Water Policy 15 (2013) 364–385

Adaptive management and governance of Delaware River water resources

Lynn A. Mandarano[a] and Robert J. Mason[b]

[a]*Corresponding author. Community and Regional Planning, Temple University, 580 Meetinghouse Road, Ambler, PA 19002, USA. E-mail: lynn.mandarano@temple.edu*

[b]*Geography and Urban Studies, Temple University, 316 Gladfelter Hall, Philadelphia, PA 19122, USA*

Abstract

This paper articulates the complexities of adaptively managing Delaware River water resources to meet shifting priorities of drinking water supply, drought mitigation and flood mitigation, as well as conflicting stakeholder interests. In particular, the paper examines the short-term and long-term programs that comprise the Delaware River Basin Commission's (DRBC) and the 1954 US Supreme Court Decree parties' successful adaptive management approach that seeks to balance the growing list of demands for water resources management, including drinking water supply, drought management, flood control and cold water fisheries protection. Review of the DRBC's adaptive governance approach reveals the critical complexities of designing experimental, yet science-driven management approaches and effectively engaging various sets of stakeholders in the associated decision-making processes.

Keywords: Adaptive management; Interstate compacts; River systems; Water policy; Water resources management; Water-use conflicts

Introduction

The Delaware River basin, which is modest in size compared with other interstate watersheds, is of outsized importance to the states of New York, New Jersey, Pennsylvania and Delaware. These states depend on the river's fresh and estuarine waters as a resource for electricity generation, drinking water, agriculture, manufacturing, fisheries, navigation, recreation and other needs. The major upstream user is New York City (NYC), which maintains a system of water-supply reservoirs in the headwaters located in the Catskill Mountains, in south eastern New York State. Management of the Delaware River is governed by the Delaware River Basin Commission (DRBC), which was created by compact legislation in 1961. The Flexible Flow Management Plan (FFMP) negotiated between the 1954 US Supreme Court

doi: 10.2166/wp.2012.077

Decree parties[1] (decree parties or parties), provides for the adaptive management of NYC's Delaware basin reservoirs to address multiple competing issues, including water supply, drought management, flood mitigation and habitat protection.

The occurrence of three extreme floods between 2004 and 2006 – a 'surprise' confluence of hazardous events responsible for millions of dollars of cumulative damages – opened a window of opportunity to evaluate how to manage the Delaware River basin to address flooding. In response to the recurring flood crisis, interest groups have mobilized at a range of scales from the small, but vocal citizen organizations of flooded property owners to the more formal task force, which has been created at community, county, state and regional levels. Those closest to the inundated areas tend to favor maintaining voids (i.e. maintaining reservoirs levels at 80% capacity and thereby provide 20% of reservoir storage capacity for flood mitigation) in the NYC reservoirs to reduce the potential for spillover events, whereas the various task forces propose a multipronged approach including, for example, operating the reservoirs for flood management, creating basin-wide floodplain regulations and implementing structural flood controls. In addition, the DRBC, which needs unanimous approval from the decree parties to modify decree-mandated operations of NYC reservoirs, has convened a regional task force and has procured studies directed toward providing a sound scientific basis for determining optimal reservoir release schedules.

This paper articulates the complexities of adaptively managing and governing the basin to accommodate shifting priorities of drinking water supply, drought mitigation, flood mitigation and habitat protection and conflicting stakeholder interests. In particular, we examine the short-term and long-term management perspectives espoused by the various actors, the rationales for their positions and the DRBC's and decree parties' responses to calls to raise the level of priority for flood mitigation, all within the context of long-term implications for watershed management.

Sustainable water resources management

Conflicts over interstate and intrastate water resources have challenged local, state and federal policymakers over the course of the past century trying to create sustainable arrangements to manage water resources. Some of the challenges stem from the multiple, conflicting and overlapping functions and interests – such as water quality regulation, endangered species protection, flood protection – that are administered by multiple tiers of government. Added to this are the competing demands and priorities associated with the use of water resources for drinking water, agriculture, power generation, navigation, recreation, flood control and environmental protection. The management of water resources is complicated further by the mismatch between hydrologic boundaries, such as watersheds, and socially constructed boundaries, such as the traditional jurisdictions of government. Lastly, our nascent understanding of landscape-scale ecosystems and potential increased climate variability associated with climate change hinder reaching short- to long-term agreements to manage water resources equitably.

In America's federalist system, primary responsibility for water management rests at the state level, with the federal government imposing regulations, such as the Clean Water Act of 1972; however, there is no coherent federal policy for integrated water resources management. While states have authority to allocate water resources, the federal government maintains a strong role in water resource regulation and

[1] There are five parties to the 1954 Supreme Court Decree including the four basin states and New York City.

development for federal purposes (Sherk, 2005). Over the past century, federal and state governments have struggled to create institutions to manage interstate river basin resources effectively. Such approaches have included United States Supreme Court (Supreme Court) litigation, interstate compacts[2] and informal associations at the state level. The federal government's efforts have ranged from the Title II river basin commissions under the Water Resources Planning Act to collaborative federal–state partnerships such as the National Estuary Program.

Water resources scholars (Muys, 1971, 2001; Donahue, 1987; McCormick, 1994; Kenney, 1995; Featherstone, 1996; National Research Council, 1999; Scholz & Stiftel, 2005; Sherk, 2005; Gerlak, 2006) have assessed a variety of these approaches, seeking to uncover the best institutional structures and distribution of powers to manage river basin water resources. A recent article by Mandarano *et al*. (2008) highlights federal–interstate compact[3] commissions and federal–state partnerships as moderately successful river basin organizations. While deemed capable of coordinating state and federal actions and overcoming conflicting interests and limitations of fragmented governance, only four federal–interstate compacts have been enacted: the Delaware River Basin Compact (DRBC, 1961); Susquehanna River Basin Compact (SRBC, 1970); Alabama–Coosa–Tallapoosa River Basins Compact (ACT, 1997); and Apalachicola–Chattahoochee–Flint River Basins Compact (ACF, 1997). Of the four, only the SRBC did not emerge from litigation over the allocation of water rights between states and was formed based on the DRBC model.

In addition to shifting institutional approaches during the latter portion of the 20th century, water resources management more generally, including US Environmental Protection Agency (EPA) guidance, shifted focus from favoring large infrastructure projects such as dams, levies and the like, which address water supply and flooding concerns, to emphasizing non-structural solutions to address a broader range of issues. This integrated and systems-based approach encourages management of water resources to restore chemical, biological and physical properties as well as manage at the watershed scale. Concurrent with this shift in perspective was a growing appreciation of adaptive management, originally an approach to managing water resources for species protection and/or ecosystem restoration that promotes policymaking as an iterative process through which policy and expectations are changed based on knowledge gained from scientific monitoring, assessment, reporting and learning (Lee, 1993; Gunderson *et al*., 1995; National Research Council, 2004). Adaptive management has recently been endorsed by federal agencies as a strategy to guide operation of reservoirs for integrated water resources management (Brekke *et al*., 2009). Moreover, various scholars (National Research Council, 2004; Scholz & Stiftel, 2005; Feldman, 2007) deem this to be the most promising of management approaches for integrated water resources management because it enables action in the face of limited scientific information and knowledge regarding the complex and variable behavior of large ecosystems such as the watershed.

More recently, Scholz & Stiftel (2005) called for adaptive governance as a necessary complement to adaptive management approaches to integrated water resources management. They claim that a new generation of governance institutions is needed to replace single-purpose resource management agencies

[2] Interstate compacts are voluntary agreements that are designed to solve shared concerns among the states and have been created for a broad range of policy domains. Interstate compacts are subject to approval by each state before becoming state law and are by federal law subject to Congressional approval and upon such approval become federal law.

[3] Federal–interstate compacts differ from interstate compacts in that the contract extends to include the federal government and thus are enforceable upon both the state and federal agencies.

at the local, state and federal levels in order to arrive at collective action solutions. Adaptive governance is rooted in the creation of institutions and processes capable of coordinating politically fragmented authorities, dealing with unexpected responses from the natural system and/or unfamiliar issues beyond traditional agencies' established expertise and effectively engaging new stakeholders (Scholz & Stiftel 2005). The Delaware River case study highlights the DRBC's policymaking as it shifted the management of water resources in New York's reservoir system from a single purpose goal, water supply, to a more complex adaptive management policy embracing multiple and often competing goals and modified its public forums to engage new stakeholders in collaborative decision-making.

Case study context

Although the main stem Delaware River, which is 330 miles (531 km) long, holds honors as America's longest undammed waterway, it is nonetheless an intensively used, highly contested resource. Its modest watershed, covering 13,539 square miles (8,893 m^2), constitutes substantial portions the states of New York, New Jersey, Pennsylvania and Delaware – as well as a small portion of Maryland (Figure 1). It is a critical water supply for the residential, agricultural, commercial and industrial needs of more than 17 million people. More than 8 million people reside in the basin and an additional 8 million people who do not live in the basin, in NYC and northern New Jersey, rely on the Delaware for drinking water (Kauffman, 2011). Reservoirs in the basin's upper reaches, in southeastern New York, store water for export to NYC. New Jersey also exports water from the basin through the Delaware and Raritan Canal. In addition to being a critical water supply, the basin's water resources support many other important uses, such as navigation[4], power generation, fishing, oyster fishing and recreation.

Conflicts over Delaware River management have been with us since the earliest days of the republic; the most notable was resolved with New Jersey and Pennsylvania agreeing by treaty in 1783 that there would be no dams on the Delaware main stem (Albert, 2005). The basin states have embraced multiple approaches to resolve the more recent conflicts of the 1900s focusing on securing water allocations for growing populations. In 1924, New York, Pennsylvania and New Jersey appointed commissioners to negotiate a compact to allocate water resources equitably. After the first commissioners failed to reach an agreement, a second commission was formed and an agreement reached; however, New York was the only state to ratify the draft compact in 1927 (Weston, 1989). Following this failure to agree to a compact, New Jersey sued New York State and NYC over the decision to permit exporting water out-of-basin for NYC's water supply. The 1931 Supreme Court Decree affirmed New York's decision to permit NYC to divert 440 mgd (million US gallons per day) (1,665 million liters per day (ml/d), thus setting the stage for construction of the Neversink and Pepacton reservoirs, two of the three reservoirs comprising the NYC's Delaware reservoir system. This allocation was made contingent upon maintaining compensating releases to maintain a specified flow at Port Jervis, NY. Pennsylvania and New Jersey – lacking specific projects to support their claims – were denied specific allocations (1931; Albert, 2005).

In 1934, the US Army Corps of Engineers (ACE) Philadelphia District conducted a basin-wide investigation recommending the formation of an interstate agency to plan and manage the basin's water resources. The four states agreed to form the Interstate Commission on the Delaware River Basin

[4] The main navigation channel maintained by the Army Corps of Engineers extends 133 miles upstream to Trenton, NJ.

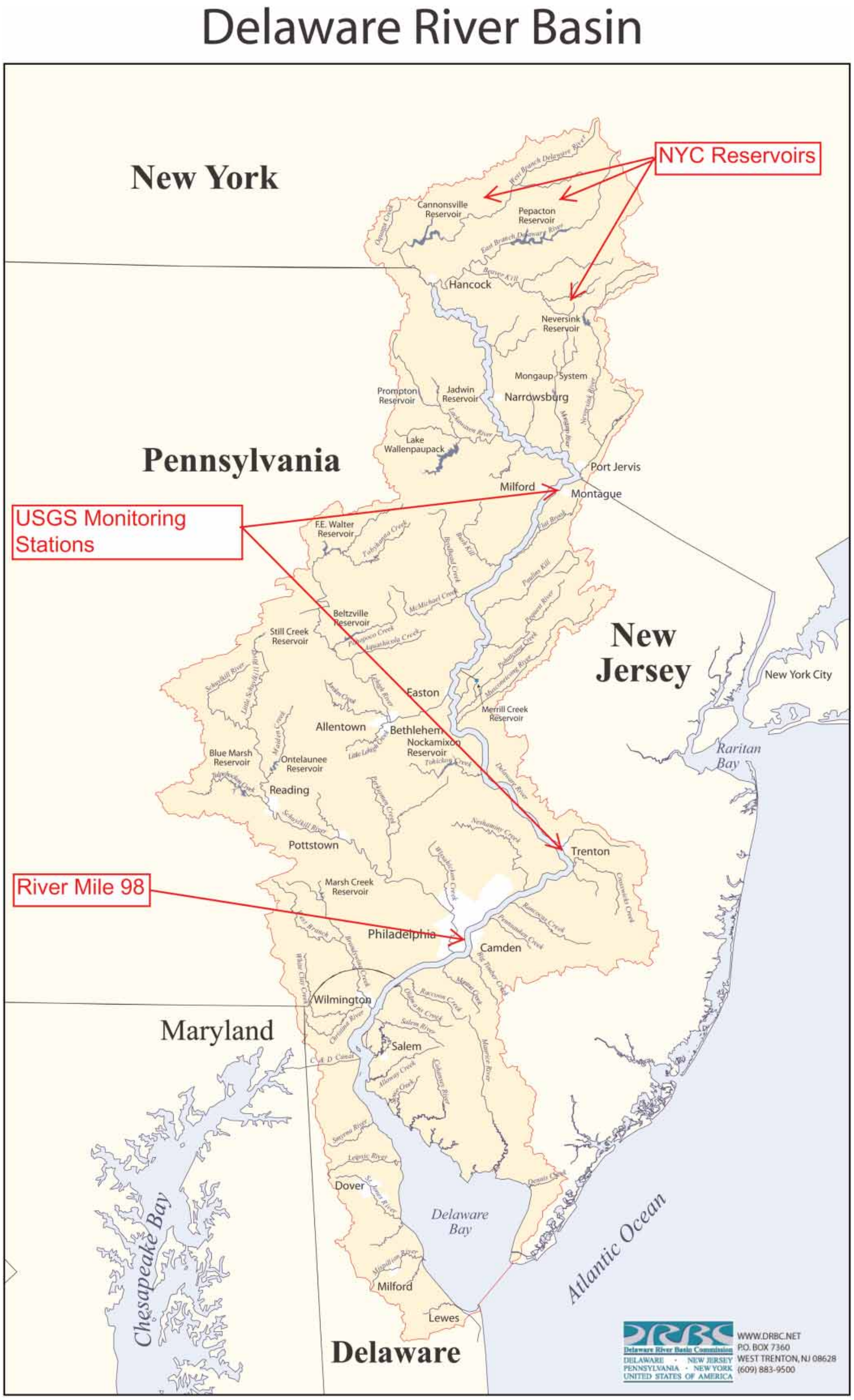

Fig. 1. Delaware River basin.

(INCODEL) following a major flood event in 1936. INCODEL's *Report on the Utilization of the Waters of the Delaware River Basin* (Malcolm Pirnie Inc. and Albright & Friel Inc., 1950) recommended the construction of eight reservoir systems; however, the states failed to agree to implement this plan (Weston, 1989).

Soon after, NYC and New York State petitioned the Supreme Court to increase its allocation for water supply purposes. Pennsylvania joined New Jersey in disputing this claim to divert more water out of the basin. The resultant 1954 Consent Decree (decree) increased NYC's allocation in steps, raising it to 800 mgd (3,028 ml/d) upon completion of the Cannonsville Reservoir. Moreover, New Jersey was allowed to divert 100 mgd (379 ml/d) to supply water to the Delaware and Raritan Canal, which supplies water to central New Jersey. The decree also requires NYC to make reservoir releases, as needed, to maintain a minimum flow of 1,750 cubic feet per second (cfs) (50 m^3s) at the US Geological Survey (USGS) gauge station at Montague, NJ or 3,400 cfs (96 m^3s) at Trenton, NJ and to make 'excess quantity releases', the volume of which is calculated to be 83% of the difference between NYC's annually forecasted consumption and safe yield[5] (1954). The Supreme Court appointed an officer of the USGS to serve as Delaware River Master, who is responsible for administering the decree and monitoring and enforcing the diversion and release provisions.

The four basin states, recognizing that litigation through the Supreme Court is not the most productive method for managing the basin's resources, formed a commission to negotiate a compact to allow for development of a comprehensive regional plan to guide water resources management. The result was the unanimous ratification in 1961 of a federal–interstate compact – specifically, the Delaware River Basin Compact – and the creation of the DRBC. The DRBC comprises five commissioners: the governors of the four states or their appointees and a federal commissioner appointed by the president. NYC and Philadelphia, however, were granted only advisory rather than voting rights (Albert, 2005). 'Where governance of the basin had previously been unevenly divided among forty-three state agencies, fourteen interstate agencies and nineteen federal agencies, it was now unified in one body…' (Clemons, 2004). Although one of the DRBC's main functions is to provide a forum for the decree parties to negotiate changes to the decree's reservoir releases program, the DRBC is a separate entity with broad authority with respect to such matters as comprehensive planning, pollution control and allocation of withdrawals and diversions. The DRBC is supported by approximately 45 staff and a recently authorized annual budget for 2013 of US$5.8 million. The budget is funded by the four basin states and fund revenues with zero contribution from the federal government since Congress deleted funding to federal–interstate compact commissions in 1997 (Mandarano *et al*., 2008).

In its early years, the DRBC favored structural approaches to river management and was influenced by the INCODEL plan mentioned earlier and ACE's Delaware River Basin Report (US Army Corps of Engineers, 1960). The ACE's report was the product of a 6-year comprehensive study of flooding and water supply needs in the basin, which was ordered by the Senate Committee on Public Works after the region was ravaged by floods caused by two hurricanes in quick succession, Connie and Diane, in August 1955, which claimed 100 lives and caused more than US$100,000,000 in damages (US Army Corps of Engineers, 1960). The comprehensive study recommended the development of a system of 19 major control projects (dams and reservoirs) to meet the demands for water supply,

[5] The definition of reservoir safe yield varies but a general definition is the maximum amount of water that can be supplied by the reservoir to withstand the drought of record without impacting water quality.

flood control, recreation, hydropower and other water management needs; its centerpiece was the Tocks Island Dam. Tocks Island Dam would provide reservoir storage, sufficient flood control to reduce the 1955 flood crest at Trenton by 6 ft (183 cm) and hydropower, all at a cost of US$31,600,000 (US Army Corps of Engineers, 1960). While Congress authorized the construction of the Tocks Island Dam in 1962, it was never constructed owing to intense public opposition. The ACE subsequently constructed five flood management reservoirs and several other multi-purpose reservoirs on tributaries.

Although the DRBC's initial undertakings were in response to the 1954 Decree and the 1955 floods, its early years were marked by a period of record drought. The 1961–1967 drought surpassed the 1930s drought as the basin's drought of record. During 1965, NYC reservoir levels were so low that the New York City Department of Environmental Protection (NYCDEP) unilaterally decided to suspend decree-mandated reservoir releases. As a result, fresh water flows in the lower portion of the river were insufficient to repel the estuarine salt line, which advanced 20 miles (32 km) upstream to river mile 102 (164 km) and posed a threat to Philadelphia's water supply – the salt line was within a few miles of Philadelphia's Baxter Water Treatment Plant intake – as well as southern New Jersey's aquifer systems. Under these crisis conditions, the DRBC held an emergency summit to resolve this conflict and, for the first time, the parties did not seek conflict resolution through the Supreme Court. Through direct negotiations, the decree parties agreed to the DRBC's declaration of a drought emergency and adjustments to decree-mandated releases.

As a result of the 1960s drought of record, the parties came to the harsh realization that the volume of water in the Delaware River basin was insufficient to meet decree-mandates consistently, as well as the basin states' water resources needs. However, it was not until the onset of the next drought, in the 1980s, that the parties agreed to codify a response to severe drought conditions into a formal policy. More recently, weather impacts have shifted toward major episodic flooding. During the period 2004–2006 alone, parts of the basin were ravaged by three extreme floods. National Weather Service (NWS) data indicate that the floods were caused by unusually heavy rain and snow melts. The most recent event in June 2006 was a 700-year storm (Delaware River Basin Commission, 2008). In response, the decree parties and DRBC faced an urgent challenge to adapt water resources management to address severe flood events, relying upon the adaptive management approach they had started to set in place.

An incremental approach to adaptive management

Over the past 35 years, the decree parties and DRBC incrementally shifted the management of NYC's Delaware basin reservoirs from a single-purpose perspective – water supply – to multiple and often competing purposes, including drought management, flood control and fisheries management. The DRBC and parties employed an adaptive management approach based on using experimental policy and monitoring and research to generate scientific information to ground decision-making. Table 1 highlights the decision-making criteria and monitoring and reporting requirements for each of the policies discussed in this section.

1977 Experimental Release Program

In 1977, the DRBC approved docket D-77-20 (Delaware River Basin Commission, 1977), marking the first attempt to modify decree mandates in order to manage NYC's reservoirs adaptively, using

Table 1. Adaptive management reservoir operations, monitoring and reporting criteria.

Reservoir operations criteria	Monitoring and reporting requirements
1977 Experimental Release Program	
Conservation release schedule: Table 1 establishes a baseline conservation release schedule, seasonally adjusted, for each reservoir.	*Daily by NYCDEP:* Accounting of the credits or debits to the excess release bank.
Special thermal releases: Establishes releases when in-stream temperature is expected to exceed 75 °F (24 °C) or 72 °F (22 °C) daily average at three monitoring locations.	*Monthly by NYCDEP:* Reservoir operations; storage levels; conservation releases, and Montague flows.
Excess release bank: An 'account' based on the 1954 Decree excess release quantity formula. Conservation and special releases may not exceed the total volume of the excess release bank.	*Annually by multiple parties:* Impacts on fisheries; recreational uses; NYC reservoir storage, yield and shortage, and salinity.
1983 Good Faith Agreement	
Salinity objective: limit salinity to a maximum 30-d average (180 mg l^{-1} chlorides and 100 mg l^{-1} sodium) at river mile 98.	Policy calls for periodic review and continued long-term planning studies to identify projects to increase water storage, water supply and flow augmentation and to establish a depletive use budget.
Salt front: 250 mg^{-1} chloride isochlor 7-d average.	
Drought operations curve: Figure 1 defines three zones of reservoir storage: normal, drought warning (upper and lower) and drought conditions, seasonally adjusted.	
Adaptive allocations and flow objectives: Table 1 establishes an adaptive schedule in which reductions to NYC and NJ allocations and the Montague and Trenton flow objectives are based on reservoir storage for drought warning and drought conditions, seasonally adjusted.	
Drought conditions salinity control: Table 2 establishes reductions, seasonally adjusted, in the Montague and Trenton flow objectives based on four predetermined salt front river mile locations.	
2007 Flexible Flow Management Plan	
Montague flow objective: Decree-mandated flow objective increase to 1,850 cfs (52 m^3s) during summer months.	*Annually by NYSDEC:* Status reports of the effectiveness of the tail waters habitat projection and discharge mitigation program.
Interim excess release quantity: Temporarily replaces the decree's excess release quantity formula with a defined volume of 15,468 cfs-d (438 m^3s-d) based on the revised Montague flow objective as well as recent data on NYC's consumption and safe yield studies.	*Two-year by NYSDEC:* Status report on NYS effort to secure additional storage capacity in Delaware River basin.
Drought operations curve: Figure 1 now defines five zones of reservoir storage: normal (L1 and L2) drought watch (L3), drought warning (L4) and drought emergency (L5).	*Three-year reassessment study by decree parties and DRBC:* A comprehensive reassessment of the operative objectives and protocol.
Adaptive allocations and flow objectives: Table 1 modifies the allocation and flow schedule presented in the 1983 Good Faith Agreement.	*Five-year by NYSDEC:* Biological monitoring to report the effects on fishery and other aquatic resources.

(*Continued.*)

Table 1. (*Continued.*)

Reservoir operations criteria	Monitoring and reporting requirements
Drought emergency conditions salinity control: Table 23 modifies flow objectives established in the 1983 Good Faith Agreement.	*Periodic assessments and evaluations by decree parties and DRBC:* To support the adaptive management process and to improve the scientific basis for the FFMP, an evaluation plan shall be developed and implemented.
Adaptive release schedule: Table 3 establishes reservoir-specific releases, seasonally adjusted, based on combined reservoir storage: normal conditions (L1) for discharge mitigation and drought conditions (L2–L5) for conservation. Release are tabulated for four predetermined rates (35–0 mgd; 132 to 0 ml/d) of forecast available flow, annually estimated unused portion of NYC's 800 mgd (3,028 ml/d) allocation.	
2011 Flexible Flow Management Plan	
Montague flow objective: Reverts back to the Decree flow objective to 1,750 cfs (50 m^{3}s).	*Daily by river master:* Daily accounting of the releases in accordance with Table 4 with respect to the interim excess release quantity.
Interim excess release quantity: Reduces 2007 FFMP defined volume to 6,045 cfs-d (171 m^{3}s-d) to enhance baseline releases from the reservoirs.	*Annually by NYSDEC:* Report water temperatures within the stream reaches specific in the Habitat Protection Program and biological implementations with respect to the define protection levels.
Drought operations curve: Figure 1 now defines six zones of reservoir storage: normal (L1, L2-a and L2-b) drought watch (L3), drought warning (L4) and drought emergency (L5).	
Drought allocations and flow objectives: Table 1 reflects slight modifications to the 2007 FFMP.	
Drought emergency conditions salinity control: Table 2 significantly reduces the Montague flow objective and increases to the Trenton flow objective during drought emergency corresponding to four predetermined salt front river mile locations.	
Habitat protection program (formerly conservation releases): Plate 1 establishes the in-stream locations for four ecosystem protection levels, which are to be maintained during non-drought years. Only the excellent and good categories include in-stream temperature objectives.	
Table 3 establishes the adaptive release schedule for drought conditions (L3–L5).	
Table 4 establishes the adaptive release schedule for normal conditions (L1a–L1c and L2) using six predetermined amounts (0–100 mgd; 0–379 ml/d) of forecast available flow.	
Discharge mitigation operations curve: Figure 2 establishes a conditional storage objective to achieve 90% storage capacity (10% voids) from September to March.	

experimental policy to test potential benefits to fisheries resulting from modifications to the existing conservation release schedule. New York State Environmental Conservation Law requires a reservoir conservation release schedule to offset the impacts of the interrupted stream flow on habitat and public uses. The construction of the Neversink, Pepacton and Cannonsville dams in the headwaters of the upper branches of the Delaware River together with the decree-mandated releases noted earlier, introduced a continuous flow of cold fresh water into the system, through the outlet structures at the bottom of the reservoir, thus creating year-round cool water temperatures in the tributaries that extend for some 40 miles downstream and into the Delaware River main stem. This phenomenon changed the upper reaches of the basin into a cold water fishery habitat, albeit man-made, and world-class trout fisheries. At the urging of cold-water fisheries advocates, New York State Department of Environmental Conservation (NYSDEC) undertook studies to understand the impact of thermal stresses caused by low flows or periods of extreme heat. Based on its findings, the NYSDEC proposed regulations under NYS law to modify the decree-mandated conservation release schedule. The proposed experimental policy would establish a new reservoir-specific conservation release schedule, seasonally adjusted, direct special thermal releases when in-stream temperatures exceed 75 °F (24 °C) or a 72 °F (22 °C) daily average at three monitoring locations and require a daily accounting of debits and credits to the excess release bank (an annually calculated 'account' of stored based on the excess release quantity formula stipulated in the decree). The proposal did not alter the decree's Montague flow target. Following a review of the proposed regulations and proposals by NYCDEP, Pennsylvania Department of Environmental Resources and DRBC, and an associated public hearing, the DRBC approved the proposed 'experimental modification' to the decree reservoir release schedules with the addition of several conditions. DRBC Docket D-77-20 stipulated, for example, that there be monitoring and reporting by the NYCDEP on reservoir operations and by others on the 'impacts on fisheries, recreational uses, water shortage and yield of the NYC reservoirs and estuary regimes (particularly salinity)'. Docket D-77-20 also tasked the decree parties with establishing a drought emergency water allocation and release plan, which the DRBC would implement, and developing a long-term reservoir operations scheme. The DRBC's approval was contingent on the decree parties' unanimous approval, which was granted. D-77-20 and its subsequent revisions joined the decree as the rules guiding the operations of NYC's Delaware basin reservoirs. The experimental release program initially was approved for 2 years and was renewable for 1 year upon agreement of all parties. Through a series of eight resolutions, the DRBC and decree parties approved extension of the experimental release program.

In 1983, in response to recommendations of the decree parties' 1983 Good Faith Agreement (GFA), described below, the experimental release program was made permanent and the releases were limited by the drought operation curves established in the GFA. The decision to make the experimental release program permanent was based on the monitoring and evaluation program for which the NYSDEC prepared three performance reports. The findings highlighted such beneficial effects as 'improved and extended [the] trout fisheries downstream of the reservoirs'; 'improving black bass, walleye and American shad fisheries as well as invertebrate communities'; and increases in other water-related recreational activities, particularly boating, all of which 'are having a multi-million dollar impact annually on local and regional economies' (Delaware River Basin Commission, 1983). Since 1983, the DRBC has unanimously approved eight revisions to the docket D-77-20 CP (revised) to modify operations in response to monitoring results, scientific studies and changes in environmental conditions.

1983 Good Faith Agreement

Although a DRBC resolution called the parties into good-faith discussion in 1978 to grapple with how to modify the decree for drought management, negotiations did not come to closure until another drought emergency arose. With the onset of a drought watch in October 1980, the decree parties, with the DRBC acting as the mediator, established an operations plan for drought emergencies. In 1983, the decree parties unanimously approved 'Interstate Water Management Recommendations of the Parties of the Supreme Court Decree of 1954 to the Delaware River Basin Commission Pursuant to Commission Regulation 78–20' (Parties of the Supreme Court Decree of 1954 1982), commonly known as the GFA. The GFA established a more integrated approach to manage reservoir releases.

Under the GFA, reservoir operations are based on a range of management standards and criteria. The central component of the GFA is a drought operations curve, which defines normal, drought warning (upper and lower) and drought emergency conditions, seasonally adjusted based on reservoir volumes. NYCDEP developed the drought operations curve based on results of analysis using a daily flow model designed by Camp Dresser & McKee to guide reservoir operations (Office of the Delaware River Master, 1996). Using these drought definitions as a framework, the GFA establishes an adaptive allocation and flow objective schedule, see Table 2. During drought operations, the GFA calls for a reduction in out-of-basin allocations to a greater extent than downstream flow targets. In addition, an adaptive schedule of Montague and Trenton flow objectives are defined specifically for drought conditions, with the flows triggered by four pre-determined salt front river-mile locations, based on maintaining the salinity objective at River Mile 98 (158 km) and adjusted seasonally. The GFA mandates that changes in allocations and releases should go into effect immediately when reservoir levels dip below the drought operating curves for 5 consecutive days.

Figure 2 highlights the three main drought operation curves, historic reservoir level trend and the reservoir-level trend line for the drought of 2001. The latter demonstrates how quickly the reservoirs can drop from 102% capacity to a record low. The final section of the GFA calls for its periodic review, continued long-term planning, ongoing studies and modifications to respond to changing conditions.

2007 Flexible Flow Management Plan

The FFMP is the decree parties' first agreement to incorporate explicitly adaptive management principles as one of the criteria[6] for modifying the document and to incorporate numerous provisions in

---

[6] The decree parties and the DRBC will consider the following criteria in reviewing proposed modifications to the FFMP: (i) decree party equity; (ii) net benefits and costs to environmental and economic resources; (iii) source and sustainability of water available to support modification and the environmental or economic resource(s); (iv) habitat types – with naturally occurring habitats receiving consideration over man-made habitats; (v) scientific basis for modification; (vi) impacts to drought management, water supply and flood mitigation, including but not limited to: (1) frequency, duration and seasonal timing of the various levels of drought; and (2) frequency, duration, levels of storage, diversions, releases and flows; (vii) extent to which the diversions and the Montague minimum basic rate of flow provided in the decree are met; (viii) potential impacts to water quality, existing National and State Pollution Discharge Elimination System permits and the assimilative capacity of the Delaware River; (ix) ease and practicability of operation; (x) consistency with adaptive management principles; (xi) applicability and implementation of water conservation practices; and (xii) impacts to salinity.

Table 2. Adaptive allocation and flow objective schedule.

Storage condition	NYC allocation (mgd)	NJ allocation (mgd)	Montague flow objective (cfs)	Trenton flow objective (cfs)
Normal	800 (3,028 ml/d)	100 (379 ml/d)	1,750 (50 m^3s)	3,000 (85 m^3s)
Drought warning, upper	680 (2,574 ml/d)	85 (322 ml/d)	1,655 (47 m^3s)	2,700 (76 m^3s)
Drought warning, lower	560 (2,120 ml/d)	70 (265 ml/d)	1,550 (44 m^3s)	2,700 (76 m^3s)
Drought	520 (1,968 ml/d)	65 (246 ml/d)	1,100–1,650* (31–47 m^3s)	2,500–3,000* (71–85 m^3s)

*Varies with time of year and location of salt-front line as defined in Table 2 of the Good Faith Agreement.
Source: Good Faith Agreement, Table 1.

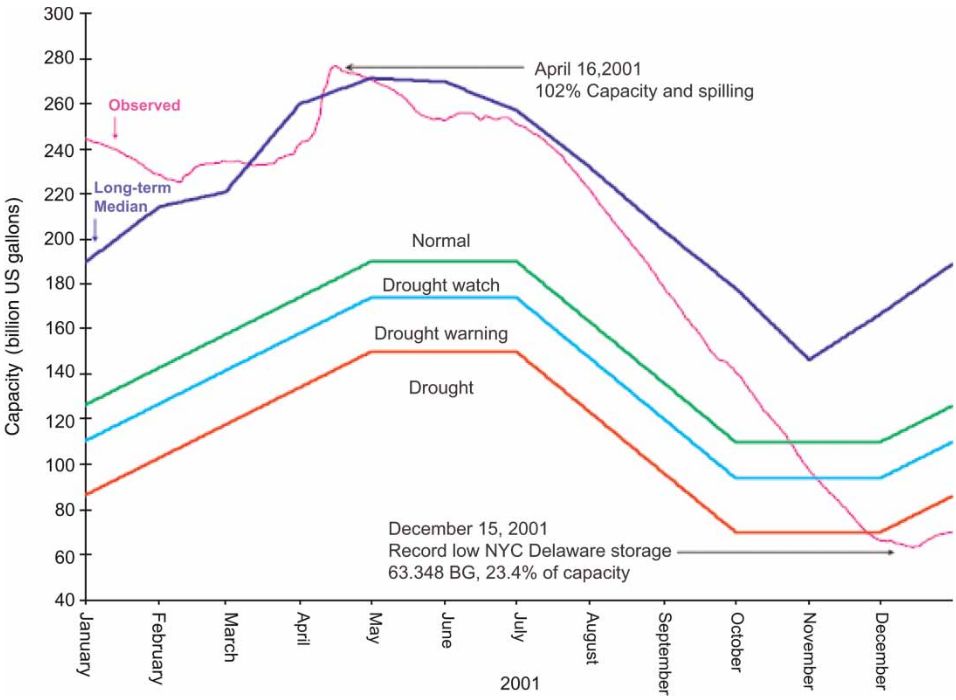

Fig 2. New York City Delaware basin storage, 2001 (1 US gallon = approx. 3.785 l).

which the parties agree to modify the FFMP based on the review and evaluation of scientific studies and other information as it becomes available. To this end, the parties sought to establish a flexible approach to managing the complexity of competing demands. The FFMP not only combines all of the operating parameters into one comprehensive document but also modifies several aspects of the operating parameters established in previous policies. Two core changes involve the conservation releases program and the addition of a discharge mitigation program to reduce flooding from reservoirs spills. The adaptive management provisions of the FFMP largely were made possible by the analysis of a new reservoir flow model, OASIS, developed by HydroLogics in 2004 at the request of the DRBC (Office of the Delaware River Master, 1996), a USGS fisheries habitat model (Bovee *et al*., 2007) and other research such as analyses conducted by a volunteer, *ad hoc* group of scientists, the Delaware River Releases Coalition.

The FFMP presents a fundamental change to the conservation release program. For the first time, conservation releases are based on actual reservoir storage levels instead of the cumbersome daily accounting of storage remaining in the excess release bank and thermal releases protocol established in the 1977 policy. To this end, the FFMP establishes an adaptive release schedule for habitat protection for reservoir-specific storage, adjusted seasonally, for the combined storage levels L2–L5 shown in the drought operations curve. The drought operations curve was revised by dividing the normal zone into two zones (the upper L1, which includes subzones a, b, c; and the lower (L2); the remaining zones are renamed drought watch (L3), drought warning (L4) and drought emergency (L5). Central to these new operating procedures is an increase to the flow objective at Montague to 1,850 cfs during summer months. These modifications to reservoir operations result in larger releases for fishery habitat protection when water is available.

The adaptive release schedule also includes releases for the new discharge mitigation program. Discharge mitigation releases are based on reservoir-specific storage when the combined storage is in Zone L1, normal condition, of the revised drought operations curve. Adaptive release schedules for the combined habitat and discharge mitigation program are tabulated for four predetermined rates (35–0 mgd) (132–0 ml/d) of forecast available flow. The forecast available flow is the projected unused quantity of NYC's 800 mgd (3,028 ml/d) allocation, not to exceed 35 mgd (132 ml/d). Table 3 provides the adaptive release schedule for Cannonsville reservoir with a projected 35 mgd (132 ml/d) available flow.

The FFMP, which was effective from December 2008 to May 2011, was not intended to be a static document. The parties designed the FFMP to include placeholders for operating criteria not yet established for such parameters as dwarf wedge mussel protection, Lake Wallenpaupack reservoir levels (snow melt spill mitigation), recreational boating, estuary and bay ecological health and warm-water and migratory fish populations. This policy also includes calls for routine monitoring, reporting and evaluations. For example, NYSDEC must submit annual reviews of the tail waters habitat protection releases and had to conduct a biological monitoring program in 2009 and every 5 years thereafter. The parties and the DRBC also are required to conduct a comprehensive reassessment study of reservoir safe yield, allocations, reservoir operations, flow objectives and salt line in order to establish recommendations to improve water management in the basin. Finally, the document calls for periodic reviews and evaluations 'to support an adaptive management process and to improve over time the scientific basis for the various elements' (Parties to the 1954 US Supreme Court Decree, 2007).

Table 3. Adaptive release schedule (cfs) with 35 mgd available. Metric values are in brackets (m^3s).

Cannonsville	Dec 1– Mar 31	Apr 1– Apr 30	May 1– May 31	Jun 1– Jun 15	Jun 16– Jun 30	Jul 1– Aug 31	Sep 1– Sep 30	Oct 1– Nov 30
L1a	1,500 (42.5)	1,500	*	*	1,500	1,500	1,500	1,500
L1b	250 (7.1)	*	*	*	*	320 (9.1)	275 (7.8)	250
L1c	110 (3.1)	110	225 (6.1)	275	275	275	140 (4)	110
L2	80 (2.3)	80	215 (6.1)	260 (7.4)	260	260	115 (3.3)	80
L3	70 (2)	50	100 (2.8)	175 (5)	175	175	95 (2.7)	70
L4	55 (1.6)	55	75 (2.1)	130 (3.7)	130	130	55	60
L4	50 (1.4)	50	50	120 (3.4)	120	120	50	50

*Releases to be made in accordance with zone L1C.
Source: 1997 Flexible Flow Management Plan, Table 3.

Since its approval, the FFMP underwent temporary and permanent modifications. The most notable of these are changes to allow increased reservoir releases for fisheries habitat protection needs in late May and early September, to address storage zone bouncing and to incorporate the water equivalent of snow pack in reservoir storage calculations (Parties to the 1954 US Supreme Court Decree, 2011).

2011 Flexible Flow Management Plan

The 2011 FFMP is a 1-year interim agreement replacing the original FFMP. The two key modifications concern releases for cold-water fisheries protection and discharge mitigation. In this version of the FFMP, the combined adaptive release schedules for habitat protection and discharge mitigation are uncoupled as well as the program descriptions and protocol. The new Habitat Protection Program reflects recommendations of a joint NYSDEC and Pennsylvania Fish and Boat Commission fisheries study, which recommends a fixed release schedule based on 'season, reservoir storage level and the amount of water made available from the NYC allocation for the program during a given year' (New York State Department of Environmental Conservation and Pennsylvania Fish and Boat Commission, 2010). The purpose of the fixed release schedule is to 'provide more stable base flows' (New York State Department of Environmental Conservation and Pennsylvania Fish and Boat Commission, 2010). The Habitat Protection Program includes two components. The first is a diagram that highlights the extent of the cold water ecosystem and four zones corresponding to four cold water ecosystem protection levels, which include temperature targets for the excellent and good levels of protection. The second is a revised adaptive release schedule during normal conditions (L1 and L2) only and six pre-determined states of forecast available water (FAW) ranging from 10 to 100 mgd (38–379 ml/d). The FAW will be calculated using the NYCDEP's new state-of-the-art operation's support tool (OST). Starting in February 2010, NYCDEP invested US$5,000,000 in developing the OST, a monitoring, modeling and forecasting system that uses near real-time data, to help guide the decree parties and water system managers in managing water in NYC's reservoir system and the basin (New York City Department of Environmental Protection, 2010). Such near real-time data inputs include, for example, USGS stormwater flow data, NWS forecasts and NYCDEP water quality and reservoir-level data. One of the key benefits of the OST is that it allows the NYCDEP to manage risks to its water supply better and to provide opportunities for improved fisheries habitat protection and enhanced flood mitigation (New York City Department of Environmental Protection, 2010). The OST results allowed the NYCDEP to commit to substantially increasing releases for habitat protection manage while maintaining its drought neutrality objective.

The FFMP also integrates NYCDEP's OST into the discharge mitigation program. Using the OST, the NYCDEP predicts that it can mitigate spills by aiming to achieve a conditional storage objective, a rule curve for zone L1 combined storage conditions. This would result in voids in the reservoirs to avoid spills during periods of high inflows to the reservoirs and heavy snow melt. The void schedule incorporated into the FFMP is shown below.

July 1–September 1: 5% void in NYC reservoirs
Sept 1–March 15: 10% void in NYC reservoirs
March 15–May 1: 5% void in NYC reservoirs

The FFMP includes two other significant revisions. The most significant is the relocation of the adaptive release schedule for drought conditions from its former location in the combined habitat and discharge mitigation program to the drought management protocol. The newly named ‘schedule of releases during drought operations’ table includes a schedule of reservoir-specific releases, seasonal adjusted, for zones L2–L5 and for 0 mgd (0 ml/d) of forecast available flow only. The other notable change increases New Jersey’s maximum diversion from 65 to 80 mgd (246–303 ml/d) during a drought emergency. Through these modifications to the FFMP, the DRBC and the decree parties seek to adapt management of water resources incrementally in an effort to balance the often conflicting demands presented by the need to manage water resources for water supply protection, flood mitigation and habitat protection. On March 31, 2012, the FFMP was renewed for 1 year with the notation that additional analyses and studies are needed for the parties to reach a long-term agreement (Parties to the 1954 US Supreme Court Decree, 2012).

Challenges of adaptive governance in the face of crisis

The DRBC and decree parties have had to navigate a complex course that has been heavily influenced by discrete hazard events. They were fortunate to have the workings of a multi-criteria adaptive management policy in place that provided a framework to react to the more recent series of flood events, which resulted in a new water resources management demand – a ‘repurposing’ of the NYC reservoir system to afford flood protection for existing floodplain communities. On the other hand, the flooding crisis introduced a new priority management objective for which there was little scientific evidence to guide reservoir operations and new stakeholders seeking priority status in an unfamiliar decision-making process. Both of these factors presented challenges to the DRBC’s adaptive governance decision-making process.

DRBC’s interstate flood mitigation task force

Prior to the onset of the 2004–2006 flood events, in 2000 the DRBC had established a Flood Advisory Committee (FAC). The FAC was tasked with providing a forum to coordinate activities of the numerous authorities responsible for flood loss reduction and providing technical support to develop flood warning and flood loss reduction strategies for the basin. As part of this effort, the FAC developed reports such as recommendations for improving flood warning and response (Delaware River Basin Commission: Flood Advisory Committee, 2002), as well as recommendations for more effective floodplain regulations (Delaware River Basin Commission: Flood Advisory Committee, 2009). The FAC comprises 19 individuals: representatives from federal, state and county governments, electric power generation and other authorities with flood management responsibilities (Delaware River Basin Commission, 2000).

The June 2006 flood escalated the awareness of the need for a coordinated regional flood management approach, as evidenced by the four basin state governors’ directive to the DRBC to convene an interstate task force to recommend flood management measures. The Interstate Flood Mitigation Task Force (IFM Task Force) is a fairly inclusive and diverse committee comprising 31 members from federal, state, county and local government and non-profit organizations. In its July 2007 report, the IFM Task Force identified 45 consensus-based recommendations for a coordinated regional approach to flood damage reduction. The 45 measures were grouped into six priority management areas: reservoir operations, structural and non-structural measures, stormwater management, floodplain mapping, floodplain regulation and flood warning. In response to public comment on the draft recommendations, the IFM Task Force also highlighted four immediate actions:

- Establish priority funding areas for acquisition, elevations and flood proofing.
- Develop flood mitigation operating plans for all reservoirs in the basin.
- Develop and implement consistent, comprehensive floodplain regulations for the basin.
- Enable the establishment of stormwater utilities or authorities (Delaware River Basin Commission, 2007).

Although not highlighted as an immediate action, recommendation R-1 highlights the DRBC's prior commitment to develop a flood analysis model (FAM) to inform and thereby precede the development of reservoir flood mitigation operating plans (Delaware River Basin Commission, 2007). The FAM project was initiated in August 2007 with US$500,000 contributed by the basin state governors and an additional US$285,000 by the ACE. The DRBC contracted technical services from the USGS, ACE and NWS to develop a model to simulate the impact of modified reservoir (15 reservoirs including NYC's three reservoirs) operations on flooding.

At the DRBC's public meeting on December 15, 2009, the IFM Task Force presented progress on implementation of its recommendations, the most important of which were the FAM results. FAM results indicated that maintaining partial voids in the NYC reservoirs would decrease flood crest levels, but that extensive flooding still would have occurred except at two locations in the tributaries a short distance below the reservoirs. The model results indicated that main stem river levels would have exceeded flood stage at all downstream forecast points, with the largest flood crest reduction of approximately 4.5 ft (137 cm) at Easton, PA associated with the 2006 storm and a 20% void scenario; however, the crest at Easton still would have exceeded a major flood stage (Delaware River Basin Commission, 2009). At the public meeting, Carol Collier, DRBC Director, summarized the findings: '[t]he results of the flood analysis…indicate that operational changes to reservoirs alone will not substantially reduce flooding if we experience storms similar to the three major events in September 2004, April 2005 and June 2006' and expressed support for the IFM Task Force conclusion 'that no single approach will eliminate flooding along the Delaware River and that we must continue to focus efforts on implementing a combination of flood loss reduction strategies' (Delaware River Basin Commission, 2009). In light of these findings, the DRBC agreed to continue to pursue the IFM Task Force's recommendations, especially working with basin reservoir operators to develop improved spill management programs to alleviate flooding immediately downstream. NYCDEP, a key partner in the effort to establish spill management programs, invested heavily in developing a reservoir model to guide reservoir operations for flood mitigation. NYCDEP not only committed to a spill operating plan in September 2006, revision 9 to D-77-20 CP (revised), based on ongoing studies for the 2007 FFMP, but also invested US$5 million in developing the OST, described earlier.

Response to flood crisis provides opportunity to address safe yield conflict

Of the decree parties, New Jersey leads in challenging NYC's reservoir operations. It would be overly simplistic, though, to characterize New Jersey and New York as river antagonists. While New Jersey is the party that twice disputed New York State's right to authorize the exportation of water out of basin to serve NYC's drinking water supply needs, leading to the two Supreme Court Consent Decrees, the adversarial approach to conflict resolution has tempered over the years as the parties have become accustomed to a consensus-based approach to conflict resolution facilitated by the DRBC. Yet, there remained a contingent within the New Jersey Department of Environmental Protection (NJDEP) that has long maintained that NYC's safe yield that was defined in the 1954 decree and remained unchanged in the 1983 GFA was outdated and warranted reassessment to reflect NYC's current consumption and reservoir operations (New Jersey Department of Environmental Protection, 2007). The NJDEP safe yield advocates contend that the use of the historic consumption and safe yield values overestimates the city's water needs and drought days and underestimates the excess release quantity.

During the negotiations mediated by the DRBC that arrived at the 2007 FFMP, NJDEP aired these concerns and NYCDEP responded with updated modeling results for its consumptive use and safe yield leading to a resolution of this long-standing conflict. The 2007 FFMP defines NYC's system-wide safe yield at 1,290 mgd (4,883 ml/d), which marks a significant reduction from the decree's 1,665 mgd (6,303 ml/d). Using these updates, the schedule of reservoir releases changed, affording NJ 85 mgd (322 ml/d) instead of only 65 mgd (246 ml/d) as per the 1983 GFA. This change results in NYC accepting a proportionately larger reduction in its allocation than NJ. Updating NYC's consumptive use and safe yield also allowed greater reservoir releases to address spill mitigation and habitat protection.

Flooding crisis introduces new stakeholders and new interests

Local governments have become especially active in the wake of the 2004–2006 floods. While some local government representatives became members of the DRBC's IFM Task Force, the following discussion highlights the diversity of actions taken locally and aimed at challenging the DRBC. After the third flood event, Bucks County (PA) commissioners formed a county-wide task force comprising one representative from each of the 17 riverfront communities and three appointed county representatives. This task force set out to cull a list of the communities' top five priorities and to hold meetings with representatives from the DRBC, government agencies and experts, to develop strategies to address each priority area. But after a presentation by the NWS based on preliminary studies that showed that maintaining a 4% void in the NYC reservoirs could result in 6–18 inch (15–46 cm) flood crest reductions, the county task force members were convinced that there was adequate science indicating that the reservoirs had a compelling impact on flooding in their communities. Their strategy shifted to lobbying the Pennsylvania governor and the appointed representative to the DRBC to push for changes in management of NYC's reservoirs. However, Governor Edward Rendell was reluctant to act until there was concrete data linking reservoir management with flooding. Then, when the DRBC released the results of the FAM in late 2009, the general consensus of the riverfront community representatives was that the DRBC was pushing the burden onto riverfront communities, rather than imploring NYC to manage the reservoirs for flood reduction.

During interviews task force representatives specifically noted implementation of the DRBC FAC's 2009 recommendations for basin-wide floodplain regulations would make it impossible for many historic riverfront communities to continue to exist as they do today. Among the riverfront community representatives participating in the county task force, there is a shared perception that 'the DRBC is locked in to the interests of NYC'. The general consensus of the task force is that the DRBC needs a stronger commitment to flood management, even if 20% voids may not be the complete answer (confidential interviews, February 22, 2010).

Interviews with IMF Task Force representatives from riverfront municipalities in Pennsylvania and New Jersey indicate that they are newly active stakeholders serving on DRBC forums and act locally not to challenge the DRBC but to improve the safety of the communities served. Yardley, PA is ranked second in Pennsylvania for the highest payouts from the National Flood Insurance Program. The community received US$14 million in 2004 and US$7 million in 2006. The losses were less in 2006 because the flood crest was lower than in earlier floods, some homes had not been rebuilt following previous floods and at least 24 vulnerable floodplain homes have been elevated. The municipality also has implemented an improved flood warning and emergency management program and several structural flood mitigation projects. Yardley embraces a multi-pronged approach to flood mitigation and, as part of that approach, it envisions repurposed management of the NYC reservoirs as part of the solution based on the notion that a 3 inch (7.6 cm) reduction in a flood crest could reduce the number of homes that experience first-floor flooding (confidential interview, February 19, 2010).

On the New Jersey side of the river, the small city of Lambertville also is very much engaged in implementing flood mitigation projects, including improved flood warning systems, buyouts of a handful of homes and structural measures to prevent the Delaware River from backing up into local tributaries. Lambertville commends the DRBC on its commitment to flood management but does not see maintaining voids in the NYC reservoirs as the cornerstone of the solution. Lambertville sees the problem as a matter of risk management. Droughts pose a risk to a larger population, upwards of 15 million and to a more expansive geography. In contrast, floods have an impact on between 5,000 and 10,000 people. If flood risk management is approached from the perspective that ‘floodplains flood’ then a range of measures, beyond relying on reservoirs operations, can be deployed to reduce flood losses (confidential interview, February 15, 2010).

Victims’ groups, the most vocal of the new stakeholders, have organized themselves to represent their interests in basin-wide flood management dialogue. Among them are the North Delaware River Watershed Conservancy, Friends of the Upper Delaware River, Aquatic Conservation Unlimited and the now largely defunct Delaware Riverside Conservancy, Drowning on the Delaware and Residents Against Flood Trends. These groups do not always march in step in the ways in which they view the flood issues and how governments and individuals should respond to them. But they are united in calling for voids in the NYC reservoirs, generally on the order of 20% (confidential interviews, April 5 and 9, 2010). The victims’ groups’ call for 20% voids is based on a preliminary analysis (Ruggles, 2008) by a civil engineering faculty member at Lafayette University, who was hired by the Delaware Riverside Conservancy. The findings of the preliminary analysis indicate that if 20% voids were available to capture stormwater runoff at the three NYC reservoirs and Lake Wallenpaupack reservoir, an ACE flood-management reservoir, then a reduction of up to 6 ft (183 cm) in peak flow elevation would be realized at the Montague gauge (Ruggles, 2008).

While a representative of the victims’ groups participated in the DRBC’s IFM Task Force, she did so primarily to advocate for their single interest: maintain 20% voids in NYC reservoirs. Victims’ groups claim that ‘others do not understand that the 3–4 ft (91.5–122 cm) crest reduction afforded by the 20% voids means first floors – where all the household valuables are – will not be inundated’. In addition, they reject the DRBC FAC’s and IFM Task Force’s integrated approach to flood management and downplay the role of floodplain regulations because it offers no relief for existing floodplain properties. When the representative felt that the voice of the groups were not being heard because the ‘formation of the various committees were politicized to control the agenda’, she escalated advocacy of their interests by reaching out to people in positions of power, including basin state governors and DRBC and NYCDEP senior staff (confidential interviews, April 5 and 9, 2010). Given the enormity of the flood events, the inclination of many politicians was to be sympathetic to victims’ plights. After a meeting with members of the flood victims’ groups on April 2, 2008, Pennsylvania Governor Rendell issued a call-to-action letter to the basin state governors calling on NYC to release water from the reservoirs in anticipation of spring rains. The letter, however, did not specifically call for 20% voids (De Palma, 2008; Mastrull, 2008).

By and large, the victims' groups see the DRBC staff as acting almost entirely in the political interest of the DRBC commissioners and rejecting science. The DRBC is viewed as intransigent, beholden to NYC's interests and opaque in its decision-making processes. The groups' distrust of the DRBC is routinely expressed by the president of Aquatic Conservation Unlimited (Aquatic), who is frequently quoted in regional and local newspapers as the voice articulating victims' groups' positions. With respect to the 2011 FFMP, Aquatic dismisses the plan, stating that the proposed voids are inadequate and that NYC continues to benefit, while the risks are borne by others (Satullo, 2011). Aquatic further contends that the 'plan was adopted in a close-door meeting' (Duffy, 2011).

In the larger scheme of things, the criticisms of the DRBC's adaptive governance approach reveal a conflict of interests and values, the latter being much more resistant to resolution through negotiation, collaboration and other forums of adaptive governance. Still, the DRBC and decree parties have been successful at negotiating policy that seeks to balance the competing demands of flood risk, NYC's and NJ's water supply and habitat protection.

Discussion and conclusions

The adaptive management of river basin resources requires not only adaptive management policy to direct water resources management but also an adaptive governance approach to provide a forum for negotiation, mediation and coordination of interests and activities. The DRBC is an example of a river basin organization that has established both. The case study highlights DRBC's incremental approach to developing policy to manage reservoir operations adaptively, responding to changing hydrologic conditions in the basin caused by shifts in human usage, development and increasing climate variability. However, when the flooding crisis of 2004–2006 introduced demands for the DRBC and decree parties to commit to operating the reservoirs to mitigate flooding, the DRBC's adaptive governance approach was challenged by the lack of scientific data to inform decision-making and by the demands of new stakeholders seeking to influence its decision-making. The DRBC experience highlights several lessons that are transferrable to other river basin organizations facing similar challenges.

First, scientific studies and monitoring are fundamental to informing adaptive management policy development and reassessment. Central to the DRBC's incremental development of adaptive management policy were scientific studies and monitoring reports introduced by the DRBC, decree parties, their consultants and other authorities in water resources management. For example, the 1977 Experimental Release Program marks the first time that the decree-mandated reservoir releases were modified via a formal policy. This policy was grounded in the findings of scientific studies undertaken by the NYSDEC, which took roughly a decade to produce after the realization that the 1960s drought caused thermal stresses to the basin's fisheries. In addition, the policy was subject to frequent re-approvals and revisions based on the results of ongoing monitoring and studies. Moreover, the DRBC and an *ad hoc* research team were awarded the 2010 Franz Edelman Award: Achievement in Operations Research for the research and coordination that informed the 2007 FFMP (Institute for Operations Research and the Management Sciences, 2010).

Second, the adaptive management policies adopted are not static operating rules. Multiple decision points are embedded in each of the reservoir operations guidelines for such objectives as spill mitigation, habitat protection and drought management. These decision-making points are triggered by well-defined and measureable criteria such as in-stream temperatures, in-stream flows and reservoir storage levels. The inclusion of decision-making points linked to routinely measured criteria allows flexible reservoir operations that respond to changes in environmental conditions. Details of the policies' key decision-making parameters were previously highlighted in Table 1. Additional flexibility is built into the policies using 1- to multi-year durations requiring reassessment based on monitoring results and research and then, if appropriate, re-approval.

Third, the decree parties recognize the value of the DRBC as a forum for negotiating changes to water management policy. After the creation of the DRBC in 1961, the decree parties relied on the DRBC as mediator to respond to a series of drought emergencies from 1961–67 and then again in the early 1980s. At first the NYCDEP acted unilaterally to change decree-mandated reservoir operations, which led the DRBC to hold an emergency summit to negotiate an equitable reapportionment of water resources under drought emergency conditions. Through this crisis and subsequent negotiations the parties came to realize that there was insufficient water to meet the decree mandates and that cooperation to arrive at a timely negotiated solution was preferable to litigation. From this point forward the parties continued to rely on the DRBC to provide a forum to negotiate adjustments to the static decree-mandated releases to create more flexible policies.

However, in the wake of the 2004–2006 flooding crises, the DRBC's adaptive governance approach, which became routine to the decree parties, was challenged by the lack of reliable scientific information and new stakeholders seeking to influence DRBC decision-making. As noted earlier, it took roughly a decade from the time that the cold-water fishery advocates mobilized and communicated their concerns, until the development of scientific studies and then the enactment of the 1977 Experimental Release Program. In response to the flooding crisis, the DRBC adopted a temporary flood mitigation operation policy for NYC's reservoirs as early as September 2006. In addition, although a victims' group representative was a member of the DRBC's IFM Task Force and engaged in the discussions to arrive at consensus-based recommendations, the victims' groups challenged the DRBC's response as being biased and insufficient. Several factors that appear to feed this distrust are delay in the release of the FAM results and preliminary studies circulated by others. In this instance, the DRBC committed to a fairly ambitious timeline to complete the FAM; it projected that the federal agencies would complete the assessment by January 2009 (Delaware River Basin Commission, 2008). Interviews indicate that frustration built up as the results were delayed on many occasions (confidential interview, February 22, 2010). The final results were not released until a public hearing on December 15, 2009. During this delay, the victims' groups resorted to paying for their own study, the findings of which they support with steadfast conviction and use to support their position that the DRBC is not asking NYCDEP to manage the reservoirs aggressively enough for flood mitigation. As noted earlier, they also sought to influence reservoir operations by appealing to Pennsylvania's Governor Rendell and others in positions of power.

This research demonstrates that the DRBC successfully developed an adaptive management approach to address changing hydrologic conditions and multiple, sometimes competing, mandates. Furthermore, this case study presents several lessons that are important to policy-makers and practitioners engaged in river basin management. One key limitation this paper raises is the capacity of adaptive governance approaches to respond to the challenges presented by emotionally charged stakeholders introduced to river basin management in response to crisis. While the DRBC continued its practice of securing sound science upon which to base flood management policy, acceptance of scientific findings and resulting policy continue to be challenged mainly by the well-organized victims' groups relying on scientific information that has not been properly reviewed and vetted. This underscores the need for clear and consistent communication to allay frustration and distrust and for joint fact finding in order to avert stakeholders' use of biased or unvetted scientific information. Yet with these suggested changes it is unclear if the DRBC would be capable of addressing the concerns of stakeholders who seek to undermine the collaborative decision-making process exemplified by the IFM Task Force through such practices as the use of biased scientific information and outreach to persons in position of power to achieve their desired outcome.

References

(1931). New Jersey v New York, 283 US.

(1954). New Jersey v. New York, 347 US.

Alabama–Coosa–Tallapoosa River Basin Compact (1997). Public Law No. 105–105, 111 Statute 2233.

Apalachicola–Chattahoochee–Flint River Basin Compact (1997). Public Law No. 105–104, 111 Statute 2219.

Albert, R. (2005). *Damming the Delaware: the Rise and Fall of Tocks Island Dam*. University Park, Penn State University, PA.

Bovee, K. D., Waddle, T. J., Bartholow, J. & Burris, L. (2007). *A Decision Support Framework for Water Management in the Upper Delaware River*. US Geological Survey, Reston, VA.

Brekke, L. D., Kiange, J. E., Olsen, J. R., Pulwarty, R. S., Raff, D. A., Turnipseed, D. P., Webb, R. S. & White, K. D. (2009). *Climate Change and Water Resources Management: A Federal Perspective*. US Department of the Interior and US Geological Survey, Washington, DC.

Clemons, J. (2004). Interstate water disputes: a road map for states. *Southeastern Environmental Law Journal 12*(2003–2004), 115–142.

De Palma, A. (2008). A fight over taming the Delaware. The New York Times. The New York Times Co, New York.

Delaware River Basin Commission (1977). Experimental Modification to the Current Release Schedules from Canonsville, Papacton and Neversink Reservoirs. Docket No. D-77-20. Delaware River Basin Commission, Trenton, NJ.

Delaware River Basin Commission (1983). Modifications to the Release Schedules from the Cannonsville, Pepaction and Neversink Reservoirs. Docket No. D-77-20 (revised). Delaware River Basin Commission, Trenton, NJ.

Delaware River Basin Commission (2000). Resolution No. 2000–8. Retrieved April 1, 2011, from http://www.nj.gov/drbc/.

Delaware River Basin Commission (2007). *Interstate Flood Mitigation Task Force Action Agenda*. Delaware River Basin Commission, Trenton, NJ.

Delaware River Basin Commission (2008). *2006–2007 Report*. Delaware River Basin Commission, Trenton, NJ.

Delaware River Basin Commission (2009). *News Release: DRBC Releases Results of Flood Analysis Model*. Delaware River Basin Commission, Trenton, NJ.

Delaware River Basin Commission: Flood Advisory Committee (2002). *Recommendations to address Flood Warning Deficiencies in the Delaware River Basin*. Delaware River Basin Commission, Trenton, NJ.

Delaware River Basin Commission: Flood Advisory Committee (2009). *Recommendations of the DRBC Flood Advisorty Committee for more Effective Floodplain Regulations*. Delaware River Basin Commission, Trenton, NJ.

Delaware River Basin Compact (1961). Public Law No. 87–328, 75 Statute 688.

Donahue, M. J. (1987). *Institutional Arrangements for Great Lakes Management: Past Practices and Future Alternatives*. Michigan Sea Grant College Program, East Lansing, MI.

Duffy, E. (2011). Flood plan for Delaware River puts NYC water in the mix. The Times of Trenton. NJ.com, New Jersey On-line LLC.

Featherstone, J. P. (1996). Water resources coordination and planning at the federal level: the need for integration. *Water Resources Update* (104), 52–54.

Feldman, D. L. (2007). *Water Policy for Sustainable Development*. The Johns Hopkins University Press, Baltimore.

Gerlak, A. K. (2006). Federalism and US water policy: lessons for the twenty-first century. *Publius: The Journal of Federalism 36*(2), 231–257.

Gunderson, L. H., Holling, C. S. & Light, S. S. (eds) (1995). *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. Columbia University Press, New York.

Institute for Operations Research and the Management Sciences (2010). *2010 Edelman Award Presentations*. Retrieved July 16, 2010, from www.informs.org.

Kauffman, G. J. (2011). *Socioeconomic value of the Delaware River Basin in Delaware, New Jersey, New York and Pennsylvania*. University of Delaware, Newark, DE.

Kenney, D. S. (1995). Institutional options for the Colorado River. *Water Resources Bulletin 31*, 837–850.

Lee, K. (1993). *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Island Press, Washington, DC.

Malcolm Pirnie Inc. and Albright & Friel Inc. (1950). *Report on the Utilization of the Waters of the Delaware River Basin*. Interstate Commission on the Delaware River Basin, Philadelphia, PA.

Mandarano, L., Featherstone, J. & Paulsen, K. (2008). Institutions for interstate water resources management. *Journal of the American Water Resources Association 44*(1), 136–147.

Mastrull, D. (2008). Delaware river flooding plan reported likely representatives from the four states involved met via conference call yesterday, but few details were released. Philadelphia Inquirer. Philadelphia, PA.

McCormick, Z. L. (1994). Interstate water allocation compacts in the western united states – some suggestions. *Water Resources Bulletin 30*(3), 385–395.

Muys, J. C. (1971). *Interstate Water Compacts*. National Water Commission, Springfield, VA.

Muys, J. C. (2001). Beyond allocation: equitable apportionment and interstate watershed protection and management. 19th Annual Water Law Conference, American Bar Association, Washington, DC.

National Research Council (1999). *New Strategies for America's Watersheds*. National Academy of Sciences, Washington, DC.

National Research Council (2004). *Adaptive Management for Water Resources Project Planning*. The National Academies Press, Washington, DC.

New Jersey Department of Environmental Protection (2007). *Preliminary Assessment of the Safe Yeilds & Operations of New York City's Major Water Supply Reservoirs with NJDEP Findings. Draft 2*. New Jersey Department of Environmental Protection, Division of Water Supply, Trenton, NJ.

New York City Department of Environmental Protection (2010). *New York City's Operations Support Tool (OST) White Paper Prepared for the Delaware River Basin Supreme Court decree parties*. New York City Department of Environmental Protection, New York, NY.

New York State Department of Environmental Conservation and Pennsylvania Fish and Boat Commission (2010). *Recommended Improvements to the Flexible Flow Management Program for Coldwater Ecosystem Protection in the Delaware River Tailwaters*. New York State Department of Environmental Conservation, Bureau of Fisheries and Pennsylvania Fish and Boat Commission, Albany, NY and Bellefont, PA.

Office of the Delaware River Master (1996). *Delaware River Basin Daily Flow Model*. US Geological Service, Milford, PA.

Parties of the Supreme Court Decree of 1954 (1982). Interstate Water Management Recommendations of the Parties of the Supreme Court Decree of 1954 to the Delaware River Basin Commission Pursuant to Commission Regulation 78–20. Trenton, NJ.

Parties to the 1954 US Supreme Court Decree (2007). *Agreement of the Parties to the 1954 US Supreme Court Decree (Flexible Flow Management Plan)*. Office of the Delaware River Master, Milford, PA.

Parties to the 1954 US Supreme Court Decree (2011). *Agreement of the Parties to the 1954 US Supreme Court Decree*, Effective June 1, 2011. Office of the Delaware River Master, Milford, PA.

Parties to the 1954 US Supreme Court Decree (2012). *Agreement of the Parties to the 1954 US Supreme Court Decree*, Effective June 1, 2012. Office of the Delaware River Master, Milford, PA.

Ruggles, R. (2008). *Report on the Impact of Reservoirs on the Flow in the Delaware River*. Delaware Riverside Conservancy, Stewartsville, NJ.

Satullo, S. K. (2011). One-year plan to manage New York City reservoirs on Delaware River Effective Today. Express Times. lehighvalleylive.com, PennLive LLC.

Scholz, J. T. & Stiftel, B. (eds) (2005). *Adaptive Governance and Water Conflict*. Resources for the Future, Washington, DC.

Sherk, G. W. (2005). The management of interstate water conflicts in the twenty-first century: is it time to call uncle? *New York University's Environmental Law Journal 12*(3), 764–827.

Susquehanna River Basin Compact (1970). Public Law No. 91–575, 84 Statute 1509.

US Army Corps of Engineers (1960). *Delaware River Basin Report*. US Army Corps of Engineers, Philadelphia District, Philadelphia, PA, pp. 1–11.

Weston, R. T. (1989). *The Delaware River Basin: Courst, Compacts and Commissions*. Kirkpatrick & Lockhart, Harrisburg, PA.

Received 1 May 2012; accepted in revised form 21 July 2012. Available online 27 October 2012