis they had done in the original FFMP design to more realistic City diversion scenarios, Kolesar and Serio showed that realism about diversions would lead to substantially superior release policies. Their policy modification, called the ‘augmented FFMP’, was presented to the DRBC in January 2008 (Kolesar & Serio, 2008). The immediate reaction was that ‘The City will not even discuss such a proposal’. Yet, four years later, the concept of keying releases to anticipated actual diversions was incorporated into the 2012 FFMP when it was augmented as part of the City’s Operational Support Tool (OST) (DRBC, 2015; NYCDEP, 2012).

The OST is a complex set of water allocation and forecast algorithms whose original mission was to assist the NYCDEP in managing water turbidity issues in its (non-Delaware) Catskill reservoirs, such as the Ashokan reservoir. The OST periodically, say weekly, generates forecasts of anticipated water inflows to the PCN reservoirs from the current date forward to the end of the water year (June 1 for the PCN system). It also provides an estimate of the expected City diversions from the PCN reservoirs from the current date to the end of the water year. Given the total storage in the PCN system on the
current date, and the targeted end-of-year storage (typically having full reservoirs), the OST computes the quantity of water available for release over the rest of the year, and uses this to guide its choice of the FFMP releases to be made. Such computations are posted on the Office of the Delaware River Master’s (ODRM) website (http://water.usgs.gov/osw/odrm/) whenever the FFMP/OST changes from one release table to another. Since the OST-augmented FFMP began being implemented in June 2011, such postings have appeared approximately monthly. Because the OST’s forecasts permit a more realistic assessment of water availability, the OST should theoretically make it possible to achieve higher conservation releases than would be possible under the rigid and unrealistic assumptions of the continual 800 MGD diversions. Our analysis in Section 5 of this paper indicated that this has been so, and statistical analysis of the OST summary postings on the ODRM website since June 2011 has revealed that additional PCN water is available for conservation usage, even beyond the releases made. This water availability estimate supports the current goal of the conservation community to have a thermal relief program implemented in the upper Delaware (to be discussed in Section 6, Conclusions). Such a program could mitigate the episodes of thermal stress that still occur in the upper River despite the advances in release policy brought about by the FFMP (Kolesar et al., 2012, 2015). This latest DRBC release policy, now called FFMP-OST, holds the promise of further improving the ecological health of the upper River, as it uses water more carefully.

5. An analytical review of the release policies

5.1. Exploratory analysis of the reservoir data

An exploratory data analysis was performed to evaluate whether the improvements intended by the FFMP policies occurred. Data describing the drought criteria rule curves over a reservoir ‘water year’ (June 1 to May 31 of the following year) are obtained from the Delaware River Master (FFMP, 2015) and shown in Figure 2. These four curves delineate the reservoir storage zones and represent the drought threshold levels for the system. The corresponding drought zones are designated L2 to L5 representing normal (L2), drought watch (L3), drought warning (L4), and drought emergency (L5) conditions. L2–L5 rule curves are used to maintain adequate storage at all times to ensure New York City’s 35.1 m³/s (800 MGD) by controlling downstream flow release. The release rate for the reservoirs is dictated by how the combined storage of the reservoirs lies in relation to the rule curves. Data for the Cannonsville, Pepacton and Neversink reservoirs from the DRB reservoir system were obtained from the New York City Department of Environmental Protection and used here. The dataset, running daily from January 1, 1982 to March 31, 2010, includes observed storage levels, diversions, conservation releases, directed releases, and spills – all in millions of gallons per day (MGD) – for each reservoir. We defined a yearly cycle beginning on April 1 of each year, which allowed us to include all of the data from 2010 as part of one complete annual cycle without compromising any of the critical summer season (June through August) data from any of the years on record. Hence, we have 28 complete yearly cycles. The given US customary units (MGD) were converted to SI units of cubic metres per second. Diversion releases, labeled as ‘NYC Diversions’ in Figure 3, are controlled out-of-basin discharges for New York City consumption. Conservation releases are controlled releases from the reservoir for maintaining a sufficient flow rate of water for downstream ecosystems and marine life.
The data for observed storage, spills, conservation releases and diversions for each of the three reservoirs were added and subsequently averaged over each of the 28 years. The general procedure is to discern trends in the storage levels, spills, conservation releases, diversion releases and percentage drought days and compare the directionalities between the pre- and post-FFMP eras. Figure 3 shows the time series of the annual average storage, releases and spills and the percentage drought days along with the LOWESS (LOcally WEighted Scatterplot Smoother) smoothed mean estimated time series using robust local linear regression (Loader, 1999). The LOWESS technique performs a weighted linear least squares regression using the data within a pre-defined neighborhood of the datum value being smoothed as the covariates of the regression while treating the datum value itself as the response. The smoothing coefficient was chosen to be 0.3, which means that at each step, we utilized 30% of the data (or roughly 9 years) to smooth. This coefficient was chosen among several different candidates as it was found to avoid the pitfalls of over-smoothing and insufficient smoothing. Hence, the critical trends are observable in these smoothed time series. We also assess the monotonic trends in the average reservoir storage, releases and spills and the percentage drought days using the Mann-Kendall non-parametric trend test (Mann, 1945; Helsel & Hirsch, 2002). The Mann-Kendall test is a rank-based test that is typically used for detecting trends in the data with no assumption of the underlying distribution of the data (Helsel & Hirsch, 2002). Results (slope (τ) and the p-value) from the test are presented in Table 1.

Figure 3(a) shows a steady, but not consistently, increasing trend in the average reservoir storage during the pre-FFMP era, indicating that before the implementation of the FFMP, an insufficient amount of water was being released from the dams and as a consequence, more water was held in storage. This was due to conservative release policies that, as discussed before, were heavily concerned with holding more than enough...
water to supply New York City. This trend is seen to increase the most between 2001 and 2006 and begins to diminish and stabilize after that in the post-FFMP years. The Mann-Kendall tau (slope), which is significant at 99% confidence interval, provides evidence for a monotonically increasing average storage in the reservoir over the last 28 years. Similarly, Figure 3(b) shows an initially increasing and then steady decreasing trend in New York City diversion releases before the year 2007, when the FFMP was implemented. In the post-FFMP era, this trend continues to decrease. This decreasing trend is also revealed through the Mann-Kendall test, which shows a negative slope that is statistically significant at 99% confidence interval. This indicates an

Table 1. The results of the Mann-Kendall trend test for each of the time series listed (McLeod, 2011).

<table>
<thead>
<tr>
<th>Time series</th>
<th>Tau test statistic value</th>
<th>2-sided p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual-Averaged Total Observed Storage</td>
<td>0.349</td>
<td>0.0096506</td>
</tr>
<tr>
<td>Annual-Averaged Total Spills</td>
<td>0.206</td>
<td>0.1282</td>
</tr>
<tr>
<td>Annual-Averaged Total NYC Diversion Releases</td>
<td>-0.471</td>
<td>0.00047069</td>
</tr>
<tr>
<td>Annual-Averaged Total Conservation Releases</td>
<td>0.455</td>
<td>0.0007292</td>
</tr>
<tr>
<td>%-Drought Days</td>
<td>-0.367</td>
<td>0.012339</td>
</tr>
</tbody>
</table>

Statistically significant slope parameters at >95% confidence interval are shown in bold font.
understanding that the amount of water allocated (35.1 m$^3$/s or 800 MGD) for release to New York City was far more than the actual usage and, even before the FFMP, these releases were duly decreasing. Improvements in infrastructure, various conservation efforts and increasing water rates have led to reduced water consumption in the City and hence reduced diversions from the reservoirs.

The spills from the three reservoirs follow a noticeable increasing trend between 2001 and 2006, but sharply decline after 2006 and this declining trend continues into the FFMP era. Conservation releases, illustrated by the orange time series in Figure 3(b), are consistently low for most of the pre-FFMP period, and only increase after the year 2001, towards the end of the pre-FFMP years. This increasing trend continues into the post-FFMP years, indicating that a concern for the welfare of the downstream marine life existed before the implementation of the FFMP. This concern was reflected in the FFMP as well, and conservation releases have continued to increase. This trend is also revealed through the Mann-Kendall test. Finally, Figure 3(c) shows the time series of the percentage drought days per year. We define drought days as the total number of days when the reservoir storage is less than the L2 criterion. We see a decreasing trend that is gradual but virtually persistent until the implementation of the FFMP, at which point the percentage drought days becomes zero.

5.2. Hypothesis test on downstream low flows

In addition to investigating the trends in the release data from the reservoirs, we also conducted a hypothesis test on the summer 7-day low flow data for the four primary monitoring gages downstream (Hale Eddy, Harvard, Bridgeville and Callicoon). We obtained the flow data from the USGS National Water Information System. We computed the 7-day low flow for the summer months of June, July and August for each station. The 7-day low flows, the smallest values of mean discharge over a consecutive 7-day period, is a common method for estimating the low-flow magnitude and a measure of water quality and ecological health (Smakhtin, 2001). We use the non-parametric Wilcoxon Rank Sum test (Hollander & Wolfe, 1973) to verify whether there is a significant change in the low flows below the reservoirs post-FFMP when compared to the pre-FFMP period. The rank sum test is used to test the null hypothesis that the two population distribution functions corresponding to the two random samples (pre-FFMP and post-FFMP) are identical against the alternative hypothesis that they differ by location (Helsel & Hirsch, 2002). Through this method, we test the statistical significance of a change in properties of a time series of the low-flow data before and after the institution of the FFMP. Table 2 presents the W-statistic and the corresponding p-values for the four stations. It indicates

Table 2. The results of the Wilcoxon Rank Sum hypothesis trend test for low flows before and after FFMP’s institution (R Core Team, 2014).

<table>
<thead>
<tr>
<th>Station</th>
<th>(X_{1967-FFMP})</th>
<th>(Y_{Post-FFMP})</th>
<th>Wilcoxon Rank-Sum Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n_1)</td>
<td>(n_2)</td>
<td>(W\text{-Statistic})</td>
</tr>
<tr>
<td>Hale Eddy</td>
<td>40</td>
<td>9</td>
<td>47</td>
</tr>
<tr>
<td>Bridgeville</td>
<td>14</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Harvard</td>
<td>30</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Callicoon</td>
<td>32</td>
<td>9</td>
<td>46</td>
</tr>
</tbody>
</table>

The \(p\)-values are shown in bold font.
that the null hypothesis, which states that there is no difference in the low-flow data before and after the policy institution in 2007, can be rejected in favor of the alternative hypothesis, which states that the FFMP policy altered (increased) the low flows below the reservoirs. We present the data distributions before and after the implementation of the FFMP in Figure 4 as boxplots. We can see that there is a definite increase in low flows post-FFMP. However, it should also be noted here that precipitation in the region has trended upwards since the 1960s drought of the century (Burns et al., 2007), and some of the increases in the flows may be attributed to the general upward trend in rainfall.

6. Summary, open issues and a policy stalemate

The narrative of our paper has described the long series of negotiations and agreements regarding Delaware release policies since the 1954 Supreme Court decree, concluding with the complex FFMP/OST of 2015. There emerges a theme of increasing concern for the environment of the upper River, coupled with an increasing sophistication of the release rules’ heavier reliance on quantitative scientific analysis. The quantitative section of the paper indicates both long-term and immediate-term patterns of improving water availability for the ecology of the upper Delaware. Both the narrative and the analysis suggest that to a considerable extent the stated goals of the FFMP, to revise the previous release policies, to better sustain the fisheries and aquatic habitat downstream of the dams and to mitigate potential flood impacts in the basin without increasing the drought risk to the City, have been achieved.

While willingness to change policy has been demonstrated between 1954 and 2010, the inability of the Decree Parties to agree on any modifications to the FFMP since the 2010 incorporation of the OST is, we believe, indicative of deep unresolved problems. To illustrate, we list some outstanding issues.

Fig. 4. Boxplots comparing low flows before and after the FFMP’s institution for the four lower basin streamflow stations (R Core Team, 2014).
An environmental issue that has been on the agenda for the DRBC for some 20 years is responding to the ecological needs of the federally endangered dwarf wedge mussels that reside in the upper Delaware. As an endangered species, the dwarf wedge mussel requires protection and the DRBC has committed to attend to this issue. However, no progress has been made to date.

In addition, the fishing community, while continuing to press for increased conservation releases above the FFMP-OST levels (Pettinger, 2012), have also identified two immediately pressing issues for which they argue that feasible solutions have been identified and presented to the DRBC. The first and simplest issue is that by rigidly following the dictates of the 1954 Decree on meeting the Montague flow target with precision, the River Master frequently calls for sudden drops in directed releases, which can be very destructive to the habitat. A more gradual ramping down of the directed releases over some days would more closely imitate what happens in nature, avoiding the sudden de-watering of the river that now occurs. It would easily solve the problem at a minuscule ‘cost’ in increased reservoir releases. The issue has been identified for at least four years, and a concrete proposal has been presented to and discussed within the DRBC. However, no action has been taken.

The second, and more complicated issue is that despite the FFMP’s increased base conservation releases, water temperatures in the upper River can rise to lethal levels for the trout. Based on findings that such trout-stressing temperature episodes can often be predicted days in advance, that a statistical calibration indicates the amount of additional cold water required to mitigate them, and that in all but the most severe cases this water is, in fact, available, a framework for amelioration has been presented to the DRBC for implementation (Kolesar et al., 2012). Again, no action has been taken by the Decree Parties. Further development of a thermal relief algorithm is also one of our current research activities.

Several of the Decree Parties have informally recognized the desirability and feasibility of action on both the ramping and thermal relief issues, yet these two proposals are stymied. This is indicative of a larger dilemma: There has been a water policy stalemate on the Delaware since at least 2010. At the December 3, 2015 public meeting of the DRBC’s Regulated Flow Advisory Committee (RFAC), the source of the stalemate was revealed as a disagreement (predominantly) between the State of New Jersey and New York City. New Jersey wants a permanent end to the restrictions on its 100 MGD diversions during drought, restrictions that were negotiated in the Good Faith Agreement. Furthermore, New Jersey, feeling that its water needs were not fairly met in the Good Faith Agreement, is calling for a complete reassessment of New York City’s water supply resources. To obtain satisfaction on its requests, New Jersey stated that it is blocking approval of any modifications to the Delaware release rules, however beneficial – including the two issues mentioned above (New Jersey Department of Environmental Protection (NJDEP), 2014; Ramie, 2015). Should there be no agreement among the Parties, the Delaware release policy could revert to Revision 1 of 1983 – to the detriment of the environment.

Just below the surface are enormous financial stakes for both parties. New York City has depended heavily on the relatively cleaner water from its Delaware reservoirs (PCN) to avoid the need to filter the frequently turbid water available from its Hudson River drainage Catskill reservoirs. Maintenance of its federal filtration avoidance determination has motivated the City’s investment of millions of dollars in its OST system. It has been estimated that, should the City lose its federal filtration avoidance determination, it would have to invest in the order of $10 billion (10^9) in filtration facilities. On the other hand, New Jersey wishes to avoid making investments to increase its water resources and storage facilities (NJDEP, 2014). The provisions of the Good Faith Agreement, which force unanimity among the Decree Parties on any modification to the 1954 Decree’s apportionment rules, and its stipulation that
they abandon their rights to return to the Court for redress, appear to lock the Parties into a perpetual stalemate.

Another symptom of the conflict of interest between New York City and in-basin Delaware stakeholders is the issue of the City’s use of water from its Croton reservoirs. After an investment of more than $3.2 billion (10^9) in an improved filtration facility, water from the Croton system now meets federal water quality standards and means an additional 290 MGD of high-quality water is available to the City. How much of the available capacity will be used by the City, thereby alleviating some demand for Delaware water, remains to be seen. The City appears to be reluctant to use its new Croton plant near its capacity because of the cost of operating the pumping and filtration plant.

And so, in 2016 the Decree Parties and the DRBC face many critical issues without a clear path toward resolution. And, in contrast to 1954 when little emphasis was placed on the River’s ecology, the environment of the upper River now has multiple voices. Since 2015 two environmental coalitions: The Upper Delaware River Tailwaters Coalition, a political advocacy coalition of the towns and villages below the PCN dams coordinated with the fishing oriented Friends of the Upper Delaware, and the Coalition for the Delaware Watershed, a constellation of some 40 environmental organizations whose interests include the entire Delaware River from its sources in the Catskills all the way to the Delaware Bay, have been making themselves heard.

Acknowledgements

James Serio, founder of the Delaware River Foundation, has kindly shared his expertise and experience on the River and provided access to his extensive archive of Delaware release policy documents. Dr. Durbhakula Muralidhar, retired from the New York State Department of Environmental Conservation, who was directly involved in the design and administration of the Delaware release policies from 1977 until his retirement 2008, generously shared his experiences and insights.

This research was supported by:

(a) National Science Foundation grant 1360446 (Water Sustainability and Climate, Category 3).
(b) Professional Staff Congress – City University of New York award 67832-00 45.
(c) City University of New York – Collaborative Incentive Research Grant award 80209-13 21.
(d) National Oceanic and Atmospheric Administration – Cooperative Institute for Climate and Satellites – Maryland award 76514-05 01.

The statements contained within the manuscript/research article are not the opinions of the funding agency or the U.S. Government but reflect the authors’ opinions.

References


Received 31 July 2015; accepted in revised form 30 April 2016. Available online 29 June 2016