Reservoir Simulations for the Delaware River Basin Flood of June, 2006

Middle Atlantic River Forecast Center
State College, PA
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Introduction:

In the late spring of 2005, the Delaware River Basin Commission (DRBC) in West Trenton, NJ asked the National Weather Service (NWS) Middle Atlantic River Forecast Center (MARFC) to perform some model simulations using their operational forecast system to examine the effects of spilling reservoirs during the April 2-4, 2005 major flood on the Delaware River. Initial results were presented at a public officials meeting on May 25, 2005 and demonstrated that even though the reservoirs spilled during this event, they reduced downstream flood crests.

During the fall of 2005, DRBC asked MARFC if it could run additional hypothetical simulations to examine the impacts various voids in the New York City water supply reservoirs would have had on April 2-4 flood crests on the Upper Delaware. Results from those simulations shed some light on the impact those reservoirs had at downstream locations during the flood event, or would have had given varying amounts of storage.

In late June 2006, another major flood event affected the Upper Delaware Basin as a nearly stationary frontal boundary interacted with deep tropical moisture over a several day period. The result was episodes of heavy rainfall which led to moderate to major flooding throughout the Upper Delaware Basin on June 26th and June 27th. With another major flood event in just over a year's time from the April 2005 event, MARFC decided to see what impacts the Cannonsville and Pepacton water supply reservoirs had on this event, and to see how these results compared with those from the April 2005 event. This exercise was done primarily as a learning experience.

During the June 26-27 event, major flooding was observed at many locations throughout the basin. This report addresses in detail the effects of two large dams affecting the watershed: Cannonsville and Pepacton. MARFC currently models inflows to these two reservoirs as well as the Neversink reservoir. Other reservoirs in the basin, such as Rio and Wallenpaupack are not currently modeled by MARFC.

Methods:

For Cannonsville and Pepacton, MARFC ran five hypothetical model simulations for the cases of no reservoir, three different reservoir voids, and no spill, to show the effects of these hypothetical scenarios on river levels at ten downstream NWS forecast points. Summaries of the simulation results are shown in the tables in this report. The numbers in the tables indicate what effect the particular case had on the simulated crest/flow in comparison to the actual crest/flow at the given forecast point.

All model simulations done for this report begin at 8am June 22nd, prior to the heavy rain that caused the June 26-27 major flood.

To run these cases, MARFC first set up its forecast model with all initial conditions that were present at 8am June 22, prior to the flood event. The original "actual event" case was run first to coordinate all relevant information including maximum pool levels at Cannonsville and Pepacton and crests at the ten NWS forecast points (Hale Eddy, Fishs

Eddy, Callicoon, Barryville, Port Jervis, Montague, Tocks Island, Belvidere, Riegelsville and Trenton) which will be used for these scenarios. Once this information had been verified, the model was then altered or modified to fit each of the case scenarios described below and re-run. These scenario case runs were then compared with the "actual event" case.

For Case 1, both dams were virtually removed from the model. All modeled inflow into the Cannonsville and Pepacton pools was merely passed as outflow with no lag. Comparing this case to what actually happened provides useful information on how much the dams actually reduced the downstream flow and flood crests during this event despite being full.

For Cases 2, 3 and 4, MARFC set the 8am June 22nd model pool elevations to generate hypothetical voids of about 2.5, 5, and 10 billion gallons at each of the two reservoirs (Table 1). The main effect from these void cases is the delayed timing of reservoir spillage which allows a portion of the unregulated crests for these simulations to pass downstream forecast points before reservoir contributions arrive.

For Case 5, MARFC set outflows for Cannonsville and Pepacton to zero, which in effect held back all contributions to the downstream crest. While this no spill scenario is totally unrealistic for this event, for smaller storms or when reservoir levels are lower, these reservoirs often do hold back all the runoff. This case was run so that the hypothetical intermediate void cases 2, 3, and 4 could be compared against both theoretical extremes, a "no dams" scenario (Case 1) and "no spill" scenario (Case 5).

Table 1. Observed and hypothetical pool elevations used to initialize the model at 8am on June 22nd, 2006. Note: The spillway elevation for Cannonsville is 1150.0 ft and for Pepacton is 1280.0 ft.

	Observed	Case 1 No Res	Case 2 Void ~2.5bg	Case 3 Void ~5bg	Case 4 Void ~10bg	Case 5 No Spill
Cannonsville	1150.33 ft	n/a	1148.5 ft	1147.0 ft	1143.3 ft	1108.40 ft
Pepacton	1279.94 ft	n/a	1278.5 ft	1277.0 ft	1274.5 ft	1259.99 ft

For the Case 5 "No Spill" scenario, calculations were prepared by the NYCDEP to estimate the total amount of inflow into Cannonsville and Pepacton reservoirs for the period June 22 through June 30. For Cannonsville, the total amount of inflow into the reservoir for the 8-day period was 53.9 billion gallons. The initial pool level required on June 22 to hold back all inflow and prevent any spill during the event would have been 1108.40 ft. For Pepacton, the total amount of inflow to the reservoir for the 8-day period was 34.5 billion gallons. To prevent Pepacton from spilling at all during the event, the initial pool level on June 22 would have been 1259.99 ft.

All five hypothetical cases described above are based on the specific hydrometeorological conditions (rainfall amounts and distribution, river levels, soil moisture, etc.) prior to and during the June 2006 event. Therefore, these results cannot be used to accurately quantify the impacts reservoir voids could have on other past or future flood events. However, the results do show that the reservoirs attenuate the flood peak downstream even when they spill.

This modeling effort is strictly hypothetical in that, among other things, the void conditions analyzed do not take into consideration either New York City's water supply needs or the water supply needs of the lower basin parties who may prefer to have water stored in the reservoirs for releases at a later point in time. In addition, the scenarios modeled do not reflect the City's release obligations under the 1954 Supreme Court Decree governing operations of the reservoirs.

The results of all five hypothetical cases simulated for the June 2006 flood were also compared to the results from a previous MARFC report on the April 2005 flood (MARFC, 2006). That report included simulations for the same five hypothetical cases. Tables showing the results from that report are repeated here to make comparison easier.

Results:

Case 1. When Cannonsville and Pepacton reservoirs are removed from the model, the simulated crests at Hale Eddy, Fishs Eddy, Callicoon and Barryville for the June 2006 event are 0.9 to 1.6 ft higher than what was observed (Table 2). These results are similar to the April 2005 flood event where modeling the removal of these two reservoirs increased simulated flood crests at the above forecast points by 1.0 to 2.2 ft (Table 3). Further downstream at Port Jervis, Montague, Tocks Island, Belvidere, Riegelsville and Trenton, the removal of Cannonsville and Pepacton reservoirs results in simulated crests which are 0.6 to 1.3 ft higher than what was observed (Table 2). These results show that, even though they spilled, the Cannonsville and Pepacton reservoirs had a beneficial effect downstream by lowering flood crests during both of these events.

Cases 2 and 3. When initial voids of 2.5 to 5 billion gallons are introduced for each reservoir, simulated crests at Hale Eddy, Fishs Eddy, Callicoon and Barryville are 0.1 to 1.1 ft lower than what actually occurred (Table 2). For the April 2005 event, these same hypothetical voids reduced simulated crests by 0.7 to 1.5 ft (Table 3). Further downstream from Port Jervis to Trenton, initial voids of 2.5 to 5 billion gallons results in simulated crests which are 0.3 to 1.0 ft lower than what actually occurred (Table 2).

Case 4. When an initial void of 10 billion gallons is introduced for each reservoir, the reduction in simulated downstream crests from Hale Eddy to Barryville for the June 2006 event is 2.0 to 3.9 ft (Table 2). For April 2005, a hypothetical 10 billion gallon void in each reservoir reduced simulated crests by 1.1 to 2.4 ft (Table 3). From Port Jervis to Trenton, voids of 10 billion gallons for the June 2006 event result in simulated crests which are 1.0 to 2.0 ft lower than what was observed (Table 2).

The results for cases 2-4 from June 2006 along with the corresponding results from April 2005 event, show that the downstream flood crest reduction that can be expected from a given size initial void is highly variable. The reason for this is the high degree of variation possible in reservoir inflows from one event to another. Reservoir inflow is governed by the timing, distribution, and amount of rainfall and snowmelt, along with antecedent conditions such as soil moisture. All of these can vary greatly from one event to another.

Case 5. When the reservoirs are prevented from spilling in the model, the reduction in downstream simulated crests from Hale Eddy to Barryville for the June 2006 event is 2.0 to 10.3 ft (Table 2). For April 2005, the hypothetical no spill scenario reduced simulated crests by 1.1 to 2.4 ft, which was the same as the April 2005 simulated reduction resulting from a 10 billion gallon void (Table 3). Further downstream from Port Jervis to Trenton, the simulated crests for the June 2006 hypothetical no spill case are 1.6 to 3.1 ft lower than what was observed (Table 2).

Comparing the June 2006 and April 2005 events shows there are some significant differences in results between the 10 billion gallon void scenario and the no spill scenario. In the April 2005 event, the simulated crests on the upper Delaware are the same for both scenarios. For the June 2006 event, the simulated crests for Fishs Eddy are the same for both scenarios, but are significantly different for Hale Eddy, Callicoon and Barryville. This is due to the extreme runoff into the Cannonsville reservoir during the June 2006 event which affects all downstream forecast points except Fishs Eddy (which is only dependent on Pepacton reservoir). The runoff into Cannonsville was so extreme during the June 2006 event that even a 10 bg hypothetical void doesn't reduce or delay the simulated uncontrolled spill enough to prevent it from contributing significantly to downstream crests. These differences in results from the two events can be attributed solely to the amount and distribution of rainfall and corresponding runoff.

The same results as shown in Table 2 and Table 3 for both events, are also shown in Table 4 and Table 5 in terms of river flow in cubic feet per second (cfs) instead of crest height.

Table 2. Maximum pool elevations and flood peaks (ft) from the USGS or NYCDEP for the June 2006 event and simulation results. A "plus" sign indicates the flood peak would have been higher than the observed value and a "minus" sign indicates a lower flood peak would have occurred.

	Actual	Case 1 No Res	Case 2 Void ~2.5bg	Case 3 Void ~5bg	Case 4 Void ~10bg	Case 5 No Spill
Cannonsville	1160.08		1159.7	1159.4	1158.4	1150.0
Pepacton	1283.66		1283.6	1283.6	1283.4	1280.0
Hale Eddy	19.10	+1.6	-0.7	-1.1	-3.4	-10.3
Fishs Eddy	21.43	+1.3	-0.1	-0.4	-2.0	-2.0
Callicoon	20.38	+0.9	-0.4	-0.8	-2.6	-3.9
Barryville	28.97	+1.4	-0.5	-1.1	-3.9	-5.8
Port Jervis	21.47	+0.8	-0.3	-0.6	-1.6	-2.5
Montague	32.15	+1.3	-0.5	-1.0	-2.0	-3.1
Tocks Island	33.87	+1.1	-0.4	-0.8	-1.7	-2.6
Belvidere	27.16	+0.9	-0.3	-0.7	-1.7	-2.6
Riegelsville	33.62	+1.1	-0.4	-0.8	-1.6	-2.4
Trenton	25.09	+0.6	-0.3	-0.6	-1.0	-1.6

Table 3. Maximum pool elevations and flood peaks (ft) from the USGS or NYCDEP for the April 2005 event and simulation results. A "plus" sign indicates the flood peak would have been higher than the observed value and a "minus" sign indicates a lower flood peak would have occurred.

	Actual	Case 1 No Res	Case 2 Void ~2.5bg	Case 3 Void ~5bg	Case 4 Void ~10bg	Case 5 No Spill
Cannonsville	1156.79		1156.4	1156.2	1155.3	1150.0
Pepacton	1283.69		1283.5	1283.3	1282.8	1280.0
Hale Eddy	14.12	+2.2	-1.1	-1.5	-2.4	-2.4
Fishs Eddy	22.49	+1.0	-0.7	-1.0	-1.1	-1.1
Callicoon	17.97	+1.1	-0.8	-1.1	-1.2	-1.2

Note: For the April 2005 event, only Case 1 was simulated downstream to Trenton. Flood peaks for the no reservoir case were estimated to be 0.5 to 1.5 feet higher at forecast points from Barryville to Trenton.

Table 4. Observed flows (cfs) from the USGS or NYCDEP for the June 2006 event and simulation results. A "plus" sign indicates the flood peak would have been higher than the observed value and a "minus" sign indicates a lower flood peak would have occurred.

	Discharge	Case 1 No Res	Case 2 Void ~2.5bg	Case 3 Void ~5bg	Case 4 Void ~10bg	Case 5 No Spill
Cannonsville	34,058	n/a	31,000	29,000	22,000	n/a
Pepacton	19,108	n/a	19,000	18,400	17,000	n/a
Hale Eddy	43400	+6800	-3400	-5000	-13800	-32800
Fishs Eddy	77400	+8500	-600	-2200	-12200	-12300
Callicoon	144000	+11300	-4700	-9100	-30800	-45000
Barryville	151000	+11300	-4700	-9100	-30800	-45000
Port Jervis	189000	+13400	-5900	-11000	-28000	-41200
Montague	212000	+16500	-6700	-12200	-24100	-43500
Tocks Island	225000	+16500	-6700	-12800	-24100	-36800
Belvidere	225000	+13800	-5700	-11000	-25800	-37900
Riegelsville	254000	+16400	-6500	-12600	-23400	-35200
Trenton	237000	+19000	-5800	-11100	-20100	-32100

Table 5. Observed and estimated maximum flows (cfs) from the April 2005 event and simulation results. A "plus" sign indicates the flood peak would have been higher than the observed value and a "minus" sign indicates a lower flood peak would have occurred. An "o" indicates the flow was observed by the USGS or NYCDEP and an "e" indicates the flow was estimated using MARFC's operational forecast model.

	Discharge	Case 1 No Res	Case 2 Void ~2.5bg	Case 3 Void ~5bg	Case 4 Void ~10bg	Case 5 No Spill
Cannonsville	15,318 (o)	n/a	14,000	13,200	10,500	n/a
Pepacton	19,296 (o)	n/a	17,600	16,100	12,700	n/a
Hale Eddy	21500 (o)	+5700	-4600	-5800	-8100	-8100
Fishs Eddy	86000 (e)	+6700	-4700	-6900	-7500	-7500
Callicoon	114000 (e)	+11900	-8200	-11800	-12700	-12700

Conclusions:

1) For both events, the Upper Delaware basin crest reductions due to the presence of the Cannonsville and Pepacton reservoirs ranged from 0.9 to 2.2 feet while lower basin crest reductions ranged from 0.5 to 1.5 feet. Cannonsville and Pepacton reservoirs attenuated flood peaks downstream even though they spilled, so their mere presence was beneficial despite having no additional storage capacity.

2) A "No Spill" scenario for the June 2006 event would have required a massive pre-storm drawdown of pool levels of 41.93 feet (53.9 billion gallons) at Cannonsville reservoir and 19.95 feet (34.5 billion gallons) at Pepacton reservoir. Such an unrealistic drawdown would hypothetically yield a crest reduction of 2.0 to 10.3 ft on the Upper Delaware basin, and 1.6 to 3.1 feet on lower portions of the basin.

3) For both events, the magnitude of the flood mitigation provided by the dams (even when they spilled) was greater than or equal to the additional benefit that would have been provided by voids of 5 bg or less.

4) Voids, if possible, would have provided additional attenuation of downstream flood peaks.

5) Comparing the June 2006 and April 2005 events shows that voids up to 5 billion gallons in each reservoir would have provided a similar reduction in downstream crests. Voids of 10 billion gallons or voids large enough to prevent the reservoirs from spilling at all would provide differing degrees of downstream peak reduction, based on the characteristics of the specific hydrometeorological event. Using specific reservoir void targets thus would not yield the same level of flood mitigation for every event.

6) The case study results presented here, while demonstrating the potential benefits of reservoir voids, are insufficient for optimizing flood mitigation plans for reservoirs in the Delaware basin. A detailed modeling analysis is needed that takes into account all large reservoirs; their release capabilities; limitations due to their hydropower, water supply, and other obligations; and the full range of historical and potential future hydrometeorological conditions.

Notes: This report was revised/updated in response to requests to re-run the simulations further downstream to Trenton, NJ. In addition, updated rating curves from the USGS were utilized where available, which also leads to slight revisions in some of the numerical results.

References:

MARFC, August 2006: Model Simulations for the Upper Delaware River Basin Flooding of April, 2005. Report to the DRBC.