Model Simulations for the Upper Delaware River Basin Flooding of April, 2005

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<u>Introduction/Background:</u> 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 they spilled during this event, reservoirs contributed to a reduction in 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.

The hope was that the information from these simulations would contribute to a better understanding of the impacts of the reservoirs.

During the April 2-4 event, major flooding was observed at many locations throughout the basin. This report addresses in detail the effects of 2 large dams affecting the watershed: Cannonsville and Pepacton. MARFC currently models inflows to these two reservoirs. MARFC does not currently explicitly model inflows and outflows from the Neversink, Rio, and Wallenpaupack reservoirs. Therefore, only ballpark estimates of the impacts downstream of Callicoon could be computed.

For Cannonsville and Pepacton, MARFC was asked to run hypothetical model simulations for the cases of no reservoir, various reservoir voids, and no spill, and to show the effects of these hypothetical scenarios on river levels at 3 NWS forecast points: Hale Eddy, Fishs Eddy and Callicoon. 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.

The hypothetical simulations done in this report start at 8am April 1, prior to the heavy rain that caused the April 2-4 major flood. For the void cases, hypothetical reservoir voids of 2.5, 5, and 10 billion gallons are used at the start of these simulations on April 1st. However, it is important to note that a significant rain event also impacted the area just a few days earlier on March 28-29, 2005 and the inflow to each of the two reservoirs exceeded 10 billion gallons from this precursor event.

Limitations/Other Considerations:

The methodology used for these simulations is based on output from the MARFC's hydrologic forecast model, and MARFC believes the results in this report are reasonably accurate. However, it should be noted that this model is optimized for operational river forecasting, not hydraulic engineering studies.

The results are hypothetical cases based on a single flood event on April 2-4, 2005. Results are insufficient for accurately predicting the impacts of hypothetical reservoir voids on other past or future flood events.

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. Also, this report does not address New York City's obligation to manage the water supply system prudently for water supply purposes, to ensure a safe and adequate supply for nine million people who rely on the City's water. In addition, the scenarios modeled do not reflect the City's release obligations under the 1954 Supreme Court Decree governing operations of the Cannonsville and Pepacton reservoirs. Also, the report does not consider the potential adverse water quality impacts of maintaining drawdown conditions in these reservoirs.

Additional Background:

Pool/Spillway Elevations - The pool elevation is the elevation of the water level in the reservoir. The spillway elevation is the elevation of the top of the spillway. As the runoff from precipitation flows into the reservoir, the pool level rises. When the pool elevation rises sufficiently to exceed the spillway elevation of the reservoir, the reservoir experiences an uncontrolled spill. Spilling continues as long as the pool elevation exceeds the spillway elevation.

Spillway Elevations	Cannonsville 1150.0 ft	Pepacton 1280.0 ft

The pool elevations at both Cannonsville and Pepacton exceeded the spillway elevation during the April 2-4 flood, resulting in an uncontrolled spill. The table below shows the observed maximum pool elevations and spill rate during the flood.

Observed Max Pool Elevations and Spill Rate during Flood of April 2005

	Max Pool El	**Max Spill Rate**	**Max Spill Rate**	**Time of Max Release**
Cannonsville	1156.79 ft	9902.8 mgd	15318.4 cfs	4/4/05 225-600 am
Pepacton	1283.69 ft	12473.5 mgd	19296.5 cfs	4/3/05 610-615 am

Reservoir Voids – A void is the amount of additional water that can be added to the reservoir before it begins spilling. For a particular reservoir, the void is a function of the pool elevation. For example, a void of about 5 billion gallons corresponds to a pool elevation at Cannonsville of 1148.5 ft.

Simulation Approach: To run these cases, MARFC first set up its forecast model with all initial conditions that were present at 8am April 1, 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 3 NWS forecast points (Hale Eddy, Fishs Eddy and Callicoon) 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 and re-run. These scenario case runs were then compared with the "actual event" case.

For Case 1, the dams were virtually removed from the model. All modeled inflow into the Cannonsville and Pepacton pools was merely passed as outflow with no lag. Of course this is not realistic, but 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.

For Cases 2, 3 and 4, MARFC set the 8am April 1 model pool elevations to generate hypothetical voids of about 2.5, 5, and 10 billion gallons at both Cannonsville and Pepacton. The main effect from these void cases is the delayed timing of reservoir spillage which allows the unregulated crests for these simulations to pass downstream forecast points before reservoir contributions arrive.

After running these simulations, MARFC was asked how low the hypothetical initial pool elevation would need to be prior to the precursor heavy rain event on March 28-29 in order for the reservoirs to have been at the hypothetical voids of 2.5, 5, and 10 billion gallons at 8am on April 1. According to the New York City Department of Environmental Protection (NYC DEP), the reservoirs' operator, the precursor rain event produced inflows of about 18.5 billion gallons to the Cannonsville Reservoir and just over 14 billion gallons to the Pepacton Reservoir. Therefore, to achieve the hypothetical voids of 2.5, 5, and 10 billion gallons used in cases 2, 3, and 4, the initial voids on March 27 would have had to have been 21, 23.5, and 28.5 billion gallons at Cannonsville and 16.5, 19, and 24 billion gallons at Pepacton. Based on these voids, NYC DEP provided us with the hypothetical March 27 initial pool elevations shown below for cases 2, 3, and 4.

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, it 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).

In summary, here are the initial conditions used for each of the simulation scenarios run:

Actual Event Case

Pool Elevations 8 am March 27th	Cannonsville 1150.25 ft	Pepacton 1274.13 ft
Pool Elevations 8 am April 1st	Cannonsville 1153.47 ft	Pepacton 1280.75 ft

Simulation Case 1 – No Reservoir / Pass Outflow as Inflow

Cannonsville and Pepacton – Substituted inflow for outflow in the model.

Simulation Case 2 – Void about 2.5 billion gallons on April 1

Initial Pool Elevations March 27th	Cannonsville 1135.7 ft	Pepacton 1270.6 ft
Pool Elevations 8 am April 1st	Cannonsville 1148.5 ft	Pepacton 1278.5 ft

Simulation Case 3 – Void about 5 billion gallons on April 1

Initial Pool Elevations March 27th	Cannonsville 1134.0 ft	Pepacton 1269.0 ft
Pool Elevations 8 am April 1st	Cannonsville 1147.0 ft	Pepacton 1277.0 ft

Simulation Case 4 – Void 10 billion gallons on April 1

Initial Pool Elevations March 27th	Cannonsville 1129.9 ft	Pepacton 1266.3 ft
Pool Elevations 8 am April 1st	Cannonsville 1143.3 ft	Pepacton 1274.5 ft

Simulation Case 5 – No Spill

Outflow set to zero in the model. No spill contributions on crests from Cannonsville and Pepacton.

<u>Results:</u> The results in Table 1 show actual max pool elevations and crests from the event as well as results from the 5 case scenarios. A plus (+) indicates how much higher the crest would be for a particular scenario, a minus (-) indicates how much lower the crest would be for that scenario.

For example, Table 1 shows that for Case 3, when the void in the reservoir is initialized at 5 billion gallons, the peak in the pool elevation at Cannonsville for the April flood is 1156.2 feet and at Pepacton is 1283.3 feet. While these peaks are only slightly lower than the actual maximum pool elevations of 1156.79 feet and 1283.69 feet, respectively, the delay in the release of water results in a downstream crest at Hale Eddy that is 1.5 feet below the 14.12 foot actual crest.

Case 4 shows that, when the void is increased to 10 billion gallons, the delayed release of water results in a crest at Hale Eddy that is 2.4 feet below the 14.12 foot actual crest. Comparing to Case 5 shows that this reduction in the downstream crest is the same as for a scenario in which the reservoirs do not spill at all. This is due to the fact that this void causes a sufficiently long delay in the peak spill, such that the crest due to initial surface runoff passes the forecast point before the water from the peak spill reaches the same point. This also means that increasing the initial void to more than 10 billion gallons would not result in any further reduction in flood crests downstream.

Table 1 also shows that during the April Flood the Cannonsville and Pepacton reservoirs, even though they spilled, reduced the flood crest downstream. This can be seen by comparing the Actual column to the no reservoir scenario, Case 1. Without the reservoirs, the April flood crests would have been 16.3 feet or 2.2 feet higher at Hale Eddy, 23.5 feet or 1.0 foot higher at Fishs Eddy, and 19.1 feet or 1.1 foot higher at Callicoon.

The results in Table 2 show the corresponding impacts on flows from the same scenarios as those shown in Table 1. The table shows observed and estimated maximum flows from the event. The observed flow (USGS) was at Hale Eddy, with estimated flows from MARFC’s operational forecast model at Fishs Eddy and Callicoon (estimated flows used due to gage difficulties during the event). A plus (+) indicates how much higher the flow would be for a particular scenario, a minus (-) indicates how much lower the flow would be for that scenario.

The same conclusions as drawn from the crest results in Table 1, can also be drawn in terms of flow from looking at the flow results in Table 2.

Table 1

Actual Max Pool Elevations and Crests (USGS) in feet from the event and Results (+/-) on crests from Case Simulations (+ above actual event; - below actual event)

	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 ft		1156.4 ft	1156.2 ft	1155.3 ft	1150.0 ft
Pepacton	1283.69 ft		1283.5 ft	1283.3 ft	1282.8 ft	1280.0 ft
Hale Eddy	14.12 ft	+2.2 ft	-1.1 ft	-1.5 ft	-2.4 ft	-2.4 ft
Fishs Eddy	22.49 ft	+1.0 ft	-0.7 ft	-1.0 ft	-1.1 ft	-1.1 ft
Callicoon	17.97 ft	+1.1 ft	-0.8 ft	-1.1 ft	-1.2 ft	-1.2 ft

Table 2

Observed and Estimated Max Flows in CFS (cubic feet per second) from MARFC's operational forecast model using the most recent USGS rating curves as of April 2006 and Results (+/-) on crests from Case Simulations (o – observed, e – estimated, + above actual event, - below actual event)

	Discharge	Case 1 No Res	Case 2 Void ~2.5bg	Case 3 Void ~5bg	Case 4 Void 10bg+	Case 5 No Spill
Hale Eddy	21,500 cfs (o)	+5700 cfs	-4600 cfs	-5800 cfs	-8100 cfs	-8100 cfs
Fishs Eddy	86,000 cfs (e)	+6700 cfs	-4700 cfs	-6900 cfs	-7500 cfs	-7500 cfs
Callicoon	114,000 cfs (e)	+11900 cfs	-8200 cfs	-11800 cfs	-12700 cfs	-12700 cfs

Downstream Effects:

In addition to Hale Eddy, Fishs Eddy and Callicoon, the National Weather Service examined effects of the Cannonsville, Pepacton, Neversink, Rio, and Wallenpaupack reservoirs further downstream to Barryville, Port Jervis, Montague, Tocks Island, Belvidere, Riegelsville and Trenton. Comparing the No Reservoir Case to the actual observations, these five reservoirs reduced flood crests by roughly 0.5 to 1.5 feet at the downstream points from Barryville to Trenton.

The National Weather Service did not explicitly model the reservoirs at Neversink, Rio and Wallenpaupack. Assumptions which include inflows to these reservoirs, areal size of these drainage basins and surface runoff amounts were made to simulate the effects of removing these reservoirs from the basin. The results obtained were based on these inexact approximations. Therefore, this information on downstream effects should only be considered a ballpark estimate.

Conclusions:

1) The effect of having these 2 major reservoirs (Cannonsville and Pepacton) in the watershed subtracts 1.0 to 2.2 ft on crests at Hale Eddy, Fishs Eddy, and Callicoon for these simulations. Even though they spilled, these two reservoirs reduced crests downstream. (See Case 1)

2) The effect of reducing the pool levels at Cannonsville and Pepacton by roughly 2.5 to 5 billion gallons has the effect of reducing downstream crests at the above listed forecast points by 0.7 to 1.5 ft. (See Case 2 and Case 3)

3) The effect of reducing the pool levels at Cannonsville and Pepacton by 10 billion gallons of water or more in these simulations has the same effect on crests as a no spill scenario. The delayed spill subtracts 1.1 to 2.4 ft on crests at the above listed forecast points for these simulations. The crest is driven entirely by initial surface runoff. (See Case 4 and Case 5)

4) Even though they spilled, the five reservoirs likely reduced the magnitude of flood crests on the lower Delaware (Barryville to Trenton) by roughly 0.5 to 1.5 feet.

Limits on Scope and Application of Results:

The methodology used for these simulations is based on output from the MARFC's hydrologic forecast model, and MARFC believes the results in this report are reasonably accurate. However, it should be noted that this model is optimized for operational river forecasting, not hydraulic engineering studies.

The results are hypothetical cases based on a single flood event on April 2-4, 2005. Results are insufficient for accurately predicting the impacts of hypothetical reservoir voids on other past or future flood events.

As noted in the section labeled Limitations/Other Considerations above, this analysis does not take New York City's water supply concerns into consideration.