Delaware River Basin Flood Analysis Model
Independent External Peer Review Report

Prepared for:
Federal Emergency Management Agency, Region III
Delaware River Basin Commission

Prepared by:

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EXECUTIVE SUMMARY

An independent external peer review was conducted to review the Flood Analysis Model that was developed for the Delaware River basin and calibrated for the recent September 2004, April 2005, and June 2006 flood events. The rainfall/snowmelt-runoff processes were simulated using PRMS. Reservoir operations and flood flow routing through the river system below the reservoirs were simulated using HEC-ResSim. The HEC-ResSim model has two modeling alternatives. Alternative FC-PRMS uses inflows generated by the PRMS model. Alternative FC-GageQ uses inflows derived from the observed gage data for the three flood events.

The review was focused on the methodologies and the results presented in the PRMS and HEC-ResSim modeling reports and the HEC-ResSim model input and output. Based on the review comments and the responses to the comments, our overall findings are as follows:

- The Flood Analysis Model with HEC-ResSim Alternative FC-GageQ adequately represents the baseline conditions of the basin during flood conditions.

- The HEC-ResSim component of the model with Alternative FC-GageQ is adequate for use to investigate any impacts of alternative reservoir operations on the downstream river stages for the three flood events.

- The Flood Analysis Model with HEC-ResSim Alternative FC-PRMS did not satisfactorily reproduce the peak flows and total volumes that occurred during the three major flood events.

- The PRMS component of the model was not able to generate inflows that would result in good agreement with the observed conditions at many locations in the river system for the three events. Due to the uncertainties of the input precipitation data, the raw MPE data were adjusted as part of the model calibration.

- Unless details can be presented to clearly demonstrate that the rainfall-runoff processes were adequately represented in the PRMS model and that the discrepancies between simulated and observed hydrographs are primarily due to the errors in the input precipitation data, the model is not recommended for use to investigate any impacts of watershed conditions on the basin runoff.

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INTRODUCTION

Three major floods recently occurred in the Delaware River basin, including the September 2004 event driven by a landfalling tropical cyclone, the April 2005 event driven by a winter-spring extratropical system, and the June 2006 event driven by a warm-season convective system (Smith et al., 2010). Following the three floods, a Delaware River Basin Interstate Flood Mitigation Task Force was established to develop a set of recommended measures for mitigating and alleviating flooding impacts along the main stem Delaware River and its tributaries. One of the recommendations was to develop a flood analysis modeling tool (Delaware River Basin Interstate Flood Mitigation Task Force, 2007). Accordingly, an interagency team of the U.S. Geological Survey (USGS), U.S. Army Corps of Engineers (USACE), National Weather Service (NWS), and the Delaware River Basin Commission (DRBC) developed a flood analysis model that represents baseline conditions of the basin. The model can simulate rainfall-runoff processes, including snowmelt, and reservoir operations under flood conditions and routing of flood flows through the river system. A rainfall-runoff PRMS model was developed by the USGS for simulations of runoff and reservoir inflows (Goode et al., 2010). A reservoir operations and streamflow routing HEC-ResSim model was developed by the USACE, Hydrologic Engineering Center (HEC, 2010b and 2011). The two model components were integrated through a User-Interface. The Flood Analysis Model for the Delaware River basin above Trenton was calibrated for the September 2004, April 2005, and June 2006 flood events.

At the request of the DRBC, Region III of the Federal Emergency Management Agency (FEMA), and Risk Assessment, Mapping, and Planning Partners (RAMPP), WEST Consultants, Inc. (WEST) performed an independent external peer review (IEPR) of the Flood Analysis Model. This report documents our comments, questions, findings, and recommendations.

REVIEW SCOPE

The purpose of the IEPR is to evaluate the technical information, assumptions, and methodologies used to develop the Flood Analysis Model to ensure that the data and modeling are consistent with standard engineering practices. In accordance with the IEPR scope of work, the technical evaluation focused on the following areas:

- Adequacy of Flood Analysis Model to reproduce observed conditions for the three flood events

- Utility of the model to assess the impact of voids in designated Delaware River Basin reservoirs on the downstream river stages for the three flood events

- Utility of the PRMS component of the model to evaluate the impact of watershed conditions on the three flood events.

In addition, the IEPR focused more on the HEC-ResSim model. Only the PRMS modeling report was reviewed to evaluate the approaches and performance of the model.

REVIEW APPROACH

A formal comment-response-back-check process is followed. A technical memorandum that documents the PRMS model review was submitted to the DRBC on August 23, 2010. The DRBC provided WEST USGS' responses to the comments on April 5, 2011. A second technical memorandum that includes the HEC-ResSim model review was submitted to the DRBC on October 15, 2010. The DRBC forwarded WEST HEC's responses to the comments on June 13, 2011. A revised HEC-ResSim modeling report and a revised HEC-ResSim model were also provided. The IEPR comments, comment responses, and back-check comments on the PRMS and HEC-ResSim models are included in the next two sections. The cover pages of USGS and HEC's responses are included in Appendix A. The overall IEPR findings and recommendations are provided in the Summary and Recommendation section.

PRMS REVIEW

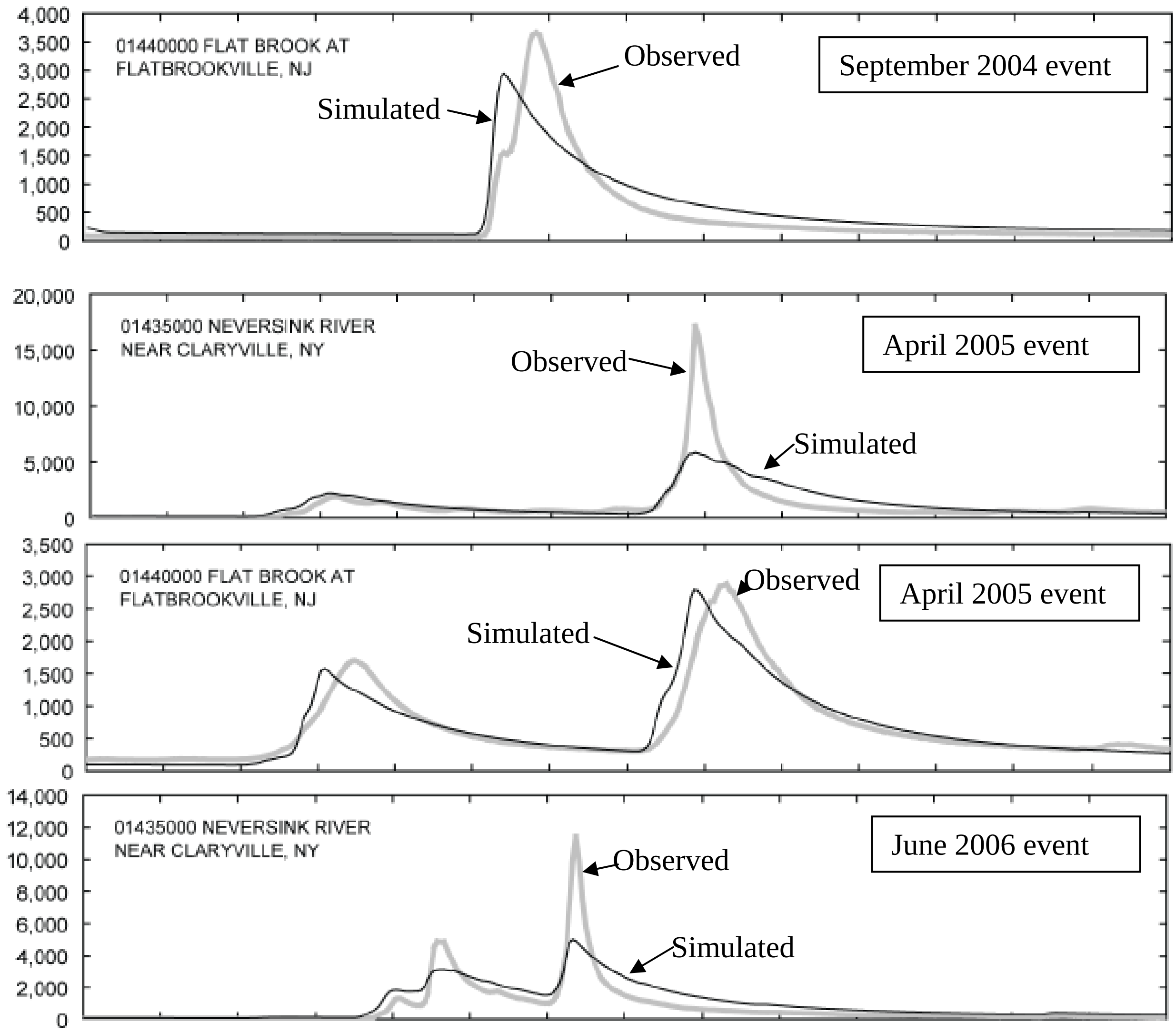
General Comments

1. Comment - The PRMS model report clearly describes the processes that were followed to collect data, estimate model parameters, and calibrate the model. However, the report does not provide details or discussions of the model parameters and results. For example, the report does not discuss the reasonableness of the calibrated model parameters. The report also does not provide detailed and subbasin-specific explanations of why the simulated hydrographs are significantly different from the observed ones at many gaging locations.

   Comment Response – We agree that the report (Goode and others, 2010) does not provide a detailed discussion of all of the model parameters and results. Additional discussion of model parameters and results could be provided if needed. There are several thousand parameters in the model and graphical tools are provided with the model to examine the parameters in detail. Dr. Hu states that "simulated hydrographs are significantly different from the observed one." We agree that the model results are different than the measured streamflow, as is the case with any model. However, we do not agree that these differences are "significant" with respect to the study purposes. We stand behind our judgment that the model results are adequate for the study purposes, as indicated in the report. Model error statistics and graphical hydrographs are provided in the report that demonstrate the accuracy, or lack of accuracy, of the model results. Additional graphs of model output can be prepared using the provided graphical tools. Additional discussion of the details of the differences in the simulated and measured streamflow could be provided if needed.

   Back-Check Comment – The IEPR has only one review cycle. The DRBC has not requested that a revised report with discussions of model parameters and results be provided by the USGS.

   WEST does not concur with the response to the comment on the accuracy of the simulated and observed flow hydrographs at many gaging stations. The PRMS modeling report (Goode et al., 2010) presents the comparisons of the simulated and observed hydrographs in Figures 10 through 14. There are clearly significant discrepancies at some stations. The following are just a few examples that are taken from the PRMS modeling report.



2. Comment - The model was calibrated to the September 2004, April 2005, and June 2006 events. Was any of the three events used as a validation event? To ensure a model's predictability, the model should also be validated for at least one independent flood event. For the validation purpose, only the event-dependent model parameters can be adjusted.

   Comment Response – The model was calibrated for three flood events; none of the three was used as a "validation event". Provided that appropriate basin-wide meteorological data could be developed at some point in the future for another large main stem flood, it would be possible to conduct an additional simulation to demonstrate the utility of the model. When commenting on the need for a validation event to ensure the model's predictability, consideration needs to be given the fact that this watershed model is by no means a standard application of a watershed model. This model is simulating flood peak discharge and stage for three exceedingly high flow events. These flow events represent the third, fourth, and seventh highest events in 111 years of record at the Trenton gage. The model is also simulating flow on an hourly time-step, which may be a first-of-its-kind application, considering the size and complexity of the Delaware Basin. Finally, one of the three events was substantially affected by snowmelt, which required the development of an hourly snowmelt routine. To hold back one of the events to use for validation purposes would have significantly hampered the calibration of the model. As pointed out by Smith and others (2010), the meteorological factors causing each of the three events were unique. Thus, eliminating one of these three unique events from the calibration set would have further limited the applicability of the model. To use a historical flood event of equivalent magnitude would require going back to at least 1955 in the record, when sparse data, different land use characteristics, and absence of several key reservoirs would block any attempt to use the event for validation purposes. For these reasons, the decision was made to use all of the event data for calibration purposes and forego a validation step. We believe this was a reasonable decision.

Back-Check Comment – Concur. WEST suggests that the discussion above be incorporated into the PRMS modeling report if it will be revised.

3. Comment - The model was calibrated to minimize the difference between the observed and simulated flow hydrographs. The normalized root mean square error (NRMSE) is a calibration measure. While NRMSE provides a good indication of the overall fit of the simulated hydrographs with the observed hydrographs both for the low and high flows, the report does not specifically discuss how well the model simulates the high flows, which appears to be the primary focus of the Flood Analysis Model. Because the purpose of the PRMS model is to provide inflows to the HEC-ResSim reservoir model, a more practical calibration approach is to reduce the difference between computed and observed results for runoff volume, peak discharge, and peaking time with a greater emphasis on matching volumes. The interagency team would need to agree on the targeted model accuracy. Based on our experience for similar flood simulations, a difference of 10% in volume may be acceptable.

   Comment Response – The normalized root mean square error was used as an objective function for the automatic portion of the model calibration. Manual adjustment of rainfall scaling factors was done to improve the graphical match between simulated and measured streamflow volume during the flood events. Thus, the manual adjustments considered the runoff volume during the event, in a graphical manner, but this was not directly used as part of the calibration objective function during automatic calibration. Peak discharge and timing of the peak were not directly included in the automatic calibration targets. It would be possible to re-calibrate the PRMS model using alternative calibration targets and approaches, beyond those identified by the project team.

   Back-Check Comment – Concur.

4. Comment - The report states that the simulated and observed hydrographs at streamgage locations demonstrate the model's ability to reproduce streamflows that were observed during the flood event. However, we are concerned that the simulated peak discharge, or the time of the primary peak, or the volume of the primary hydrograph, or a combination, are significantly different from the observed ones at many locations. Table 10 shows the observed and simulated mean of hourly streamflow. The comparisons do not indicate that a

good agreement was achieved. For example, the difference is greater than ± 10% for 32 out of 35 gages for the September 2004 event and for 25 out of 35 gages for the June 2006 event.

Comment Response - Table 10 lists the mean hourly streamflow values for the full duration of the three events. As the mean values include some antecedent and post-peak lower flows, comparison of these observed and simulated values will not be indicative of how accurately the magnitude and timing of peak flows were simulated. They can be used to compare event volumes. Inclusion of the lower flows, which were not specifically calibrated, contributes in many cases strongly to the simulation differences in table 10. We stand behind our judgment that the model results are adequate for the study purposes, as indicated in the report.

Back-Check Comment – Similar to General Comment 1, WEST does not agree with USGS' judgment that the model results are adequate for the study proposes. Our conclusion that a good agreement was not achieved at many locations was supported by the following results presented in the PRMS and HEC-ResSim modeling reports:

a. We understand that the purpose of the PRMS model was to provide reasonably accurate hydrographs of inflows to the headwater reservoirs modeled in the HEC-ResSim model and incremental local inflows downstream of the reservoirs. Therefore, both the volumes and peak flows are important. We agree that the comparisons using mean values alone do not necessarily provide indications of model accuracies of the magnitude and timing of peak flows. However, the results presented in Table 10 do not indicate a reasonable match of event volumes. For the September 2004 event, the difference in simulated and observed mean values is greater than 30% for 10 out of 35 gages. As shown in Figure 10 in the PRMS modeling report, this flood was a single peak event. The simulated hydrographs for the antecedent and post-event periods match the observed ones well, suggesting that the differences in the mean values (and the volumes) are primarily during the flood period.

b. As described in General Comment 1 and presented in Figures 10 through 14 of the PRMS modeling report, at many gaging locations, the simulated and observed hydrographs are very different.

c. As described in the HEC-ResSim modeling report (Section 5.1, Page 63, HEC, 2011), the PRMS-generated inflows were first used in the HEC-ResSim model (Alternative FC-PRMS). However, the HEC-ResSim model did not satisfactorily reproduce the peak flows or total volumes that occurred during the flood events. A second inflow data set had to be derived using observed flow data and used in the HEC-ResSim model (Alternative FC-GageQ). This alternative more closely reproduces the peak flows and total volumes that occurred. Figure 1 and Figure 2 are two examples that are taken from the HEC-ResSim modeling report. The figures clearly illustrate the significant differences in the inflows that were generated from the PRMS model and that were derived from the observed flow data.

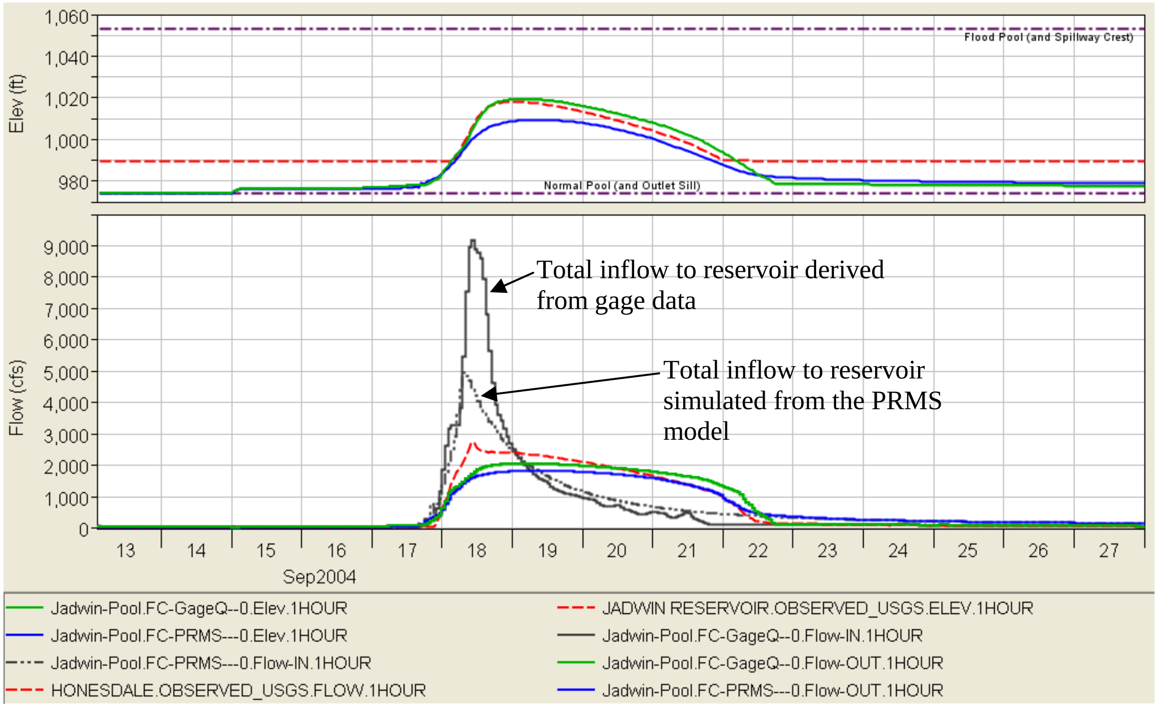


Figure 1. Jadwin Reservoir plot for the September 2004 event (source: HEC, 2011).

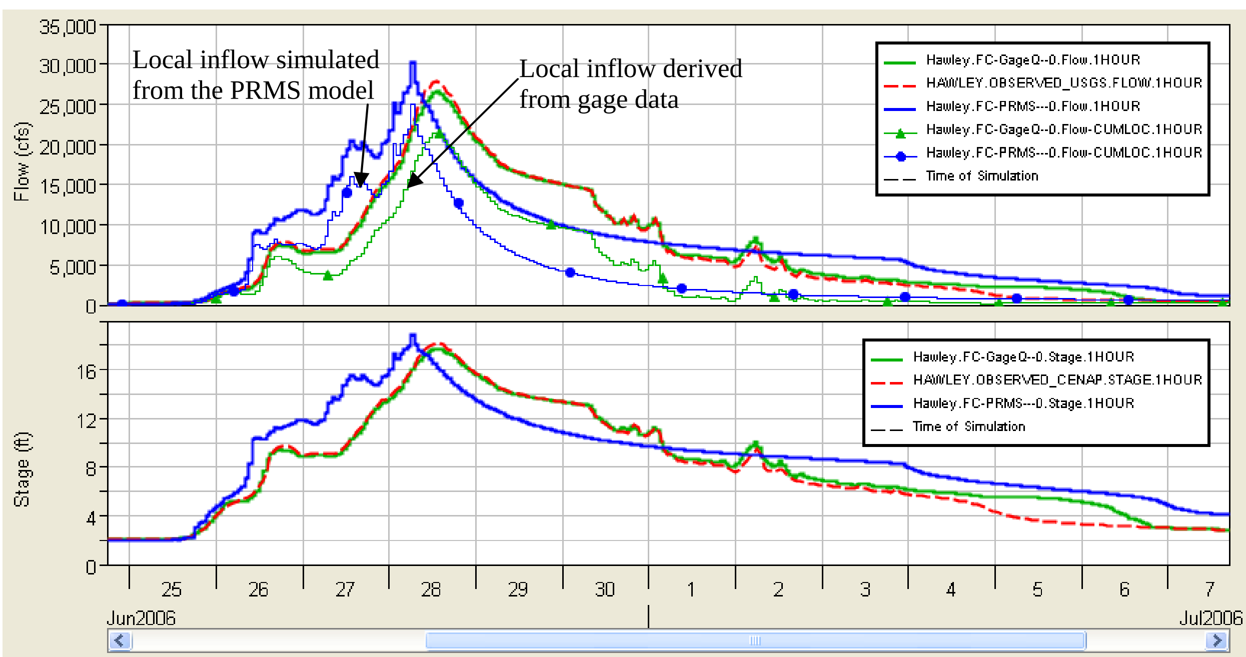


Figure 2. Hawley flow and stage plot for the June 2006 (source: HEC, 2011).

Specific Comments and Questions

1. Comment - Page 10, Hourly Simulation Mode. A kinematic wave routing approach is used throughout the model. Is the kinematic wave approach applicable everywhere? This

approach, in general, works best for well defined channels. It cannot handle hydrograph attenuation due to significant overbank storage.

Comment Response - PRMS allows selection of only one routing method. Kinematic wave was selected as the better overall choice for the hourly simulation of streamflow above reservoirs and in tributaries to the main stem. Because the reservoir simulation model performs routing downstream of the reservoirs the PRMS routing was not used below simulated reservoirs or in the main stem for the flood analysis model. The HEC-ResSim model routes streamflow below the simulated reservoirs and produces the main stem streamflow results of the flood analysis model (U.S. Army Corps of Engineers, 2010).

Back-Check Comment – Concur. WEST suggests that the justification of why the Kinematic wave method was selected be included in the PRMS modeling report if it will be revised.

2. Comment - Page 12, Elevation Data and Watershed Discretization. The watershed discretization was based on the 100-m DEM. Why the readily available 30-m DEM data were not used? Were the discretization results compared to existing delineations, for example, comparing the delineated drainage area to the USGS published values at streamflow gaging locations?

   Comment Response - Due to size-handling limitations of discretization/parameterization software, the original intent to use 30-m DEM data for the 6,780 mi^2 basin was not feasible. The minor differences observed in drainage areas were deemed acceptable for model development. Local elevations and slopes in the DEM are not used in the PRMS model, only HRU-average values. HRUs were graphically compared to HUC basins and deemed acceptable for model development.

   Back-Check Comment – Concur.

3. Comment - Page 15-Page 17, Table 3. A roughness parameter of 0.005 is used for overland flow plane. This value seems very low.

   Comment Response - The overland flow method type (99) used for all HRUs in the model does not use the ofp_rough parameter. This parameter should not have been included in the tables in the report.

   Back-Check Comment – Noted.

4. Comment - Page 35, Third Paragraph. Are there any hourly observed reservoir outflows? If so, why were the observed hourly outflows not used in the hourly calibration?

   Comment Response - Hourly outflows, or streamflows at nearby downstream gages, were available for several reservoirs. However, the automatic calibration procedure of PRMS alone did not include a simulation component for the reservoirs. In the flood analysis model the simulation of the reservoirs is done with HEC-ResSim, using PRMS inflows. HEC-ResSim calibration used hourly reservoir outflows. The manual calibration of PRMS included consideration of downstream flows simulated by HEC-ResSim at USGS gages available for calibration. Thus, the PRMS calibration did include hourly flows at the gages downstream of the reservoirs, but the automatic calibration for headwater (unregulated) areas did not.

Back-Check Comment – Concur.

5. Comment - Page 35, Fourth Paragraph. Adjustment factors were used to adjust the input of precipitation in order to achieve a better match of volume. Table 3 on Page 16 shows that the adjustment factor is as large as 3.0. We are significantly concerned about this approach. Adjusting the precipitation input is not common. Detailed justifications need to be provided to demonstrate that the MPE-based precipitation data are truly in error, and, therefore, need adjustment. It also needs to clearly demonstrate that the discrepancy between the simulated and observed hydrographs is not due to other processes modeled, such as snowmelt.

   Comment Response - Simulated storm volume with un-adjusted MPE (radar) precipitation was well below that measured at USGS streamgages for each of the three events at locations where scaling was used. Radar precipitation has rarely been used in flooding rainfall runoff simulation, so previous experience based on rain gage data is not applicable to the present study. Smith and others (2010) describe the hydrometeorology of the three events and show maps of gage-based and radar-based total storm precipitation depth for the June 2006 event (figs. 8 & 9). The gage-based precipitation is more than twice as large as the radar-based precipitation in much of the model area. Numerous other studies have suggested that radar-based precipitation can substantially under-estimate extreme precipitation depth. We re-checked the model water budget on a small subbasin to confirm that excess precipitation needed in the model was not caused by over-simulated ET or other unreasonable model fluxes. More details on the results of this analysis are available if needed. The April 2005 event was affected by snowmelt, perhaps as much as 4 inches of water equivalent, and part of the precipitation scaling used for this event compensates for under-simulated snowmelt in the model (see next reply).

   Back-Check Comment – Multisensory Precipitation Estimates (MPE) data are a combination of radar information and actual precipitation gage measurements. Hourly precipitation estimates from radar are compared to ground gage measurements, and a bias (correction factor) is calculated and applied to the radar field. Details of the analysis described in the response were not provided so WEST cannot comment on whether or not the MPE data were demonstrated to be truly substantially under-estimated and whether or not the hydrologic processes modeled were reasonably represented in the model. Assuming that the MPE data could not be directly applied without adjustment, a more correct approach would be to fix the precipitation first prior to model calibration. For example, correlations could be possibly developed using the MPE and ground rainfall measurements. Adjusting the precipitation input as part of the model calibration significantly affects the model predictability. If the model is applied to a future flood event with good MPE data or a hypothetical event, like the 100-year flood event, the model has to be recalibrated.

6. Comment - Page 38. The report does not provide any results and discussions on snowmelt

modeling. Were simulated snow water equivalents compared to observed values?

Comment Response - Simulated snow-water equivalents were not compared to observed values during model calibration. The model calibration was based on comparison of observed and simulated streamflow at USGS gages. Only the April 2005 event was impacted by snow melt. To further examine the snow in the model, we used the graphical user interface to examine the snow pack simulated in the model on each HRU and it appears that snow melt during the April 2005 event was under-simulated for many HRUs. The model generated snowfall, but it appears that the ablation of the snow pack occurred too quickly compared to NWS' SNODAS-modeled snow cover (National Weather Service, 2011). Adequate snow pack was not in the model at the beginning of the April 2005 event. We re-checked the model water budget on a small subbasin and confirmed that the under-simulated snow pack was compensated for by additional scaling of the precipitation, including snow, during the event. More details on the results of this analysis are available if needed.

Back-Check Comment – We suggest that details of comparisons between simulated and other observed or modeled snow data possibly with sensitivity analyses for a range of the parameters used in snowmelt simulation be presented to demonstrate why the snow melt was under-simulated for many HRUs. Adjusting the input precipitation to account for these possible uncertainties and without separate calibration for snowmelt again limit the model's predictability.

7. Comment - Page 50, Limitations, Third Paragraph. The report states that the reach in the vicinity of the Minisink Hills streamgage is affected by backwater. In this case, the kinematic wave routing approach is not applicable.

   Comment Response - The flood analysis model results on the main stem Delaware River in the vicinity of Minisink Hills are produced by HEC-ResSim, not PRMS. The kinematic wave method was not used in HEC-ResSim.

   Back-Check Comment – Noted.

HEC-RESSIM MODEL REVIEW

General Comments

1. Comment - The HEC-ResSim model report is well written. It clearly describes the processes that were followed to collect data, develop a watershed, create a reservoir network, create alternatives, and perform simulations. It explains the terminology used in HEC-ResSim, such as watershed configuration, computation points, and reservoir network, which is especially useful to the readers who are not familiar with reservoir modeling and HEC-ResSim.

   Comment Response – Not provided.

2. Comment - The report generally provides an adequate level of details on model development and simulation results. In particular, it clearly documents the sources of the physical and

operational data, the assumptions used in the modeling, and the explanations of why the simulated hydrographs are different from the observed ones at some locations. The HEC-ResSim model submittal also included the backup data, some of which were complied and summarized in Excel spreadsheets. With these backup data, we are able to verify that the data entered in the model match the raw data with some exceptions noted below as specific comments.

Comment Response – Not provided.

3. Comment - The HEC-ResSim model is also well documented. In particular, it provides much of the background information as notes so that the readers can better understand the model settings. The model input and results are consistent with the report with some exceptions that are included as specific comments.

   Comment Response – Not provided.

4. Comment - We agree with the many assumptions made in the flood model. Because the purpose of the HEC-ResSim model is to simulate flood events, many rules that govern operations and releases during low flow events, such as drought operations, are omitted in the model as these rules do not impact the results for high flow events.

   Comment Response – Not provided.

5. Comment - We also agree that in many cases the differences between the simulated and observed hydrographs are due to the differences between the operational rules coded in the model and the actual operating procedures, which often involved real-time decisions. Unlike other rainfall-runoff models, such as PRMS, and hydraulic models, such as HEC-RAS, it is not reasonable to expect that the simulated hydrographs can always be calibrated in HEC-ResSim to match the observed hydrographs. The flood operations described in the model represent normal flood operations in accordance with water control manuals and information gathered from operators.

   Comment Response – Not provided.

6. Comment - For the *FC-GageQ* alternative, which uses the calculated local inflows from observed gage data, the HEC-ResSim results appear reasonable and are, in general, similar to the observed data. However, as described in the section below, we do find some discrepancies between the backup data and the physical data in the model and between the report and the model. We have some comments and questions on some of the rules. We also have significant comments on channel routing. We strongly recommend that these questions and comments be addressed and back-checked as they may affect the model results.

   Comment Response – Not provided.

Specific Comments and Questions

1. Comment - Page xv, Fourth Paragraph, Third-Last Sentence. Suggest inserting a word

"simulated" between "convert" and "flow" because rating curves are normally used by USGS to convert stage to flow.

Comment Response - Agreed. Report updated.

Back-Check Comment – Concur.

2. Comment - Page 3, Second Paragraph. Suggest labeling "Montague" on Figure 1.1 as this location is referred in the text.

   Comment Response - Agree in theory, however, the figure and text in this section were provided by the DRBC. HEC does not have the original image file to make the change to. Montague is visible in later figures if the reader requires added clarity.

   Back-Check Comment – Concur.

3. Comment - Page 5, First Paragraph under Section 2.1, First Sentence. Suggest adding a word of "to" behind "added".

   Comment Response - Agreed. Report updated.

   Back-Check Comment – Concur.

4. Comment - Page 11, Table 2.3. Suggest adding units for the last column.

   Comment Response – Disagree. By default, units for the stream stations are a function the map units. As far as the ResSim model is concerned however, stream stations are essentially unitless. Adding units to this column conveys no beneficial information. Report unchanged.

   Back-Check Comment – This comment was raised because readers may relate the information from the last column to the physical locations of the computation points. Stream stations with units, for example, in river miles, may provide good references of the locations. This is a minor comment and it certainly does not affect the model.

5. Comment - Page 14, First Sentence under Section 2.4. Suggest deleting an extra space between "that" and "occurred".

   Comment Response - Agreed. Report updated.

   Back-Check Comment – Concur.

6. Comment - Page 17, Last Bullet under Section 3.1.1. Is the vertical datum consistent for all the elevation data for all reservoirs owned and operated by different entities? Because the vertical datum is not noted in many of the reservoir data, we cannot verify that all the elevations are referenced to NGVD 1929.

Comment Response - The data supplied by the DRBC and others did not come with information regarding vertical datum used to specify the reservoir pools, outlets, or zones. While the computations in ResSim rely on the elevation data defining a single reservoir be on a consistent datum; no consistency between reservoirs is required. Therefore, data for each reservoir was checked for consistency, but no effort was required or expended on identifying the vertical datum (or datums) used to determine any elevations within the model.

Back-Check Comment – Concur.

7. Comment - Page 19, Third Paragraph. It would be very useful to include a map showing the five basins.

   Comment Response - Agreed. However, several figures are provided later in Chapter 4 that provide adequate coverage of the individual basins.

   Back-Check Comment – Noted.

8. Comment - Page 20, First Paragraph below Section 4.1. Another function of junctions may simply provide flow at key locations such as damage sites and gaging stations with observed hydrographs.

   Comment Response - Agreed. Report updated.

   Back-Check Comment – Concur.

9. Comment - Page 25, Figure 4.4. The routing parameters shown in Figure 4.4 for Downsville to Harvard Reach match the values in the model. However, the parameters for this reach in Table 4.6 need to be changed.

   Comment Response - The original Figure 4.4 was removed along with a few paragraphs and replaced with an updated writeup describing the development of the routing parameters for the model. During this process, the routing used was revisited and improved. As needed, the associated figures and tables were updated to reflect the routing method and parameters used in the improved model. See comment 12's response for the new text added to the report.

   Back-Check Comment – Concur.

10. Comment - Page 27, Table 4.6. The K value is 1.0 hour when outflow is greater than 300 cfs (see Figure 3). The second row in Table 4.6 and the description in the model need to be corrected.

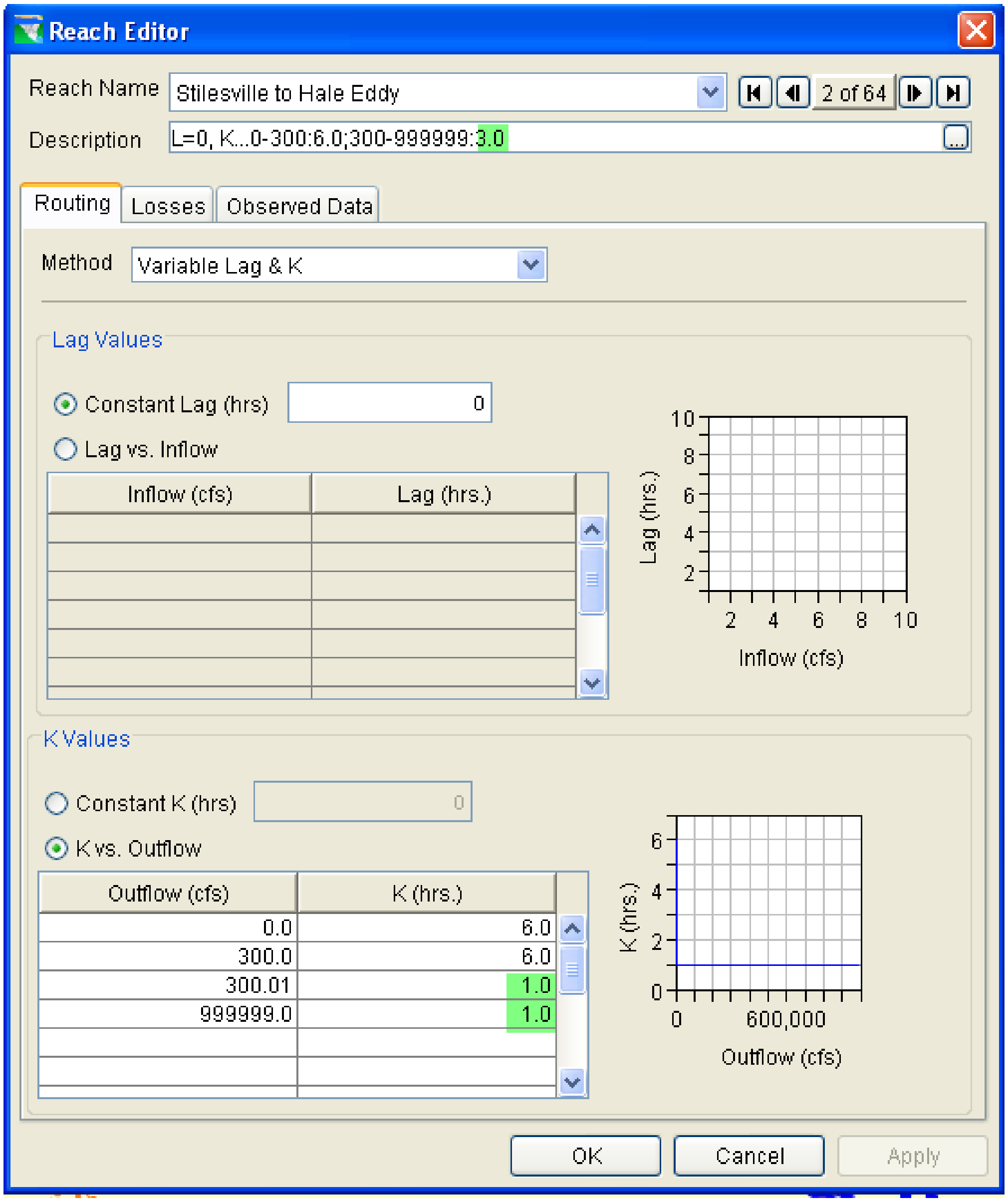


Figure 3. Reach editor for Stilesville to Hale Eddy Reach.

Comment Response - Agreed. Report updated.

Back-Check Comment – Nonconcur. The description in the model remains to be corrected.

11. Comment - Page 28, Table 4.10. The information for *Bethlehem to Del+Lehigh* Reach is not included in Table 4.10.

Comment Response - The table has been updated with parameters for the Bethlehem to Del+Lehigh reach.

Back-Check Comment – Concur.

12. Comment - Page 27 and Page 28, Table 4.6 through Table 4.10. We have several comments on these tables and on the parameters that are associated with the Muskingum routing method. Our comments include:

a. Comment- It will be useful to include the reach length in the tables.

Comment Response - The original Lag and K routing parameters were obtained from the NWS. This routing method, along with the Muskingum Cunge routing method (also used within the HEC-ResSim model), does not require reach lengths. The parameters required by these routing methods are included in Tables 4.6 through 4.10. Table 2.3 from the report does contain Stream Station locations at computation points within the HEC-ResSim model. Reach lengths can be inferred from this table.

Back-Check Comment – Nonconcur. The reach lengths inferred from Table 2.3 do not have units as the stream stations are unitless.

b. Comment - Suggest including details of how the parameter values for the Muskingum method were estimated.

Comment Response - The following text was added to the report and Tables 4.6 through 4.10 were updated with final routing parameters.

> In most cases, the Muskingum routing method was only used in reaches that exhibited attenuation of the flood hydrograph for at least one of the events being modeled (observed peak flow in downstream hydrograph was less than peak flow from upstream hydrograph). Otherwise, the Lag and K routing method was used and parameters provided by the NWS were incorporated. The Muskingum routing method requires three parameters, the Muskingum K, Muskingum X, and the number of subreaches. The K parameter is the travel time of the flood wave through the reach, the X parameter is used to model the attenuation of the flood wave due to channel and overbank storage, and the number of subreaches is an additional parameter that affects the amount of attenuation through the reach. The X parameter is dimensionless and can vary from 0.0 – 0.5. A value of 0.0 maximizes attenuation of the flood wave and a value of 0.5 does not attenuate the flood wave.
>
> The Muskingum K parameter was determined by: a) using the Lag routing parameters provided by the NWS; and, b) evaluating the time of peak flows at upstream and downstream gaged locations for the three historic events modeled in this study. In most reaches, the Lag parameter provided by the NWS varies as flow rate increases. As mentioned above, the HEC-ResSim model parameters were developed to route major flood flows; therefore, the smallest lag parameter (corresponding to flood flows) from the array of Lag and Flow provided by the NWS was selected as the best estimate for the Muskingum K parameter. Figure 4.4 can be used to illustrate how observed hydrographs were also used to estimate the Muskingum K parameter. This figure shows the observed discharge hydrograph from the Pepacton Reservoir and the observed discharge hydrograph at the Harvard stream gage for the 2004 flood event. The lag time of the

peak flow for these two hydrographs is approximately 4 hours. The 2005 and 2006 flood events were also evaluated to determine travel times. One Muskingum K parameter was

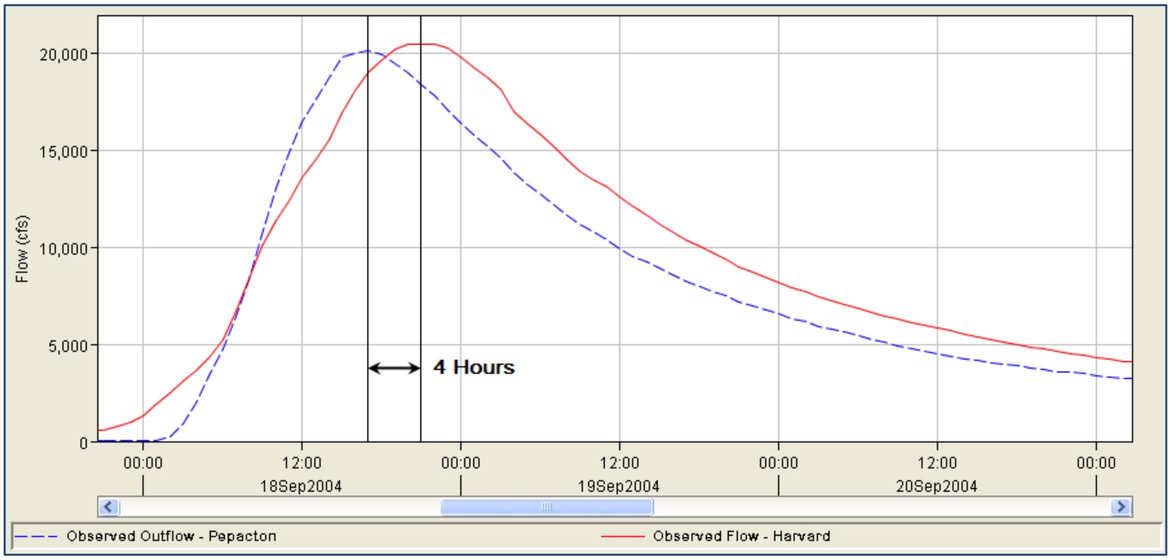


Figure 4.4 Observed Releases from Pepacton Reservoir and Observed Discharge at Harvard

selected that provided the best estimate of travel time from all three flood events.

The Muskingum X parameter is typically set by calibrating the model to observed discharge. It was found in most reaches that the Muskingum X parameter needed to be set to a relatively small value, 0.1, in order to provide adequate attenuation of the peak flow within the routing reach. These reaches generally occurred downstream of the Belvidere junction on the Delaware River and the Bethlehem junction on the Lehigh River. The Belvidere and Bethlehem junctions contain the last observed discharge until the Trenton junction (most downstream point in the HEC-ResSim model). For all three flood events, 2004, 2005, and 2006, the combined discharge at the junction of the Delaware and Lehigh Rivers was slightly larger than the observed discharge downstream at the Trenton gage; therefore, the Muskingum X was set to 0.1 to model the appropriate amount of attenuation in the downstream reaches.

The number of subreaches is a calibration parameter. Just like the Muskingum X parameter, it affects the amount of attenuation in the routed flood hydrograph. Maximum attenuation is achieved with only 1 subreach, which is typical of wide flat floodplains with overbank storage, while attenuation decreases as the number of subreaches increase. In many cases, this parameter is set so that the travel time through each subreach is equal to the simulation time step; this helps to preserve the numerical stability of the routing solution. However, this parameter can be used to calibrate the Muskingum routing model using observed streamflow data. As mentioned for the Muskingum X parameter, the Belvidere and Bethlehem junctions contain the last observed discharge until the Trenton junction. For all three flood events, 2004, 2005, and 2006, the combined discharge at the junction of the Delaware and Lehigh Rivers was slightly larger than the observed discharge downstream at the Trenton gage; therefore, the number of subreaches was set to 1 to model the appropriate amount of attenuation in the downstream reaches.

Back-Check Comment – WEST concurs with the text added to the report. The report now clearly describes the Muskingum method and how the parameters were estimated.

c. Comment - According to the guidance described in HEC-ResSim User Manual (Page 9-8, HEC, 2007), the number of subreaches should be approximately equal to travel time, which is the Muskingum K parameter, divided by the computation time step. Since the computation time step is one hour, the number of subreaches should be equal to the K value numerically. However, the numbers of the subreaches in Table 4.6 through Table 4.10 are significantly different from the K values for many reaches that use the Muskingum routing. We did a sensitivity run by increasing the number of subreaches from 2 to 6 for Bridgeville to Godeffroy Reach (Figure 5). The results for the June 2006 event indicate that the model is sensitive to the number of subreaches (Figure 5).

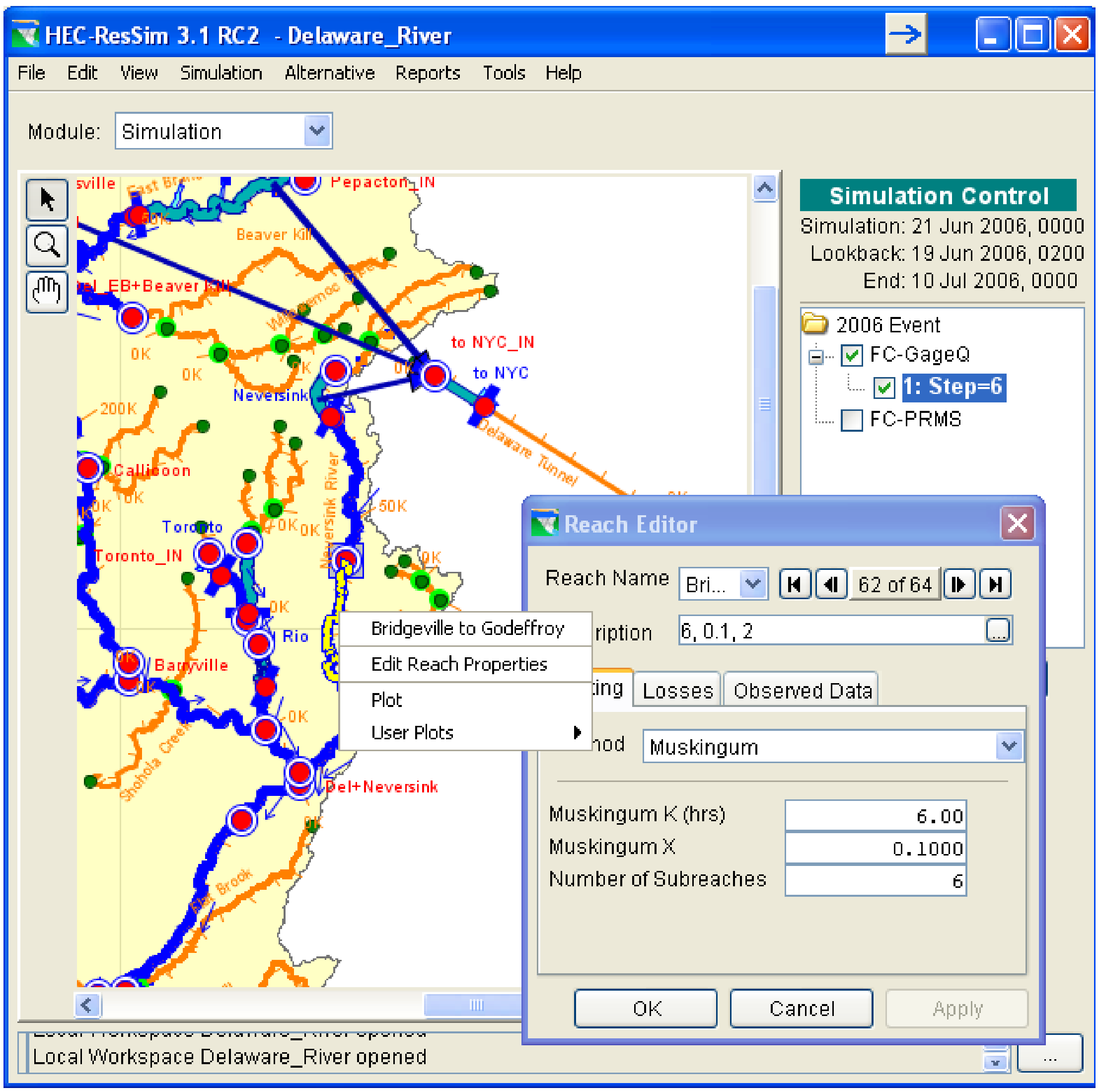


Figure 4. Reach editor for Bridgeville to Godeffroy Reach.

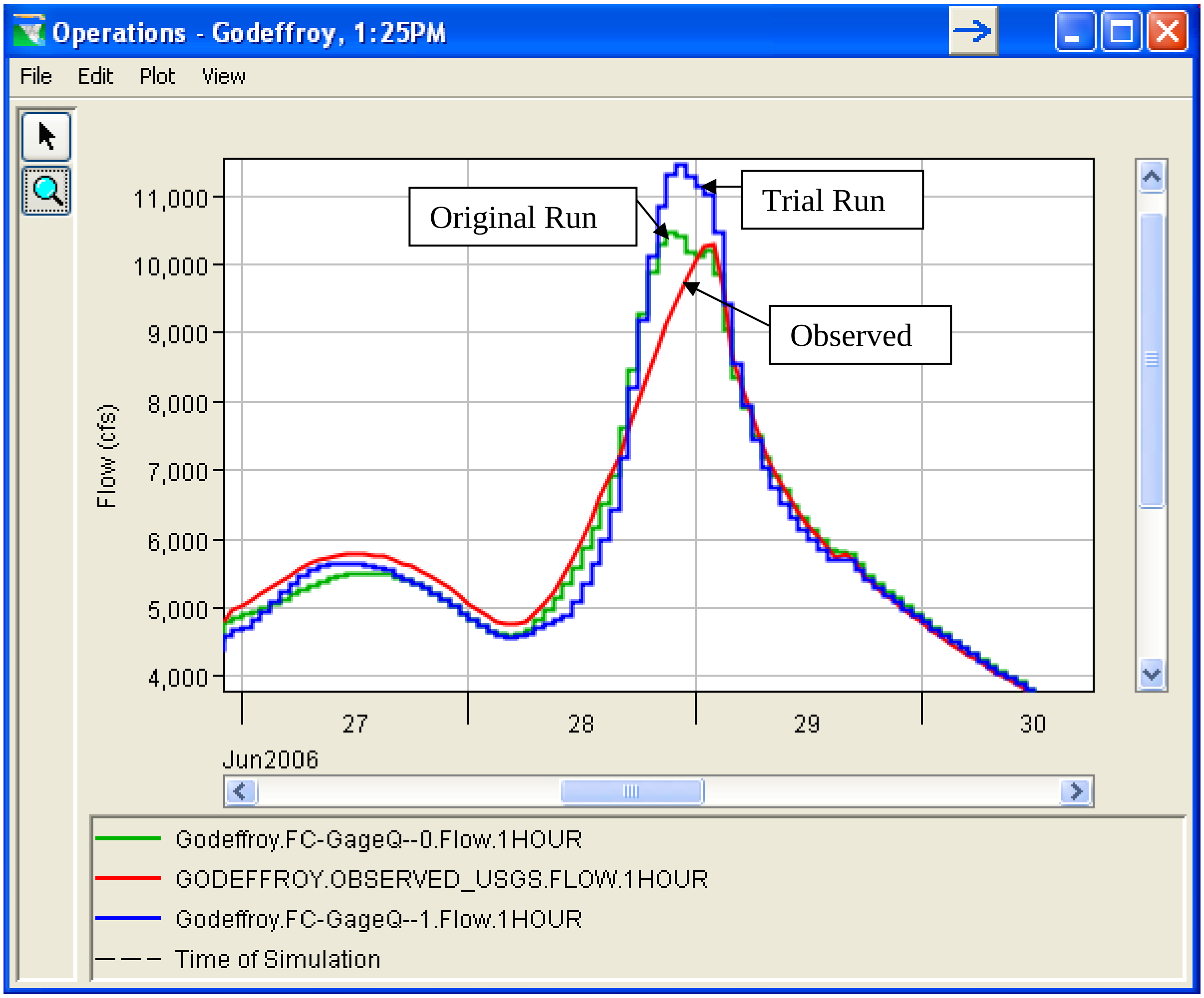


Figure 5. Flow hydrographs at Godeffroy.

Comment Response - Just like the Muskingum X parameter, the number of subreaches affects the amount of attenuation in the routed flood hydrograph. The number of subreaches is a calibration parameter, as stated in the HEC-HMS Technical Reference Manual on page 80. Figure 3 in the Reviewers Notes is a great example of how sensitive the routed hydrograph is to the number of subreaches and why the number of subreaches should be treated as a calibration parameter. This is one reason why the user has the option to adjust this parameter in both HEC-ResSim and HEC-HMS when calibrating the model to observed hydrographs. The HEC-ResSim User's Manual should be updated providing similar guidance to the HEC-HMS Technical Reference Manual. As stated in bullet b above, text was added to the report describing how the number of subreaches was estimated for the HEC-ResSim model.

Back-Check Comment – Concur.

d. Comment - Page 24, First Paragraph under Section 4.2. The report describes that null routing was used for very short reaches. However, this routing method was also used for reaches that are not short. For example, the lengths for the last three reaches (*Stockton to*

New Hope, New Hope to Washingtons Crossing, and Washingtons Crossing to Trenton) in Table 4.10, from upstream to downstream, are approximately 3.3, 6.8, and 8.4 miles, respectively. The Muskingum routing was applied to the upper and lower reaches but not the middle reach.

Comment Response - There was a mistake in the model for the Stockton to New Hope and New Hope to Washingtons Crossing reaches. The routing methods and parameters should have been switched for these two reaches. The model and report have been updated. Now, the Stockton to New Hope reach uses the null routing method and the New Hope to Washingtons Crossing reach uses the Muskingum routing method with parameters K=2, X=0.1, and subreaches=1.

Back-Check Comment – Concur.

13. Comment - Page 34, Last Paragraph above Section FC Ops – Normal Flood Operations. The description of the relationships between OASIS model rules and HEC-ResSim zone definition is not very accurate. For example, the more correct relationships for Cannonsville are as follows:

OASIS Rules	HEC-ResSim Zones
Max Storage	Maximum Pool
Upper Rule Storage	Normal Pool
Lower Rule Storage	Minimum Pool
Dead Storage	Inactive

Comment Response - Agreed. Report updated. *Nice catch.* Zones in the model were renamed after this section of the report was written and the report did not get updated to reflect the changes during in-house review.

Back-Check Comment – Concur.

14. Comment - Page 34, First Paragraph under Section FC Ops – Normal Flood Operations. The two system diversion rules, *MinSystemDiv* and *MaxSystemDiv*, are applied to the Cannonsville and Pepacton reservoirs, not the two diverted outlets, Can-Tunnel and Pep_Tunnel. Does HEC-ResSim require that system rules have to be applied to the reservoirs?

Comment Response - ResSim requires that downstream control rules be applied to the reservoir so that the reservoir can manage all its outflow paths that could affect the downstream location. When multiple reservoirs use the same downstream control rule to operate for a common downstream location, the downstream control rule acts as a system rule by allocating releases to the reservoirs based on a relative storage balance.

In this application, the common downstream control location is “visible” to the reservoirs only through their diverted outlets, not through the natural river system, so when the rule applies, only releases through the diverted outlet are affected. However, releases through the other outlets must still be accounted for when the relative storage balance objective is determined so the conditions in the whole reservoir are still part of the problem.

Report unchanged.

Back-Check Comment – Concur.

15. Comment - Page 34, last Paragraph, Second Sentence. “provide” should be “provided”.

    Comment Response – Agreed. Report updated.

    Back-Check Comment – Concur.

16. Comment - Page 46, First Paragraph under Section 4.3.3.1, Second Sentence. Suggest changing “thus” to “so”.

    Comment Response - Agreed. Report updated.

    Back-Check Comment – Nonconcur. The report has not been updated.

17. Comment - Page 47, First Paragraph under Section 4.3.3.2. Fourth Sentence. Suggest deleting “a” before “Mr. Joe”.

    Comment Response - Agreed. Report updated.

    Back-Check Comment – Concur.

18. Comment - Page 58, First Paragraph above Section 5.2.1.1, Last Sentence. Suggest changing “;see” to “.”.

    Comment Response - “See” should have been followed by figure references. Report updated to correct the oversight.

    Back-Check Comment – Concur.

19. Comment - Page 60, First Paragraph below Figure 5.3, Second-Last Sentence. Suggest changing “Figure 5.6 through Figure 5.6” to “Figure 5.4 through Figure 5.6”.

    Comment Response – Figure references in Report corrected.

    Back-Check Comment – Nonconcur. The figure reference problem remains in the report.

20. Comment - Page 76, Second Paragraph, First Sentence. Should “channel depth” be “channel bottom”.

    Comment Response - Agreed. Report updated and made clearer.

Back-Check Comment – Concur.

21. Comment - Page 79, Last Sentence. Suggest changing “uses” to “use”.

    Comment Response - Agreed. Report updated.

    Back-Check Comment – Concur.

22. Comment - Page B-27. The weir coefficient of 2.6 for the Nockamixon spillway seems low. A value of 3.0 appears to be more reasonable, and is consistent with the discussion in the main text (Page 31, first paragraph under Figure 4.9).

    Comment Response - Long, broad crested weir structures are typically modeled using a weir coefficient of 2.6-3.1. (ref: HEC-RAS Hydraulic Reference Manual, pg 8-13.) The referenced discussion in Chapter 4 was describing the information used to represent a “default spillway” for the dam structure itself. Since most dams can be described as “broad crested”, a weir coefficient of 3.0 was hardcoded into the program. For overflow spillways, such as the Nockamixon spillway, the shorter length of the spillway was considered in the selection of the weir coefficient so the smaller value of 2.6 was selected. Further investigation, however, seems to indicate that a higher coefficient as applicable to a more efficient engineered ogee-shaped weir without submergence (3.2-4.1) could be considered. However, without observed data to verify results, the conservative selection of 2.6 seems adequate.

    Back-Check Comment – Concur.

23. Comment - Page B-28, Appendix B.2. There are a total of 23 junctions in the model that have rating curves. However, Appendix B.2 includes 19 locations only. In addition, Table 4.2 through Table 4.5 on Page 23 and Page 24 indicate that only 16 junctions that have rating curves.

    Comment Response - Agreed. Report updated.

    Back-Check Comment – Concur.

24. Comment - Page B-60 – Page B-62. The modified rating table at Riegelsville shown on Pages B-60 to B-62 is actually the rating table at Belvidere (Pages B-55 to B-57).

    Comment Response - Agreed. Report updated.

    Back-Check Comment – Concur.

25. Comment - Model. Rating Curve at Minisink Hills (USGS Gage No. 01442500). Starting at stage 5.0 ft, the discharge values are slightly off compared to the raw rating curve provided by USGS. The discharge of 1,500 cfs in the model actually corresponds to stage 4.99 ft (see

Figure 6).

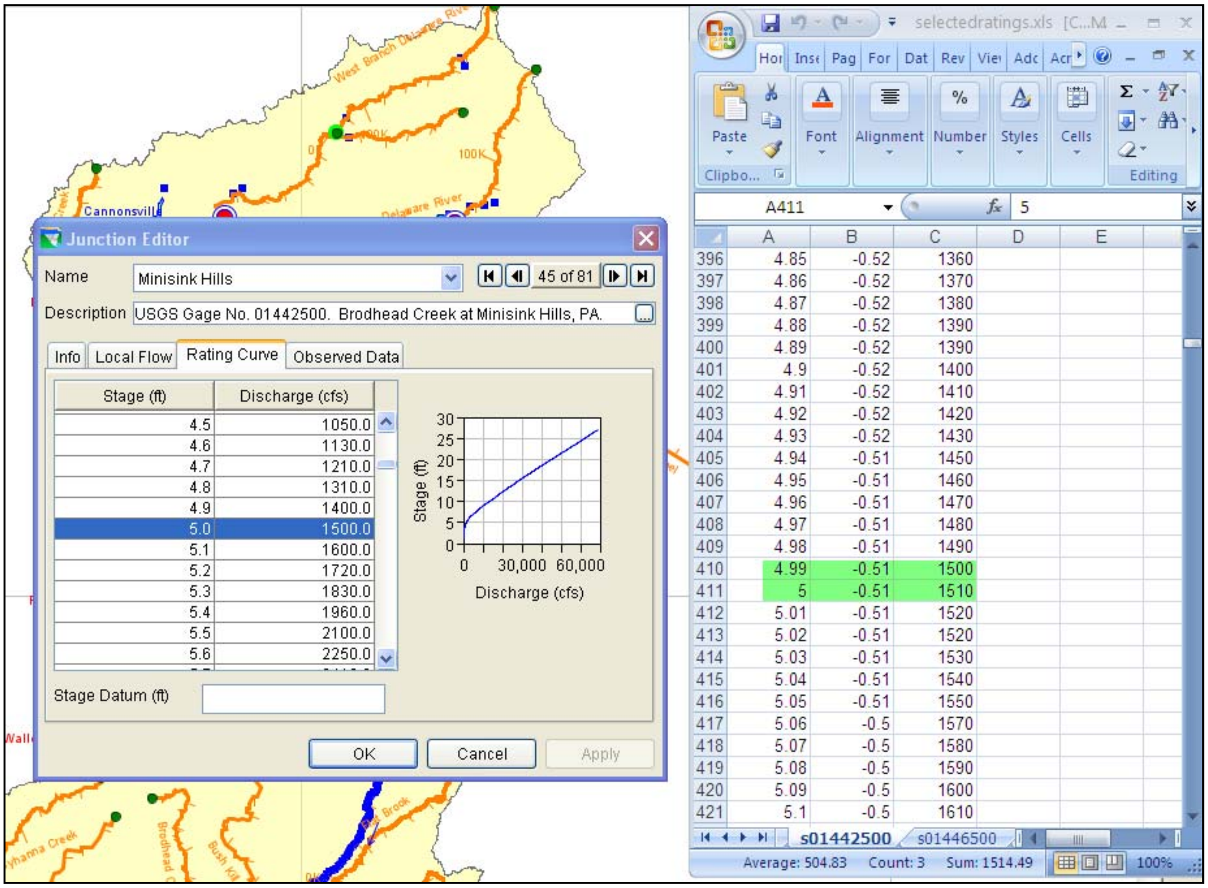
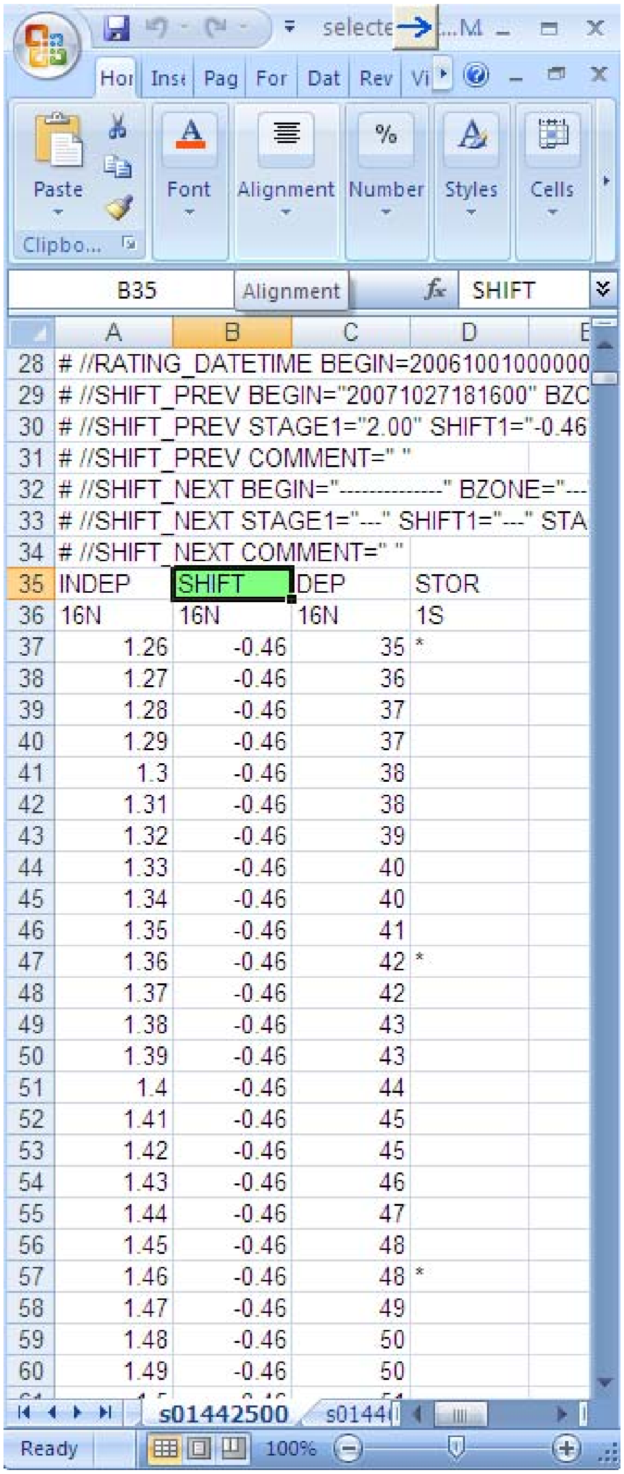


Figure 6. Rating curve at Minisink Hills

Comment Response - The rating curves used in the model were supplied by our project partners at the USGS and were expected to represent the (average) state of the rating at the time of the three events. Since a given rating could have changed during or after each event, the ratings should be considered approximate or averaged and would not likely match a current rating for any gage in the model.

Back-Check Comment – Concur.

26. Comment - Model. Rating Curves. The raw rating curves provided by USGS at Minisink Hills (Gage No. 01442500), Shoemakers (Gage No. 01439500), Port Jervis (Gage No. 01434000), and Cooks Falls (Gage No. 01420500) have non-zero shift values in the second column (see an example in Figure 7). What do the shift values mean? Is there a need to shift the rating curves?



	A	B	C	D
28	# //RATING_DATETIME BEGIN=20061001000000			
29	# //SHIFT_PREV BEGIN="20071027181600" BZC			
30	# //SHIFT_PREV STAGE1="2.00" SHIFT1="-0.46			
31	# //SHIFT_PREV COMMENT=" "			
32	# //SHIFT_NEXT BEGIN="-------------" BZONE="---			
33	# //SHIFT_NEXT STAGE1="---" SHIFT1="---" STA			
34	# //SHIFT_NEXT COMMENT=" "			
35	INDEP	SHIFT	DEP	STOR
36	16N	16N	16N	1S
37	1.26	-0.46	35	*
38	1.27	-0.46	36	
39	1.28	-0.46	37	
40	1.29	-0.46	37	
41	1.3	-0.46	38	
42	1.31	-0.46	38	
43	1.32	-0.46	39	
44	1.33	-0.46	40	
45	1.34	-0.46	40	
46	1.35	-0.46	41	
47	1.36	-0.46	42	*
48	1.37	-0.46	42	
49	1.38	-0.46	43	
50	1.39	-0.46	43	
51	1.4	-0.46	44	
52	1.41	-0.46	45	
53	1.42	-0.46	45	
54	1.43	-0.46	46	
55	1.44	-0.46	47	
56	1.45	-0.46	48	
57	1.46	-0.46	48	*
58	1.47	-0.46	49	
59	1.48	-0.46	50	
60	1.49	-0.46	50	

Figure 7. Raw rating curve at USGS Gage No. 01442500.

Comment Response - As illustrated in your figure 5, the rating data published by the USGS website ("http://waterdata.usgs.gov/nwisweb/data/ratings/exsa/USGS.%s.exsa.rdb") includes 3 columns of information labeled INDEP, SHIFT, and DEP respectively. INDEP is short for independent variable and represents the stage measurement at the gage. DEP is short for dependent variable and represents the expected (or computed) associated flow for the measured stage. SHIFT is an adjustment from the original measured or computed rating for the gage. This column is informational since the DEP column already represents the adjusted flow; thus, no application of the shift values is needed in the model.

Back-Check Comment – Concur.

27. Comment - Observed Flow Data. The watershed time in the model is defined as Eastern Standard Time (EST). By reviewing the HEC-DSS records for the observed flow data, which were used for model calibration and testing, and comparing them to the data downloaded from the USGS Instantaneous Data Archive, we found that the conversion from raw data to HEC-DSS records might not consider the time shift from Eastern Standard Time (EDT) to EST. The examples in Figure 8 and Figure 9 show that the discharge at 13:00, EST, June 27, 2006 should be 37,045 cfs, instead of 35,539 cfs.

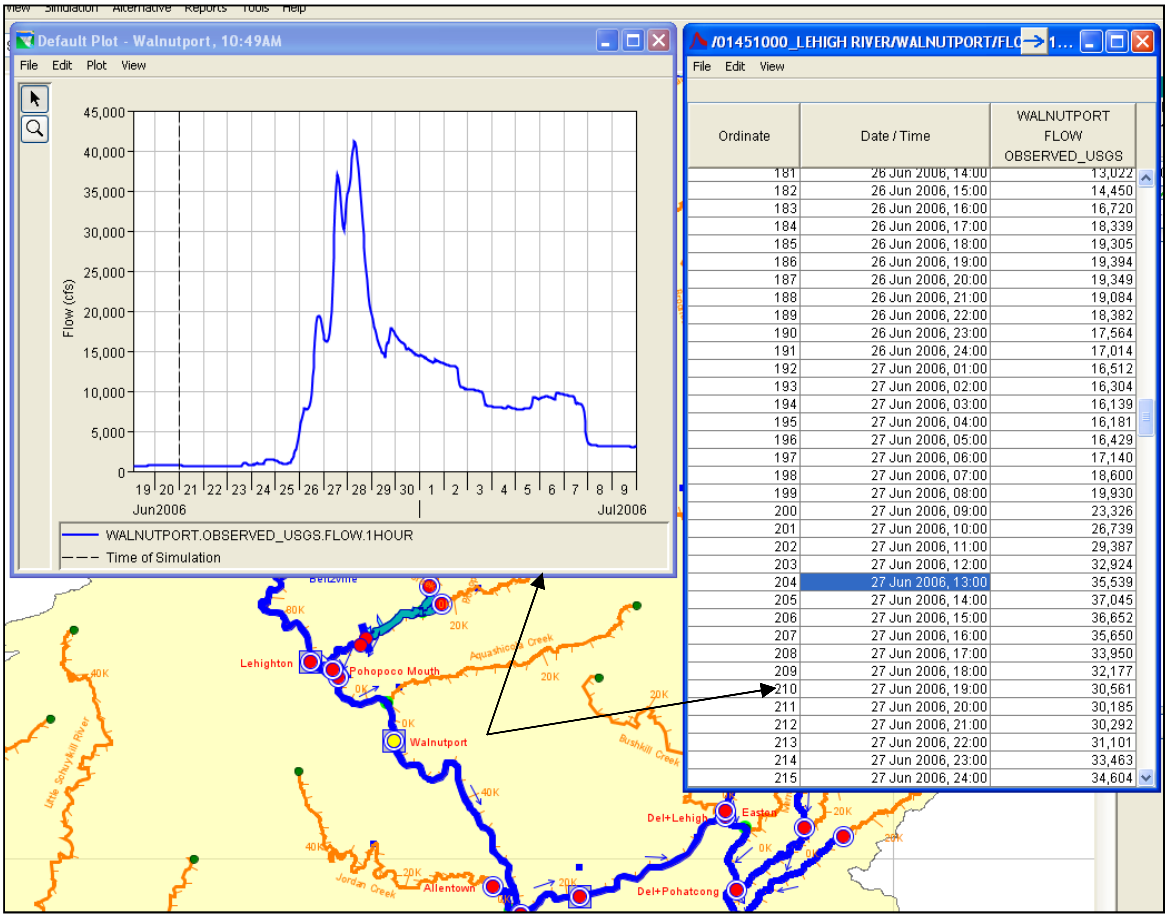


Figure 8. Observed flow hydrograph at Walnutport (USGS Gage No. 01451000) in HEC-DSS format.

```
# retrieved: 2010-09-13 19:06:29 CST
#
# Data for the following station is contained in this file
# ---------------------------------------------------------
#  USGS 01451000 Lehigh River at Walnutport, PA
#
# This data file was retrieved from the USGS
# instantaneous data archive at
# http://ida.water.usgs.gov
#
# ---------------------WARNING---------------------
# The instantaneous data you have obtained from
# this automated U.S. Geological Survey database
# may or may not have been the basis for the published
# daily mean discharges for this station. Although
# automated filtering has been used to compare these
# data to the published daily mean values and to remove
# obviously bad data, there may still be significant
# error in individual values. Users are strongly
# encouraged to review all data carefully prior to use.
# These data are released on the condition that neither
# the USGS nor the United States Government may be held
# liable for any damages resulting from its use.
#
# This file consists of tab-separated columns of the
# following fields.
#
# column       column definition
#
#
site_no date_time       tz_cd   dd      accuracy_cd     value   prec    remark
15N     14N     6S      2N      5S      16N     1S      1S
01451000        20060627000000  EDT     1       1       17000   3
01451000        20060627003000  EDT     1       1       16700   3
01451000        20060627010000  EDT     1       1       16500   3
01451000        20060627013000  EDT     1       1       16400   3
01451000        20060627020000  EDT     1       1       16300   3
01451000        20060627023000  EDT     1       1       16200   3
01451000        20060627030000  EDT     1       1       16100   3
01451000        20060627033000  EDT     1       1       16100   3
01451000        20060627040000  EDT     1       1       16200   3
01451000        20060627043000  EDT     1       1       16200   3
01451000        20060627050000  EDT     1       1       16400   3
01451000        20060627053000  EDT     1       1       16900   3
01451000        20060627060000  EDT     1       1       17100   3
01451000        20060627063000  EDT     1       1       17700   3
01451000        20060627070000  EDT     1       1       18600   3
01451000        20060627073000  EDT     1       1       19100   3
01451000        20060627080000  EDT     1       1       19900   3
01451000        20060627083000  EDT     1       1       21200   3
01451000        20060627090000  EDT     1       1       23300   3
01451000        20060627093000  EDT     1       1       25100   3
01451000        20060627100000  EDT     1       1       26700   3
01451000        20060627103000  EDT     1       1       27700   3
01451000        20060627110000  EDT     1       1       29400   3
01451000        20060627113000  EDT     1       1       31300   3
01451000        20060627120000  EDT     1       1       32900   3
01451000        20060627123000  EDT     1       1       34400   3
01451000        20060627130000  EDT     1       1       35500   3
01451000        20060627133000  EDT     1       1       36500   3
01451000        20060627140000  EDT     1       1       37000   3
01451000        20060627143000  EDT     1       1       37200   3
01451000        20060627150000  EDT     1       1       36700   3
01451000        20060627153000  EDT     1       1       36400   3
01451000        20060627160000  EDT     1       1       35600   3
01451000        20060627163000  EDT     1       1       34800   3
```

Figure 9. Observed flow hydrograph at Walnutport (USGS Gage No. 01451000) retrieved from USGS Instantaneous Data Archive.

Comment Response - The observed data mapped into the model came from a variety of sources, but the two primary sources were our project partners at the USGS and our contacts at the DRBC. In both cases, the data was supplied in either comma separated text files or in MS Excel workbooks. The method we used to get the data to DSS was to put everything into

Excel and use DSSVue import features to save the data into DSS. We supplied the import method with the start time of the data (as it was provided) and the interval between each value. Since we made no adjustments for Daylight Savings Time (DST) and neither DSSVue nor ResSim support DST, the stored data in DSS is assumed be to in standard time.

Back-Check Comment – The data as they were provided might be in local time (either EST or EDT). The new version of DSSVue has an option to convert from DST to standard time. WEST believes that this issue is minor as the observed flow hydrographs were not used to develop/calibrate the model. The 1-hour shifts are likely not noticeable when the results are plotted for the entire durations of the events, which are 2 to 3 weeks.

28. Comment - Model. For the *FC-GageQ* alternative, the model uses local inflows calculated from observed data at gaging stations. The supporting data did not include any documentation that describes how this was done. We recommend that the calculations and documentation of the local inflows be provided and checked as these local inflows are important input to the model.

    Comment Response - The FC-GageQ alternative was not part of the original scope of work; however, it was required for development of the HEC-ResSim model. Stream flows provided by the PRMS model did not match observed flows and were not able to facilitate the development of reservoir operations for the three flood events. Therefore a flow dataset was needed that provided flows, at gaged locations (computation points), that were similar to observed measurements. This precipitated the development of local inflows in the FC-GageQ alternative.

    The following paragraph and figure were added to the second paragraph in Section 5.1 to expand on the development of the local runoff hydrographs. The procedure followed is straight forward and uses observed releases from reservoirs, observed stream flow at gage locations, and the HEC-ResSim model. This description includes the basic procedure for estimating the local runoff hydrographs and can be followed to recreate the data used in the FC-GageQ alternative. All local runoff hydrographs are included in the LocalRunoff.dss file located within the HEC-ResSim model files, "shared" directory. Finally the report states that it is not intended that the FC-GageQ alternative be used for investigating the response of the reservoir network to alternative flow scenarios. This was the intended application of the inflows developed from the PRMS model (which was the intent of the study). The intended use of the local runoff hydrographs in the FC-GageQ alternative was to assist in the development of operational rules for reservoirs within the HEC-ResSim model. The goal of their development was to insure that when combined and routed they recreated observed flow at gaged locations.

    > A simplified version of the HEC-ResSim model was used to develop the local runoff hydrographs. First, all reservoirs were removed from the model and observed releases from the reservoirs were used as the boundary condition for headwater reaches. Then, these observed releases were routed downstream to the next junction with observed flow. The local runoff hydrograph was then computed by subtracting the routed flow from the observed flow. An example is shown in Figure 5.1. The observed releases from

Pepacton Reservoir were routed downstream to Harvard. Then the local runoff hydrograph was computed by subtracting the routed flow from the measured flow at Harvard.

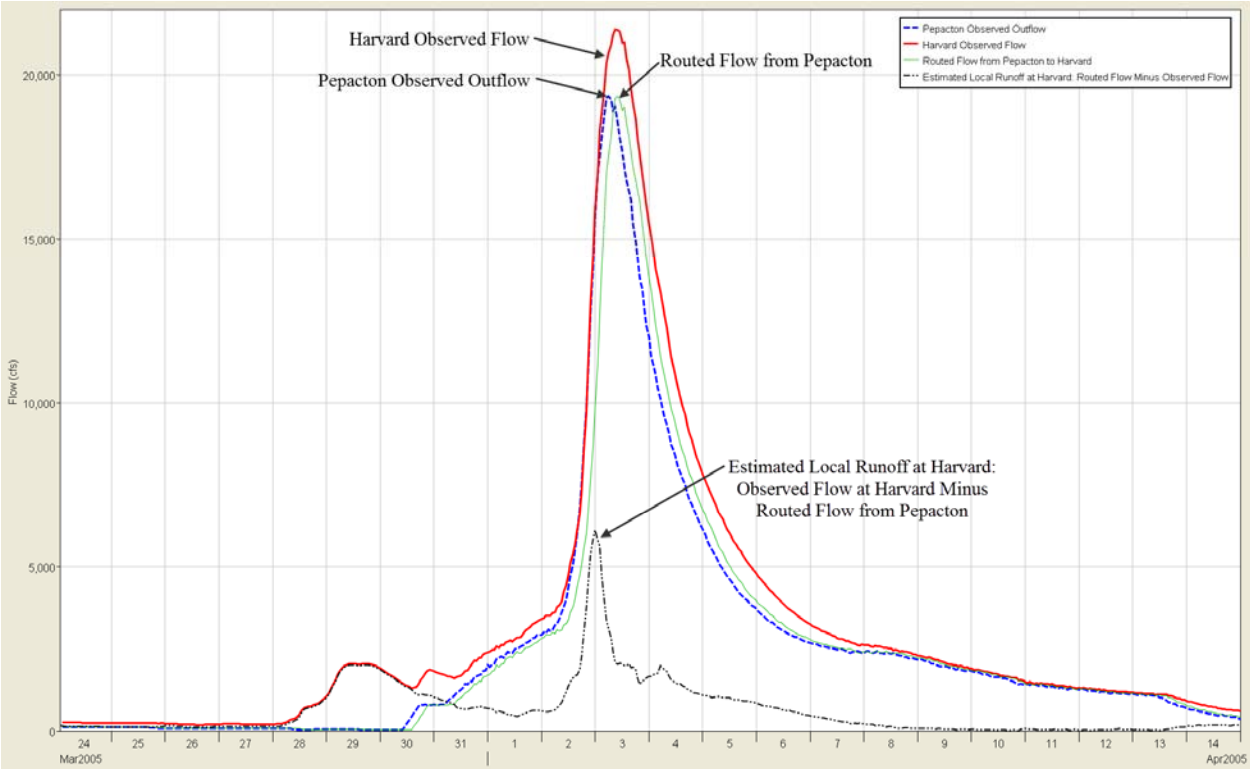


Figure 5.1 Example Showing how Local Runoff at Harvard was Estimated for the 2005 Event

Back-Check Comment – The changes made to the report are very useful. However, one of the labels in Figure 5.1 in the report is not correct. As shown in Figure 5.1 in HEC's response document, the estimated local runoff at Harvard should be equal to observed flow minus routed flow.

29. Comment - Model. Prompton. The discharge capacity curve for the main intake entered in the model does not match the chart in the water control manual. As shown in Figure 10 and Figure 11, at pool elevation 1,160 ft, the discharge from the chart is 2,500 cfs. In the model, the discharge at this elevation is 2,900 cfs.

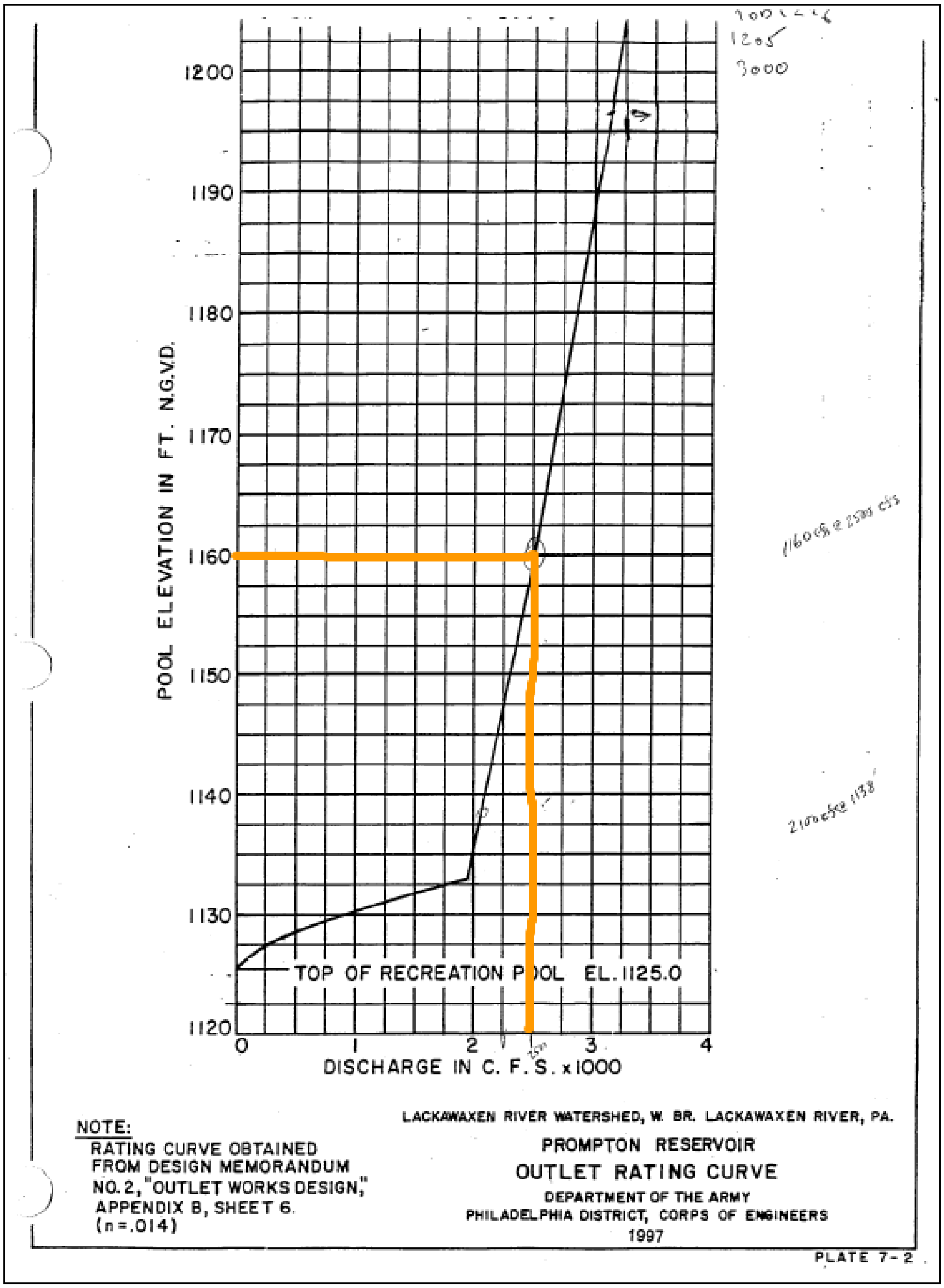


Figure 10. Main intake discharge capacity curve in water control manual.

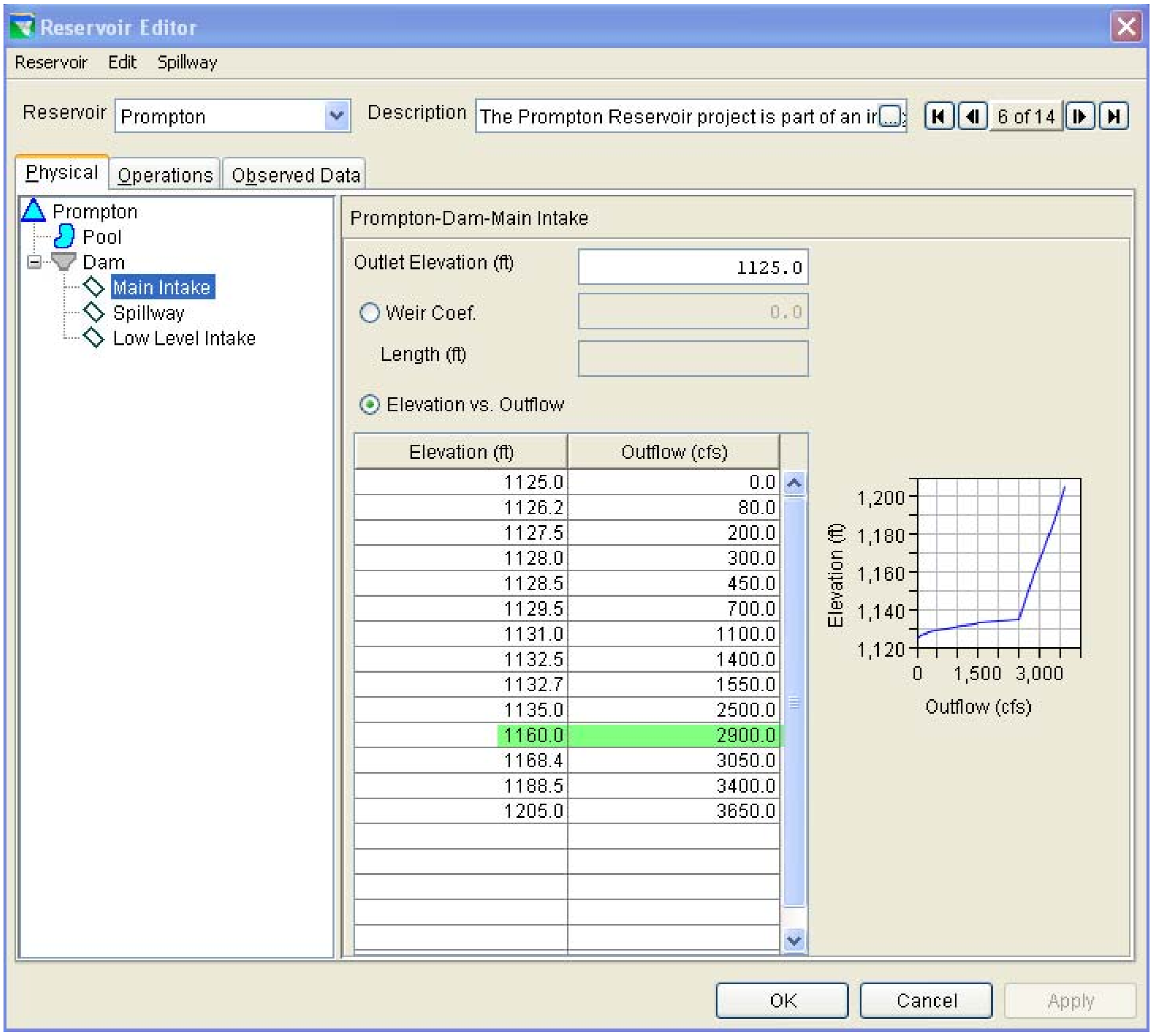


Figure 11. Main intake discharge capacity curve in the model.

Comment Response – Yes, it is true that the rating for the "main intake" outlet at Prompton does not exactly match the design capacity used in the Oasis model and documented in the water control manual. Since matching observed flows was a primary objective of the DRBC representatives, the rating of the main intake was adjusted to allow releases and associated pool elevations to better reflect observed conditions. This is best illustrated in the 2004 event – the observed data for this event only peaked at approximately 1138' with a maximum release of approximately 2600 cfs; with the original rating, the pool would have had to exceed 1160' to produce a release of 2600 cfs .

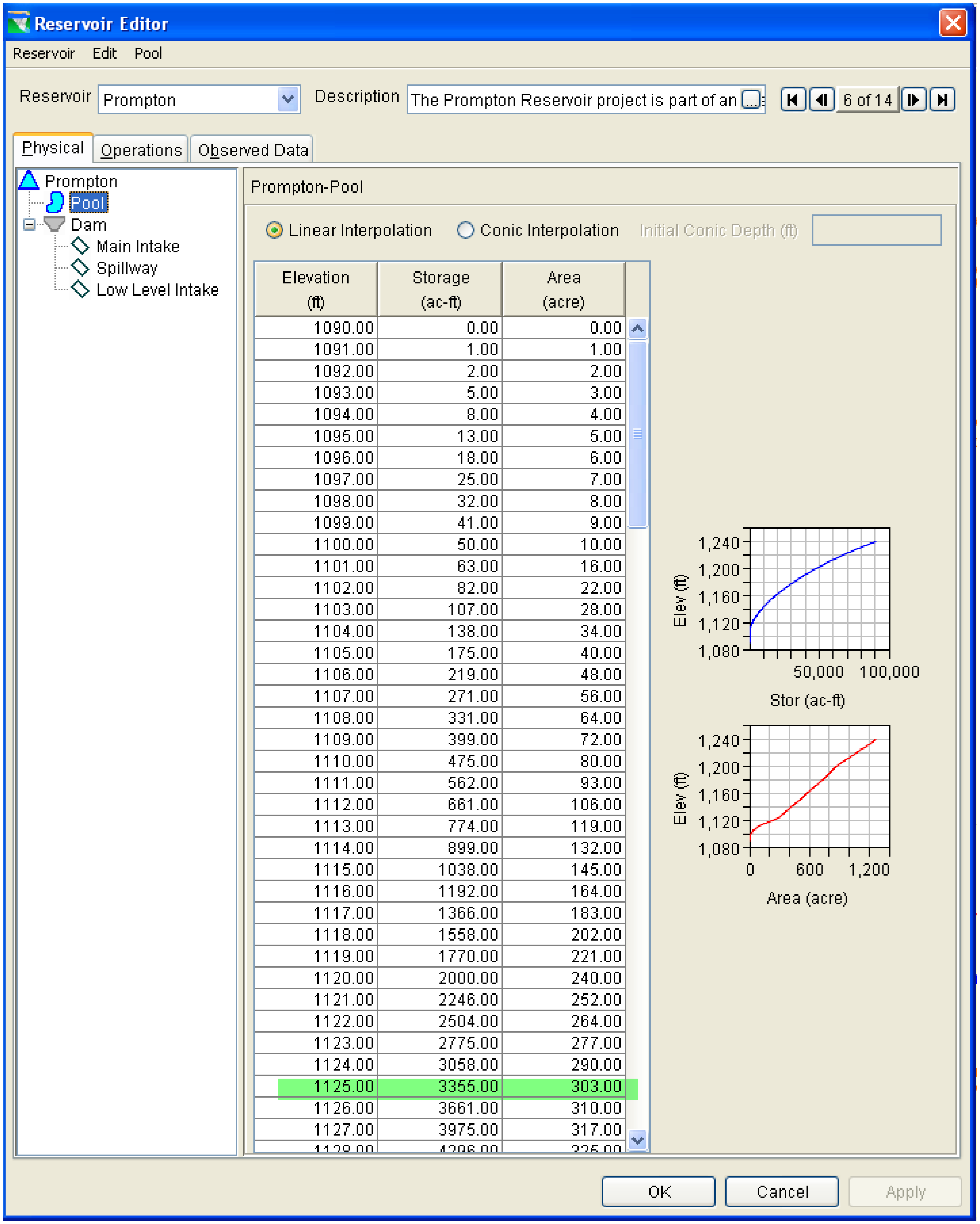
A number of factors can influence differences between design capacity and current capacity including post-design modifications resulting in a different, as-built, configuration, later modifications made to the structure after original construction, and natural "wear and tear" of the structure. A separate effort utilizing an extended period of observed data, appropriate statistical analysis methods, and all historic records of construction and alterations that may have been made to the structure would need to be performed to produce a more accurate rating of the current outlet capacity of the structure.

Back-Check Comment – Concur.

30. Comment - Model. Prompton. The elevation-storage-area data in the model were apparently taken from the water control manual. As shown in Figure 12 and Figure 13, the data are different from those used in the OASIS model. Which set of the data is more representative of the current reservoir condition?

Pool Elevation		Storage		Area		Storage	
1090	feet	0	bg	0	acres	0	ac-ft)
1120		0.69		240		2118	
1125		1.15		290		3529	
1130		1.61		325		4941	
1135		2.3		380		7058	
1140		2.85		425		8746	
1145		3.64		465		11171	
1150		4.39		505		13472	
1155		5.25		540		16112	
1160		6.17		574		18935	
1165		7.05		610		21636	
1170		8.17		643		25073	
1175		9.18		680		28172	
1180		10.4		720		31916	
1185		10.69		755		32806	
1190		12.85		790		39435	
1195		14.1		830		43271	
1200		15.51		865		47598	
1205		17.05		910		52325	
1210		18.46		965		56652	
1215		20.17		1010		61899	
1220		21.74		1060		66718	
1225		23.52		1110		72180	
1226		23.87		1120		73254	
1230		25.35		1165		77796	

Figure 12. Prompton Reservoir Elevation-Storage-Area table from OASIS model.



Elevation (ft)	Storage (ac-ft)	Area (acre)
1090.00	0.00	0.00
1091.00	1.00	1.00
1092.00	2.00	2.00
1093.00	5.00	3.00
1094.00	8.00	4.00
1095.00	13.00	5.00
1096.00	18.00	6.00
1097.00	25.00	7.00
1098.00	32.00	8.00
1099.00	41.00	9.00
1100.00	50.00	10.00
1101.00	63.00	16.00
1102.00	82.00	22.00
1103.00	107.00	28.00
1104.00	138.00	34.00
1105.00	175.00	40.00
1106.00	219.00	48.00
1107.00	271.00	56.00
1108.00	331.00	64.00
1109.00	399.00	72.00
1110.00	475.00	80.00
1111.00	562.00	93.00
1112.00	661.00	106.00
1113.00	774.00	119.00
1114.00	899.00	132.00
1115.00	1038.00	145.00
1116.00	1192.00	164.00
1117.00	1366.00	183.00
1118.00	1558.00	202.00
1119.00	1770.00	221.00
1120.00	2000.00	240.00
1121.00	2246.00	252.00
1122.00	2504.00	264.00
1123.00	2775.00	277.00
1124.00	3058.00	290.00
1125.00	3355.00	303.00
1126.00	3661.00	310.00
1127.00	3975.00	317.00

Figure 13. Prompton Reservoir Elevation-Storage-Area table in HEC-ResSim model.

Comment Response - In general, where data was available from the owners of a given project, that data was applied in the model. However, where data was otherwise unavailable, the OASIS model data was used. HEC has no knowledge of the source of the data used in the OASIS model so cannot comment on which is the more accurate.

Back-Check Comment – Concur.

31. Comment - Model. Lake Wallenpaupack. The storage in the OASIS model (Figure 14) represents the usable storage whereas the storage in the HEC-ResSim model (Figure 15) represents the total storage, which is required in HEC-ResSim. Our question is whether or not the storage data from the OASIS model for other reservoirs are usable storage, or total storage, or a mixture as the storage data for some other reservoirs were directly taken from the OASIS model to the HEC-ResSim model, such as Beltzville, Nockamixon, and Merrill Creek.

Pool Elevation		Storage		Area		Storage	
1160	feet	0	bg	4600	acres	0	(ac-ft)
1162		3.06		4690		9391	
1164		6.19		4780		18996	
1166		9.42		4880		28909	
1168		12.7		4970		38975	
1170		16		5060		49102	
1172		19.3		5150		59230	
1174		22.7		5240		69664	
1176		26.1		5320		80098	
1178		29.6		5400		90839	
1180		33.1		5480		101580	
1182		36.7		5560		112628	
1184		40.3		5640		123676	
1186		43.9		5720		134724	
1188		47.6		5790		146079	
1190		51.4		5840		157741	
1192		55.2		5890		169403	
1194		59.1		5940		181371	
1196		63		6000		193340	
1198		67		6050		205615	
1200		70.9		6100		217584	

Figure 14. Lake Wallenpaupack Elevation-Storage-Area table from OASIS model.

Lake Wallenpaupack-Pool

Linear Interpolation   Conic Interpolation   Initial

Elevation (ft)	Storage (ac-ft)	Area (acre)
1145.00	0.00	0.00
1150.00	20000.00	2300.00
1160.00	52000.00	4600.00
1162.00	61390.78	4690.00
1164.00	70996.39	4780.00
1166.00	80908.88	4880.00
1168.00	90974.82	4970.00
1170.00	101102.13	5060.00
1172.00	111229.45	5150.00
1174.00	121663.65	5240.00
1176.00	132097.85	5320.00
1178.00	142838.95	5400.00
1180.00	153580.04	5480.00
1182.00	164628.02	5560.00
1184.00	175676.00	5640.00
1186.00	186723.98	5720.00
1188.00	198078.85	5790.00
1190.00	209740.60	5840.00
1192.00	221402.36	5890.00
1194.00	233371.00	5940.00
1196.00	245339.65	6000.00
1198.00	257615.18	6050.00
1200.00	269583.83	6100.00

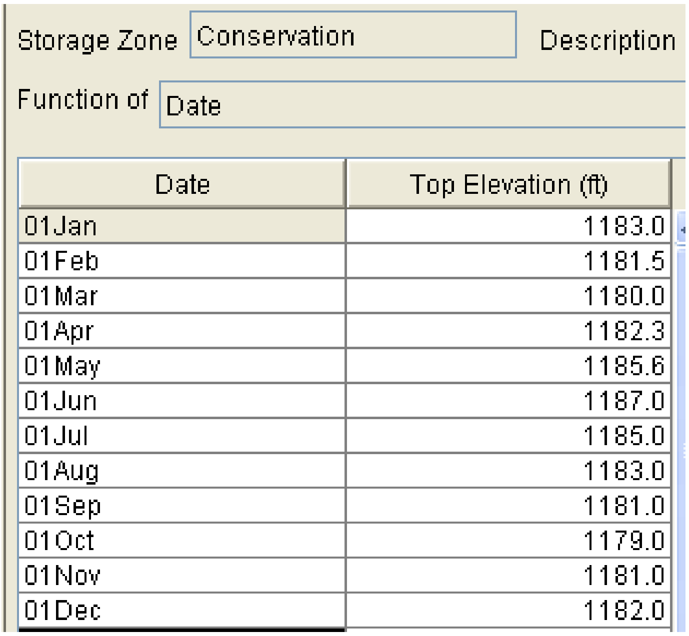
Figure 15. Lake Wallenpaupack Elevation-Storage-Area table in HEC-ResSim model.

Comment Response - Storage data for Lake Wallenpaupack was provided by the current owners through the DRBC. This data may match the OASIS data in the active storage range, but since the data was provided by the owner, it was used preferentially in the model. Beltzville is a USACE reservoir and the table should match what was provided in the water control manual, which very likely also matches the Oasis data. The OASIS model data was the only source for physical information provided for Merrill Creek and Nockamixon reservoirs. Since this data extended beyond the operating range of the pool, no concerns over active versus total storage were raised or investigated. And, without a secondary source of information, HEC cannot comment on whether the storage data for any given reservoir in the OASIS model represents total or active storage.

Note: HEC-ResSim does not require that total storage be used; however, it is strongly recommended that the modeler use total storage whenever possible to avoid some computational issues that can occur in reservoirs with small storage pools and comparatively large outlet capacity.

Back-Check Comment – Concur.

32. Comment - Model. Lake Wallenpaupack. The seasonal guide curve in the model (Figure 16) is the same for the 2004, 2005, 2006 flood events. The guide curve might be taken from Table 2 in DRBC Resolution No. 2002-33 (Page 4). However, this table might have been superseded by a more recent table included in both the Lake Wallenpaupack Emergency Action Plan, December 2007 Revision (Page G-23) and the Lake Wallenpaupack Water Elevation Information sheet (Figure 17).



Storage Zone: Conservation   Description

Function of: Date

Date	Top Elevation (ft)
01Jan	1183.0
01Feb	1181.5
01Mar	1180.0
01Apr	1182.3
01May	1185.6
01Jun	1187.0
01Jul	1185.0
01Aug	1183.0
01Sep	1181.0
01Oct	1179.0
01Nov	1181.0
01Dec	1182.0

Figure 16. Lake Wallenpaupack guide curve in the model.

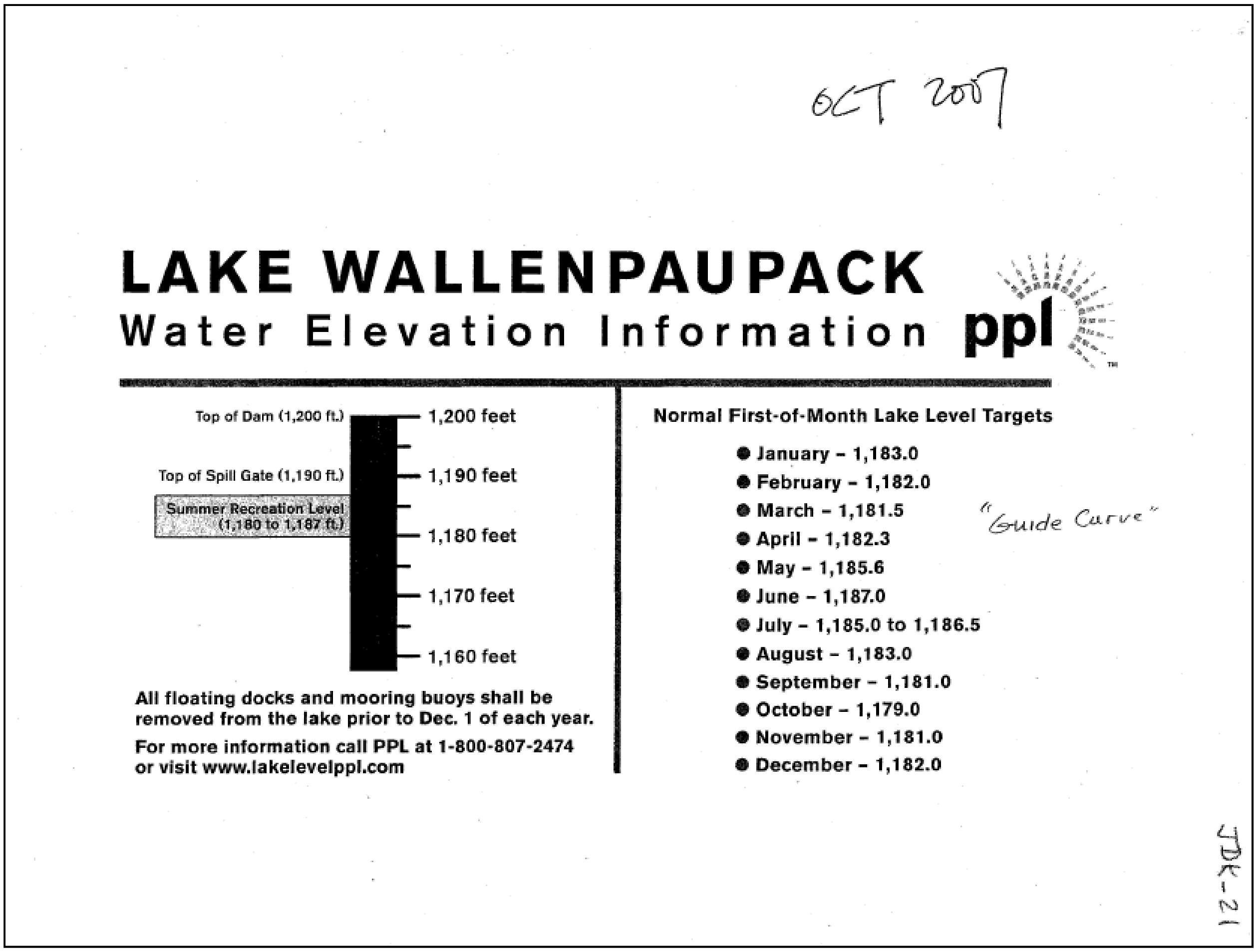


Figure 17. Lake Wallenpaupack water elevation information sheet.

Comment Response - Much of the data used for Lake Wallenpaupack came from material provided by the DRBC, including the Emergency Action Plan. Among the data sources, several different guide curves were found. The guide curve used in the model was the one that seemed most able to reflect the observed operation of the reservoir; however, the three events do not cover enough of the year to fully support a definitive selection; in fact, a different guide curve could have been in effect for each event. It should be noted that this reservoir's flood operations do not follow a fixed operating plan – in fact, the documented operating plan indicates that final operational decisions are determined by a committee of managers who, in turn, are influenced by knowledge of a variety of current conditions as well as forecast information. Being unable to represent a committee or managers nor the variety of current and forecasted information that the managers may have used, HEC modelers reviewed all the provided operational information as well as the observed elevation and release data to assemble a set of operating constraints that could approximate the operations during the three events.

Back-Check Comment – Concur.

33. Comment - Model. Toronto. Figure 18 is the state variable script used to determine whether the flashboards are up or down by comparing the pool elevation at the previous hour to two

triggers: an elevation above which the flashboards fall, labeled as *fallElev*, and another elevation below which the flashboards are reset, labeled as *resetElev*. Rows 51 through 53 in the script indicate that when the pool elevation is below *resetElev*, the flashboards will be reset in one time step, which is one hour. This may not realistically represent the time that is typically needed to reset the flashboards.

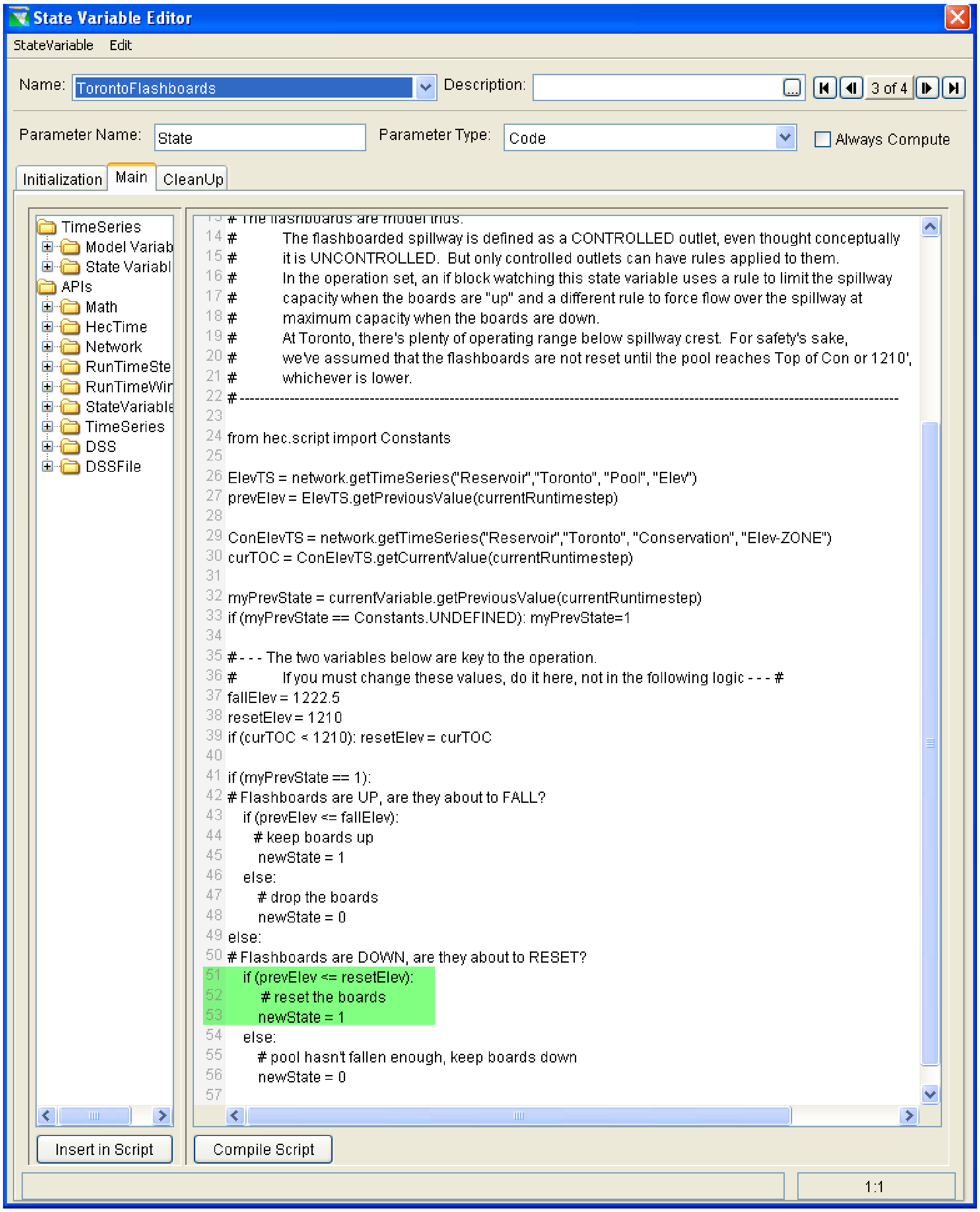


Figure 18. TorontoFlashboards state variable.

Comment Response - Agreed. In fact, both the fall and reset elevations reflect a huge simplification of the real operation. However, the operation of the flashboards is an approximated implementation and the reset elevation was selected to identify a condition that would occur long past the event peak and beyond the time when the reset of the flashboards would actually begin. In the simulation of these three events, the time window does not extend far enough beyond the peak of the event so that conditions can be met for the flashboards to reset. Additional work on this script and the associated if-block and rules should be considered if this model will be used to simulate longer periods to enable the operation to better reflect true or expected flashboard operation.

A description of the scripts as well a copy of one of the scripts was added to section 4.3.2.4 and included here:

> Although flood damage reduction is not one of the project purposes for the Mongaup reservoirs, all three reservoirs have overflow spillways with flashboards installed along the crest. The flashboards allow these reservoirs to maintain a higher pool than the spillway alone could provide and two of the three reservoirs operate with a normal pool at or near the top of the flashboards. While the size and trigger points of the flashboards differ between the projects, the basic operation is the same: water can surcharge behind and above the flashboards until the lateral forces on the flashboards cause them to "fall" and release the water stored behind them.
>
> To represent the operation of the flashboards, the model includes a scripted state variable for each reservoir that determines if the flashboards are UP or DOWN and an associated If-block to define outlet capacity based on the flashboard state.
>
> The parameters of the script include the elevation the pool must reach to cause the flashboards to fall, the elevation at which the pool must fall before the flashboards can be reset to the UP position, and the starting state of the flashboards – UP or DOWN. Because the first two parameters are hard coded into the script, a separate copy of the script was needed for each reservoir. The last parameter, as an initial condition, is set for each reservoir's script in the alternative editor.
>
> The logic of the script is as follows: first, the script retrieves the starting pool elevation and flashboard state for the current timestep. If the flashboards are UP, they will remain UP unless the pool has exceeded the fall elevation. However, if the flashboards are already DOWN, they will remain DOWN unless the pool elevation has dropped below the reset elevation. This logic is a simplification of the true operation of flashboards, which usually do not "all" fall together or instantaneously, nor do they reset instantaneously. Additionally, the reset elevations were selected for each reservoir to represent a "safe" state for construction crews come in to rebuild the flashboards on the spillway. This condition is not met (nor expected to be) during the span of the three simulated events. Where unique conditions existed at any of the three reservoirs, they are described in the sections below.

Since the three scripts are essentially the same, except for some comments and the hard-coded fall and reset elevation values, only one of the three is included here, in Figure 4.28.

```
# This state variable keeps track of the Up or Down state of the flashboards at TORONTO reservoir.
# UP...     Value = 1
# Down...Value = 0

# NOTE    NOTE    NOTE    NOTE    NOTE
# You should almost always assume that the flashboards are UP!!!
# Set initial contion (lookback) of this state variable to 1.  Do not leave blank or zero!
# NOTE    NOTE    NOTE    NOTE    NOTE

# Spillway Crest = 1215', Top of Flashboards= 1220', Flashboards fall at 2.5' over top - 1222.5'.
# Assume flashboards reset at Top of Con or 1210' (5' below Spillway crest), whichever is lower.
# -------------------------------------------------------------------------------------------------------------------------------
# The flashboards are model thus:
#           The flashboarded spillway is defined as a CONTROLLED outlet, even thought conceptually
#           it is UNCONTROLLED.  But only controlled outlets can have rules applied to them.
#           In the operation set, an if block watching this state variable uses a rule to limit the spillway
#           capacity when the boards are "up" and a different rule to force flow over the spillway at
#           maximum capacity when the boards are down.
#           At Toronto, there's plenty of operating range below spillway crest.  For safety's sake,
#           we've assumed that the flashboards are not reset until the pool reaches Top of Con or 1210',
#           whichever is lower.
# -------------------------------------------------------------------------------------------------------------------------------

from hec.script import Constants

ElevTS = network.getTimeSeries("Reservoir","Toronto", "Pool", "Elev")
prevElev = ElevTS.getPreviousValue(currentRuntimestep)

ConElevTS = network.getTimeSeries("Reservoir","Toronto", "Conservation", "Elev-ZONE")
curTOC = ConElevTS.getCurrentValue(currentRuntimestep)

myPrevState = currentVariable.getPreviousValue(currentRuntimestep)
if (myPrevState == Constants.UNDEFINED): myPrevState=1

# - - - The two variables below are key to the operation.
#           If you must change these values, do it here, not in the following logic - - - #
fallElev = 1222.5
resetElev = 1210
if (curTOC < 1210): resetElev = curTOC

if (myPrevState == 1):
# Flashboards are UP, are they about to FALL?
   if (prevElev <= fallElev):
     # keep boards up
      newState = 1
   else:
      # drop the boards
      newState = 0
else:
# Flashboards are DOWN, are they about to RESET?
   if (prevElev <= resetElev):
       # reset the boards
      newState = 1
```

Figure 4.28 Toronto Flashboards State Variable Script

Back-Check Comment – Concur.

34. Comment - Model. Swinging Bridge. Figure 19 is a similar state variable script used to determine whether the flashboards installed on Swinging Bridge Dam are up or down. As Row 36 indicates, the elevation above which the flashboards fall (*fallElev*) is currently set to a very high value (1,080 ft). The design elevation is 1,072 feet. This is a necessary modeling technique to simulate what had happened with the flashboards during the three events. In the 2005 event, the flashboards failed to fall as designed. Accordingly, setting *fallElev* to a very high elevation would keep the flashboards up. We suggest describing this modeling approach in the report and adding a warning note both in the model and in the report that this triggering elevation needs to be changed to the design elevation of 1,072 ft if the model is used for future flood events and if the flashboards have been rebuilt.

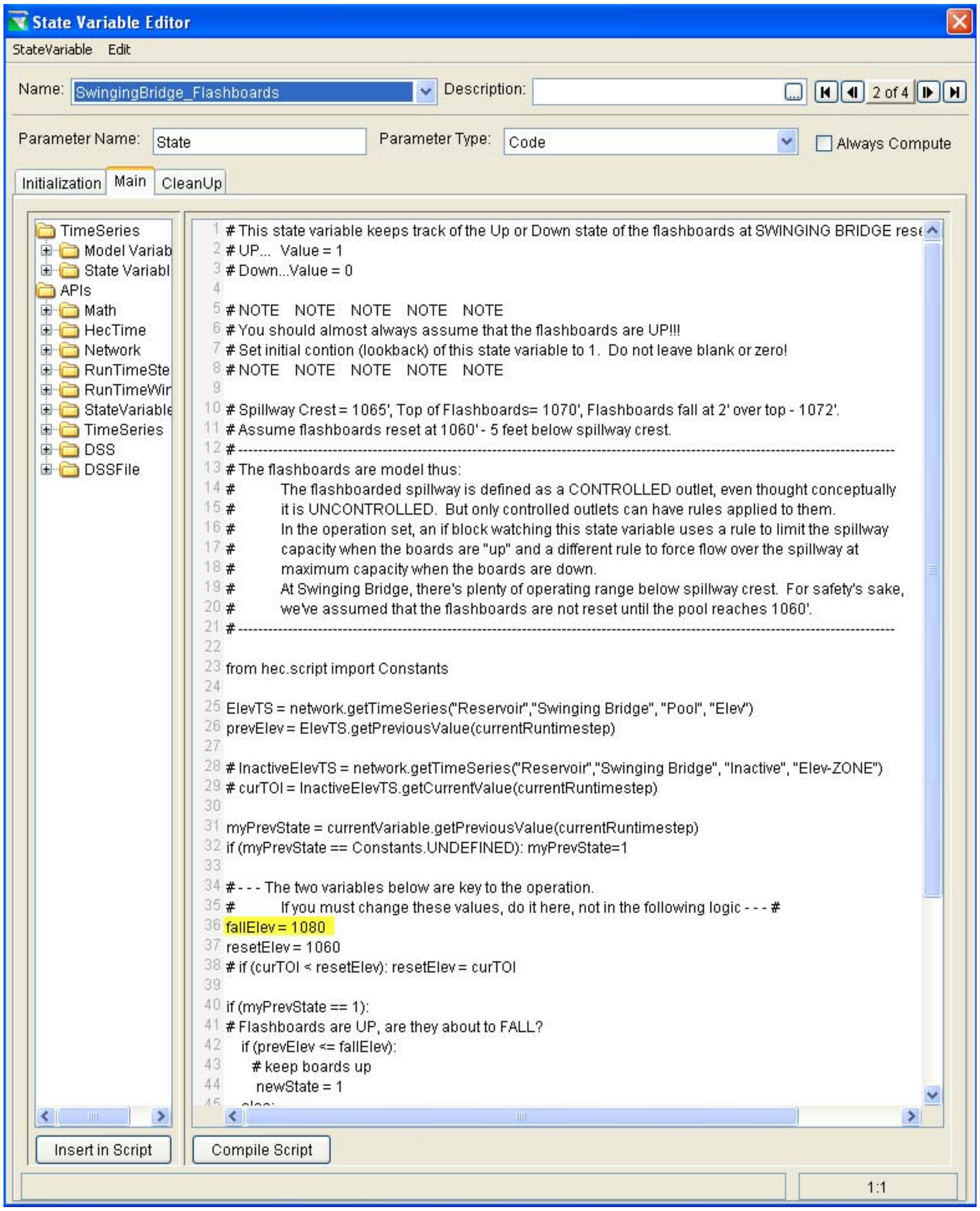


Figure 19. SwingingBridge_Flashboards state variable.

Comment Response - Agreed. The observed conditions were described in the report, but the alterations to the script were not. The following line was added to the second paragraph of section 4.3.2.6 of the report to complete the explanation:

> To reflect this “failure to fall”, the fall elevation in the state variable script was reset to 1080’, significantly higher than the design value for the flashboards.

And, the following sentence was updated in the third paragraph of the same section to make the modeled operation a little clearer:

> This initial state of the flashboards along with the lack of substantial conservation

operation demands allowed the scripted state variable to reflect the condition of flashboards throughout each simulation.

Back-Check Comment – Concur.

35. Comment - Model. Rio. Similar to the flashboards at Swinging Bridge, the flashboards at Rio failed during the 2005 event and were removed after this event. As shown in Figure 20, setting *resetElev* =0 ft and a state of "DOWN" position at the start of the simulation for the 2006 event would keep the flashboards down for the 2006 event. Again, we suggest describing this modeling approach in the report so that the users will be more aware of a need to change this elevation for future flood simulations if the flashboards have been rebuilt.

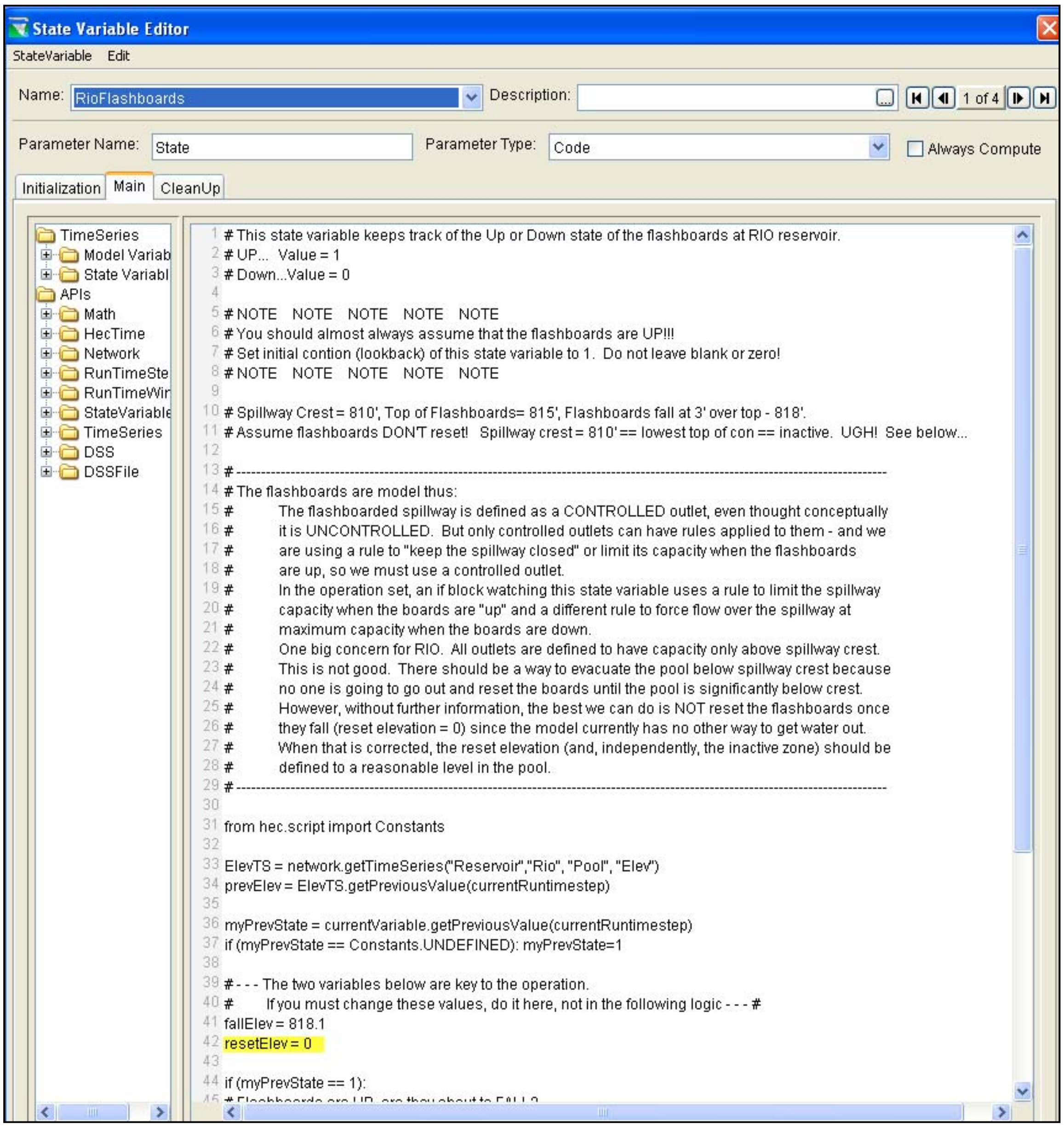


Figure 20. RioFlashboards state variable.

Comment Response - Agreed. The observed conditions were described in the report, but the alterations to the script were not. The following paragraph was added/modified in section 4.3.2.7 of the report to complete the explanation:

> In the 2005 event, the flashboards failed to fall at Swinging Bridge and Rio. As with Swinging Bridge, the flashboards were removed after the 2005 event, so a similar time-series was developed to set the flashboard state initial condition for each event appropriately. Additionally, the reset elevation for Rio in the state variable script was set to zero because a reasonable reset elevation could not be estimated from available data.

Back-Check Comment – Concur.

36. Comment - Model. F.E. Walter and Beltzville. Figure 21 and Figure 22 are excerpts of the regulation plan and maximum release schedule at F.E. Walter and Beltzville from the water control manuals. F.E. Walter and Beltzville are operated as a system to balance the flood control storages to reduce peak stages and flows at three downstream locations. We believe that the current operations implemented in the model may be over simplified. No system operation is used. Table 7-1 in the water control manual is also not fully implemented. We suggest adding system operations and additional state variables and rules to better represent the flood operations expected during the high flow events.

SYSTEM OPERATION OF F. E. WALTER RESERVOIR AND BELTZVILLE LAKE
LEHIGH RIVER PENNSYLVANIA

PART A - REGULATION PLAN

Schedule	Controlling Gaging Stations				
	Lehigh River at Bethlehem, PA Stage in feet (Discharge in cfs)	Lehigh River at Walnutport, PA Stage in feet (Discharge in cfs)	Lehigh River at Lehighton, PA Stage in feet (Discharge in cfs)	F. E. Walter Reservoir Pool Elevation (Ft. N.G.V.D.)	Beltzville Lake Pool Elevation (ft. N.G.V.D.)
A (1)	9.9 (below 23,820)	below 6.3 (below 10,960)	below 9.7 (below 15,200)	1245.0 - 1300.0	537.0 - 628.0
B (1)	9.9 (below 23,820)	below 6.3 (below 10,960)	below 9.7 (below 15,200)	1300.0 - 1450.0	628.0 - 651.0
C (2)	9.9 and above (23,820 and above)	6.3 and above (10,960 and above)	9.7 and above (15,200 and above)	1300.0 - 1450.0	628.0 - 651.0
D	Control Situations Not Considered	Control Situations Not Considered	Control Situations Not Considered	above 1450.0	above 651.0

Notes:
(1) Stages and discharges at all control gages must be below indicated level.
(2) Stage and discharge need be exceeded at only one control gage.

Schedule A - The regulation plan during this schedule is to always maintain the pool elevation at or near the designated normal pool elevation (1300.0 ft N.G.V.D. at F. E. Walter Reservoir and 628.0 ft. N.G.V.D. at Beltzville Lake) while meeting required release obligations. The required release obligations are defined in the Minimum Release Schedule which covers downstream conservation release requirements. Additional increases in minimum release requirements due to low flow augmentation or water supply needs in the lower Lehigh and Delaware River Basins in the future may be requested by the Delaware River Basin Commission. The water quality parameter guidelines for downstream releases are defined in the Water Quality Release Schedule.

Schedule B - Attempt to maintain the pool elevation at or near designated normal pool while meeting all required release criteria. In accomplishing the above, all criteria defined in the Maximum Release Schedule, the Minimum Release Schedule and the Water Quality Release Schedule should be adhered to as closely as possible. The Reservoir Filing Plan criteria described in Exhibit C should be followed when pool elevations are attained that are higher than elevations previously reached.
The Maximum Release Schedule utilized under this schedule covers release conditions during initial rising stages at key downstream control stations. When making maximum combined releases from either or both reservoirs under the Maximum Release Schedule covering rising stages, every effort should be made to balance the percentage of utilized flood control storage in each reservoir. When regulating to balance the percentage of utilized flood control storage in each reservoir, use the Time of Travel Schedule (table 7-1, Part B) in staging releases from each reservoir so as not to exceed flood control stages or create greater damage stages downstream than have already occurred for that event.

Schedule C - Criteria for this plan calls for only one of the key control gaging stations downstream of the reservoirs to equal or exceed its designated critical stage while either or both reservoirs is above normal pool elevation and below spillway crest. Once the critical storage initiation stage is reached at any one station, storage of inflow should take place at both reservoirs while making minimum releases as prescribed in the Minimum Release Schedule and meeting downstream water quality standards as

Figure 21. System regulation plan at F.E. Walter and Beltzville.

TABLE 7-1
SCHEDULE OF REGULATION
SYSTEM OPERATION OF F. E. WALTER RESERVOIR AND BELTZVILLE LAKE
LEHIGH RIVER PENNSYLVANIA

PART B - MAXIMUM, MINIMUM AND WATER QUALITY RELEASE

MAXIMUM RELEASE SCHEDULE			
INITIAL RISING STAGES (6)			
Key River Gages to be Monitored (1)			
Lehigh River at Bethlehem, Pa Stage in feet	Lehigh River at Walnutport, PA Stage in feet	Lehigh River at Lehighton, PA (3) Stage in feet	Maximum Allowable Combined Total Releases From Beltzville Lake and F. E. Walter Res. Discharge in cfs
below 7.0	below 2.5	below 5.7	11,500 (4), (5)
7.0 to 7.7	2.5 to 3.7	5.7 to 6.6	8,000
7.7 to 8.3	3.7 to 4.5	6.6 to 7.5	6,000
8.3 to 8.8	4.5 to 5.2	7.5 to 8.2	4,000
8.8 to 9.4	5.2 to 5.8	8.2 to 9.0	2,000
9.4 to 9.9	5.8 to 6.3	9.0 to 9.7	1,000
above 9.9	above 6.3	above 9.7	(2)
FALLING STAGES AFTER PEAKING			

Figure 22. Maximum system release schedule F.E. Walter and Beltzville.

Comment Response - Disagree. The three downstream flood control constraints ARE represented in the model – all three are included in the operation set for FE Walter, and the two rules for the control points below Beltzville are included in the operation set for Beltzville. By including the same downstream control rules at both reservoirs, ResSim will see the two reservoirs as a system and attempt to balance storage when allocating releases between them while meeting the downstream constraint. Normal guide curve operation and the definition of the zone and the rest of the rules effectively represent the flood control constraints described in the illustrated regulation plan. However, since this model is focused on representing flood control operation, the conservation objects have been simplified. The most significant impact of these simplifications is that the state of the reservoir pool at the onset of a flood event may be artificially high – which is a normal, conservative assumption in most flood control studies.

Back-Check Comment – Concur. The explanation is very useful.

SUMMARY AND RECOMMENDATION

An IEPR was conducted to review the Flood Analysis Model that was developed for the Deleware River basin and calibrated for the recent September 2004, April 2005, and June 2006 flood events. The model has two components. The rainfall/snowmelt-runoff processes were simulated using PRMS. Reservoir operations and flood flow routing through the river system below the reservoirs were simulated using HEC-ResSim. The HEC-ResSim model has two modeling alternatives. Alternative FC-PRMS uses inflows generated by the PRMS model. Alternative FC-GageQ uses inflows derived from the observed gage data for the three flood events.

The IEPR review was focused on the methodologies and the results presented in the PRMS and HEC-ResSim modeling reports and the HEC-ResSim model input and output. Review comments concerning the PRMS and HEC-ResSim models were provided to the USGS and HEC, respectively. Responses to the comments, a revised HEC-ResSim modeling report, and a revised HEC-ResSim model were received. WEST's back-check comments on the responses are included in this report. WEST concurs with the responses to the comments on the HEC-ResSim model except for four minor editorial comments on the revised HEC-ResSim modeling report. While we concur with many of the responses to the comments on the PRMS model, we remain concerned with the PRMS model performance and the calibration approach. Our overall findings on the three review focuses defined in the scope of work are as follows:

a. Adequacy of Flood Analysis Model to reproduce observed conditions for the three flood events

   The Flood Analysis Model with HEC-ResSim Alternative FC-GageQ adequately represents the baseline conditions of the basin during flood conditions. The simulated reservoir elevations, releases, and river stages/flows downstream of the reservoirs are generally in good agreement with the observed data for the three flood events. However, the Flood Analysis Model with HEC-ResSim Alternative FC-PRMS did not satisfactorily reproduce the peak flows and total volums that occurred during the three major flood events.

b. Utility of the model to assess the impact of voids in designated Delaware River Basin reservoirs on the downstream river stages for the three flood events

   The HEC-ResSim component of the model with Alternative FC-GageQ is adequate for use by the DRBC to investigate any impacts of alternative reservoir operations on the downstream river stages for the three flood events.

c. Utility of the PRMS component of the model to evaluate the impact of watershed conditions on the three flood events.

   The PRMS component of the model was not able to generate inflows that would result in a good agreement with the observed conditions at many locations in the river system for the three events. Due to the uncertainties of the input precipitation data, the raw MPE data were adjusted as part of the model calibration. More details need to be presented to clearly demonstrate that the rainfall-runoff processes were adequately represented in the model with reasonable hydrologic parameter values and that the discrepancies between simulated and observed hydrographs are primarily due to the errors in the input precipitation data. With this assurance, the model can be used to investigate any impacts of watershed conditions on the basin runoff. However, the impacts should be viewed as relative changes from the baseline conditions. With the same rainfall input and rainfall adjustment factors, the results for any alternative watershed conditions will have a level of accuracy similar to the baseline condition results.

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APPENDIX A

COVER PAGES OF RESPONSES TO COMMENTS

United States Department of the Interior

U.S. GEOLOGICAL SURVEY

Pennsylvania Water Science Center
http://pa.water.usgs.gov/

February 4, 2011

MEMORANDUM

To: James B. Campbell, Director, New Cumberland, Pennsylvania

From: Daniel J. Goode, Research Hydrologist, Exton, Pennsylvania

Subject: Memorandum from Dr. Henry Hu (West Consultants) to Amy Shallcross (Delaware River Basin Commission) dated August 23, 2010

The Delaware River Basin Commission (DRBC) provided the subject memorandum on "RE: Questions and Comments on PRMS Modeling Report, Review of Delaware River Basin Commission Flood Analysis Model" to USGS on November 3, 2010. The discussion below follows the organization in that memorandum of "General Comments" and "Specific Comments and Questions."

But first, on behalf of myself and my co-authors, I would like to make a few comments about the complexity and difficulty of this modeling exercise. In many ways, this project was a "first-of-its-kind" application of a rainfall-runoff model. At 6,780 square miles, the Delaware River basin above Trenton is one of the largest applications of a rainfall-runoff model to be attempted. PRMS had rarely been used at an hourly timestep, but this project required hourly timesteps for resolution of the flood hydrographs. Rainfall-runoff models are generally used to evaluate water supply and land-use-related issues using annual, monthly, weekly, or daily flows. However, this model simulates hourly flood peaks for three of the highest events in 111 years of record at the Trenton gage. Watershed models are commonly used to match simulated and observed flow events at one or a few downstream gages. This model was calibrated for three extreme flow events at 17 gages throughout the basin. The snow melt routine that PRMS uses for flow simulation on a daily basis cannot be used for hourly simulation. This project developed a new PRMS hourly snow melt module based on a National Weather Service (NWS) hourly algorithm because the April, 2005 storm was significantly influenced by snow melt. Finally, this was the first time that USGS has ever worked with the NWS's MPE radar coverage for precipitation input into the model, which presented its own unique challenges. This is all to say that this project was charting a great deal of new territory in the practices of watershed modeling and some of the normal practices of watershed simulation could not be accommodated during the execution of this project. In particular, that would include practices like inclusion of a validation event and matching simulated and observed peak discharges and timing of the primary peak to within + or – 10% at all gages.

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS, INSTITUTE FOR WATER RESOURCES
HYDROLOGIC ENGINEERING CENTER
609 SECOND STREET
DAVIS, CALIFORNIA 95616 - 4687

REPLY TO
ATTENTION OF

19 May 2011

Executive Office

Mr. Henry Gruber/Mr. William Mulloy
US Army Corps of Engineers, Philadelphia District
The Wanamaker Building
100 Penn Square East
Philadelphia, PA 19107-3390

Messrs. Gruber and Mulloy,

Thank you for giving the Hydrologic Engineering Center (HEC) the opportunity to provide responses to the comments contained in the Technical Memorandum by WEST Consultants for their Independent Technical Review of the Delaware River Basin Flood Analysis Model, Reservoir and Routing Component produced by HEC for the Delaware River Basin Commission.

For readability, our responses have been inserted into the text of the original memorandum. Please find the revised memorandum enclosed.

Many of the comments suggested changes or additions to the project report. Where HEC considered appropriate, those changes or additions were made and an electronic copy of the revised report has been provided on the CD included with the enclosed memorandum.

A few comments suggested changes to the model. All of these comments were considered carefully but the only changes that HEC made to the model were related to the calibration of the routing parameters for three reaches and the development of the local inflow at one gage location. These changes are noted in our responses to the relevant comments. The updated model is included on the enclosed CD.

HEC appreciates the opportunity to work with you and we trust that the enclosed memorandum, revised report, and updated model will be useful for the Philadelphia District and the Delaware River Basin Commission. If you have any questions about these materials, please contact Ms. Joan Klipsch or Mr Matt Fleming of our office.

Sincerely,

Christopher N. Dunn, P.E., D.WRE
Director, Hydrologic Engineering Center

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