FINAL STUDY REPORT

OPERATIONS MODELING BASELINE AND PRODUCTION RUN REPORT

ADDENDUM TO

CONOWINGO HYDROELECTRIC PROJECT - RSP 3.11
FERC PROJECT NUMBER 405

AND

MUDDY RUN PUMPED STORAGE PROJECT – RSP 3.2
FERC PROJECT NUMBER 2355

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EXECUTIVE SUMMARY

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project), and the 800-megawatt Muddy Run Pumped Storage Project (Muddy Run Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. The current license for the Muddy Run Project was issued on September 21, 1964 and expires on August 31, 2014. FERC issued final study plan determinations for both Projects on February 4, 2010.

Conowingo's final study plan determination required Exelon to conduct a Hydrologic Study of the Lower Susquehanna River. The study's objectives were to: 1) Describe the history of flow management practices in the lower Susquehanna River basin; 2) Confirm the accuracy of the Conowingo USGS gage; 3) Perform a statistical analysis to describe the lower Susquehanna River flow regime; 4) Evaluate changes in Conowingo Project operations since energy deregulation laws came into effect in 1998; 5) Conduct operations modeling production runs to evaluate various operating scenarios to understand how operation changes may impact water use in the lower Susquehanna River; and 6) Develop a bathymetric map of the tailwater area below Conowingo Dam.

Muddy Run's final study plan determination required Exelon to conduct a Hydrologic Study of the Muddy Run Water Withdrawal and Return Characteristics. The study's objectives were to: 1) Describe the history of flow management practices in the lower Susquehanna River basin; 2) Examine the water withdrawal and return characteristics of the Muddy Run Project; 3) Describe the operations of the Muddy Run Project; 4) Develop bathymetric mapping of the Muddy Run Project reservoir and tailrace; and 5) Examine the impacts of alternative flow management regimes in the lower Susquehanna River on Muddy Run Project generation.

Conowingo Study Report 3.11 addressed Conowingo study 3.11 objectives 1 through 4 and objective 6. Muddy Run Study Report 3.2 addressed Muddy Run study 3.2 objectives 1 through 4. The purpose of this addendum is to address Conowingo Study 3.11 objective 5 and Muddy Run Study 3.2 objective 5, describing the operations model "Baseline" production run.

The operations model background, calibration process and calibration results were explained in an earlier addendum to Conowingo Study Report 3.11 and Muddy Run Report 3.2 titled "Operations Modeling Calibration Report", which was filed with FERC on June 2, 2011.

This report 1) provides background on the Baseline model's development; 2) describes changes made to the model rules and engineering data relative to the calibration model; 3) describes the results of the

Baseline production run; and 4) describes the results of three production runs. The production runs were developed in consultation with relicensing stakeholders, and include a run-of-river scenario, as well as two runs examining various ramping rates, peaking restrictions and minimum flows.

The Baseline production run is a modified version of Exelon's calibration model run. The primary differences are 1) the Baseline run contains fewer operating constraints, 2) it uses a longer, modeled hydrologic record (1930-2007) instead of measured USGS gage flows and 3) the model optimization runs using a forward-looking price curve for 2014 instead of historic price data. Additionally, some engineering data have been updated to reflect information provided to Exelon since the release of the calibration model report.

An updated study report (USR) was filed on January 23, 2012, containing the Baseline model development. A meeting was held on February 1 and 2, 2012 with resource agencies and interested members of the public. Formal comments on the USR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the USR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

The Baseline model results showed that from calendar year 1930 through 2007 the average annual generation at Conowingo was 1,669 GWh/yr, and average annual generation at Muddy Run was 1,739 GWh/yr generated, while 2,261 GWh/yr was used for Muddy Run pumping operations.

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FERC	Federal Energy Regulatory Commission
GWh	Gigawatt-hours
ILP	Integrated Licensing Process
MW	Megawatt
MWh	Megawatt-hours
NGO	Non-Government Organization
NOI	Notice of Intent
OASIS	Operational Analysis and Simulation of Integrated Systems
PAD	Pre-Application Document
PPL	PPL Holtwood, LLC
PSP	Proposed Study Plan
RSP	Revised Study Plan
SRBC	Susquehanna River Basin Commission
USGS	United States Geological Survey
WSE	Water Surface Elevation
WY	Water Year

1. INTRODUCTION

Exelon Generation Company, LLC (Exelon) owns and operates the Conowingo Hydroelectric Project (Conowingo) and Muddy Run Pumped Storage Project (Muddy Run) on the lower Susquehanna River. Exelon has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt (MW) Conowingo project and the 800-MW Muddy Run project. Exelon is applying for new licenses using the FERC's Integrated Licensing Process (ILP). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. The current license for the Muddy Run project was issued on September 21, 1964 and expires on August 31, 2014.

As required by the ILP, Exelon filed its Pre-Application Document (PAD) and Notice of Intent (NOI) with FERC on March 12, 2009. On June 10-12, 2009, site visits and scoping meetings were held at each project location for resource agencies and interested members of the public. Following these meetings, formal study requests were filed with FERC by several resource agencies. Many of these study requests were included in Exelon's Proposed Study Plan (PSP), which was filed on August 24, 2009. On September 22 and 23, 2009, Exelon held a meeting with resource agencies and interested members of the public to discuss the PSP.

Formal comments on the PSP were filed with FERC on November 22, 2009 by Commission staff, and several resource agencies. Exelon filed a Revised Study Plan (RSP) for the Project on December 22, 2009. FERC issued the final study plan determination for the Project on February 4, 2010, approving the RSP with certain modifications.

Conowingo's final study plan determination required Exelon to conduct a Hydrologic Study of the Lower Susquehanna River. The study's objectives were to:

1) Describe the history of flow management practices in the lower Susquehanna River basin
2) Confirm the accuracy of the Conowingo USGS gage
3) Perform a statistical analysis to describe the lower Susquehanna River flow regime
4) Evaluate changes in Conowingo Project operations since energy deregulation laws came into effect in 1998
5) Conduct operations modeling production runs to evaluate various operating scenarios to understand how operation changes may impact water use in the lower Susquehanna River
6) Develop a bathymetric map of the tailwater area below Conowingo Dam

Muddy Run's final study plan determination required Exelon to conduct a Hydrologic Study of the Muddy Run Water Withdrawal and Return Characteristics. The study's objectives were to:

1) Describe the history of flow management practices in the lower Susquehanna River basin
2) Examine the water withdrawal and return characteristics of the Muddy Run Project
3) Describe the operations of the Muddy Run Project
4) Develop bathymetric mapping of the Muddy Run Project reservoir and tailrace
5) Examine the impacts of alternative flow management regimes in the lower Susquehanna River on Muddy Run Project generation

Conowingo Study Report 3.11 addressed Conowingo study 3.11 objectives 1 through 4 and objective 6. Muddy Run Study Report 3.2 addressed Muddy Run study 3.2 objectives 1 through 4. The purpose of this addendum is to address Conowingo Study 3.11 objective 5 and Muddy Run Study 3.2 objective 5, describing the operations model Baseline run and production runs.

The operations model background, calibration process and calibration results were explained in an addendum to Conowingo Study Report 3.11 and Muddy Run Report 3.2 titled "Operations Modeling Calibration Report", which was filed with FERC on June 2, 2011.

This report 1) provides background on the Baseline model's development; 2) describes changes made to the model rules and engineering data relative to the calibration model; 3) describes the results of the Baseline production run; and 4) describes the results of three production runs. The production runs were developed in consultation with relicensing stakeholders, and include a run-of-river scenario, as well as two runs examining various ramping rates, peaking restrictions and minimum flows.

The Baseline production run is a modified version of Exelon's calibration model run. The primary differences are 1) the Baseline run contains fewer operating constraints, 2) it uses a longer, modeled hydrologic record (1930-2007) instead of measured USGS gage flows and 3) the model optimization runs using a forward-looking price curve for 2014 instead of historic price data. Additionally, some engineering data have been updated to reflect information provided to Exelon since the release of the calibration model report.

An updated study report (USR) was filed on January 23, 2012, containing the Baseline model development. A meeting was held on February 1 and 2, 2012 with resource agencies and interested members of the public. Formal comments on the USR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the USR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

2. BACKGROUND AND MODEL OVERVIEW

The Susquehanna River is one of the United States mid-Atlantic region's major freshwater sources, and is an important alternative energy source. The lower Susquehanna has several hydroelectric projects that collectively influence the river's flow characteristics. In the approximately 45 miles between the Marietta, PA United States Geological Survey (USGS) gage (No. 01576000) and the mouth of the Susquehanna at Chesapeake Bay, there are three main channel dams and one pumped storage facility, all constructed for the purpose of hydroelectric energy generation. These four hydroelectric projects have a combined 1,897 MW nameplate capacity, and in 2010 produced a reported combined 4,844,485 megawatt-hours (MWh) of energy. In addition to the hydroelectric energy generation, there are several other withdrawals for various uses, including power generation cooling water as well as drinking water withdrawals.

Exelon developed an operations model to better understand how operational changes at the lower Susquehanna River's four hydroelectric facilities affect the timing of river flows and energy generation. This involved adjusting the model parameters and constraints to match historic[1] data (flow, stage, generation) in several "calibration" runs, and then using the parameters and constraints from the final calibration model to predict plant operations over a longer-term period (1930-2007) to establish a "Baseline" model run. The operations model's details and computational methods were described in an addendum to Conowingo Study Report 3.11 and Muddy Run Report 3.2 titled "Operations Modeling Calibration Report." This section will provide an overview on the model development, and primarily focus on the differences between the calibration and Baseline models.

2.1 Model Purpose and History

During the period 2002 – 2005, the Susquehanna River Basin Commission (SRBC) developed an operations model ("the SRBC model") of the Susquehanna River Basin to use in its "Conowingo Pond Management Alternatives Analysis" project (SRBC 2006). This model included the various hydrologic inputs, water withdrawals and returns within the entire Susquehanna River Basin, as well as engineering

[1] Historic data refers to the period 2004-2007

data (e.g. reservoir stage-storage tables). The model simulated water movement through various dams and hydropower facilities[2] on a daily time step.

In 2007, Exelon began development of its own operations model to evaluate alternative flow management scenarios' generation and flow impacts. The Exelon model is based on the SRBC OASIS model, using the same inflow and flow routing procedures. However, the Exelon model also includes hydroelectric operations at the Lower Susquehanna River hydropower projects, namely Safe Harbor, Holtwood, Muddy Run and Conowingo. The Exelon model operates on an hourly time step downstream of Safe Harbor to simulate peaking hydropower generation. To adequately predict hydropower operations, an hourly energy price time series was created and used to guide generation decisions within the model.

The Exelon model is run as a weekly optimization model, operating each hydroelectric facility to maximize revenue within a set of constraints. The model combines flow availability and energy price information to create a generation schedule in one-week blocks (Monday through Sunday). Revenue at each facility is optimized by operating the facility with week-ahead flow and energy price foresight. That is, each facility operates knowing exactly how much water will be available for generation and what the energy price will be for the upcoming week. The model calculates generation/flow releases for upstream hydroelectric projects first, and then calculates downstream projects based on upstream operations. Conowingo and Muddy Run are run in parallel because of the inherent hydraulic and operational connection between the two projects (Muddy Run withdraws water from Conowingo Pond).

Both the SRBC and Exelon models include facilities that were constructed after the model start date of January 1, 1930. Model runs reflect modern day structures and demands, even though the hydrologic simulation extends back to January 1, 1930. For example, the Muddy Run Project was licensed in 1964, but the model will operate Muddy Run in 1930. Similarly, water supply demands are different today than they were in 1930. The reason the model was run this way was so operational alternative comparisons would include the Susquehanna River's longer-term historic hydrologic conditions. Thus, energy and flow analysis comparisons were not limited to hydrologic conditions from only the most recent years.

[2] Though hydroelectric reservoirs were included in the SRBC model, hydroelectric operations were not modeled. Water was simply routed through the reservoirs.

2.2 Modifications between the Calibration and Baseline Models

The baseline model was initially created by making a copy of the calibration model. However, several modifications were necessary to develop a "baseline" run. These model modifications were limited to the changes described in the following sections. No other modifications were made to the model's rules, engineering data, inputs, or any other portion of the model.

2.2.1 Inflow Hydrology

While the calibration model utilized historic USGS gage data to determine inflow at the Marietta[3] node, the Baseline model uses model derived flows throughout the entire Susquehanna basin for the inflow hydrology. These model-derived flows are the same as SRBC's model inflow data. Additionally, the period of record analyzed in the Baseline model is much longer. The calibration model only ran from 2004-2007, while the Baseline model runs from January 1930 to March 2008. For all analyses in this report, the partial-year results from 2008 were not utilized. This was done to prevent skewing any monthly averages with partial-year data.

2.2.2 Energy Price Time Series

In order to execute the model optimization routine, the OASIS model required hourly energy prices to determine when and how much each Project would generate. For the model calibration, actual historic hourly price data were input into the model for the 2003-2007 period. For the baseline production run, Exelon provided a forecasted hourly price curve for 2014. The model used this 2014 price curve as the energy price input for all modeled years (1930-2008). For example, the price specified on 1/1 at 1:00 PM in the input energy price data would be repeated for all modeled years (1/1/1930 1:00 PM, 1/1/1931 1:00 PM, etc.). For the purposes of this model, the same hourly pricing was used to operate Safe Harbor, Holtwood, Muddy Run and Conowingo. However, in reality, each hydroelectric project (Safe Harbor, Holtwood, Conowingo/Muddy Run) may be using different energy price projections and/or operation strategies.

The OASIS model does not account for external power conditions when dispatching the hydroelectric projects. For example, within the model, Conowingo and Muddy Run are dispatched without any knowledge of external energy or transmission system needs.

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[3] The calibration model used modeled local inflows at each of the reservoirs, since no real data were available.

As was done in the calibration model, hourly prices are smoothed using a 7-hour moving average for the optimization routine, but unsmoothed prices are used to calculate final revenue figures.

2.2.3 Engineering Data

The only engineering data related change in the model was the revision of the leakage value at Safe Harbor Dam. The calibration model included no leakage at Safe Harbor, since no data were publically available to estimate this value at that time. However, Andrew Dehoff (SRBC) noted at a Conowingo/Muddy Run stakeholder meeting in August 2011 that SRBC believes Safe Harbor leakage is approximately 500 cfs. This leakage value was included in the Baseline model and all production runs.

Holtwood operations are modeled in the Baseline model as it will operate after its expansion project is complete. Holtwood was modeled in the calibration model under pre-expansion conditions. The primary difference between pre-expansion and post-expansion Holtwood conditions is the Holtwood powerhouse's hydraulic capacity increased from 31,500 cfs to 62,000 cfs. Additionally, Holtwood's tailwater rating curve was altered in the post-expansion condition. The calibration report described Holtwood's pre-expansion and post-expansion conditions. Operational changes associated with the Holtwood expansion are described in Section 3.2.4.

The engineering data for all four projects are listed in Table 2.2.3-1, Table 2.2.3-2, Table 2.2.3-3 and Table 2.2.3-4. Additionally, Conowingo's minimum flow schedule is shown in Figure 2.2.3-1.

2.2.4 Operational Constraints

The Baseline included a few modified constraints relative to the calibration model. While the constraints are primarily less restrictive, there was one increased restriction. The changes are described in the following list:

1) **Muddy Run's minimum reservoir elevation of 475 ft[4] in the calibration model was relaxed**. This was reduced to a minimum of 470 ft, which is the lower operational limit of the reservoir. There is only dead storage below that elevation.

2) **Conowingo's minimum pond elevation was reduced to 104.7 ft, from 105.7 ft.** Additionally, while the calibration model was allowed to draw from storage to meet minimum flows, the new limit was set as a firm lower limit. Thus, the model was ordered to maintain a pond elevation of

[4] All elevations in this report refer to the NGVD 1929 datum, which is 0.7 ft higher than Conowingo datum. For example, 108.5 ft Conowingo Datum = 109.2 ft NGVD 1929.

104.7 ft over meeting minimum flows, if the situation arose. A pond elevation of 104.7 is the minimum elevation at which Muddy Run can pump and is only 0.5 ft above Peach Bottom Atomic Power Station's critical pond elevation.

3) **Inflow smoothing from Holtwood was eliminated.** This was done because the smoothing routine was altering the weekly water balance significantly when a high-flow event pulsed through the system and "overlapped" two weekly optimization periods. This situation caused sporadic spill events from Conowingo resulting in drastic pond level dips of up to 10 ft. This scenario never occurred in the much smaller calibration dataset, which is why it was not previously identified as a problem.

4) **Holtwood is operated under post-expansion conditions, including mandatory minimum flow releases.** Since the Holtwood expansion is expected to be completed by the time Conowingo and Muddy Run's licenses expire (2014), Holtwood was included in the Baseline model as if the expansion project was complete. The main operational change (in addition to the increased powerhouse capacity), is related to the introduction of a minimum flow at Holtwood. Holtwood is required to provide an 800 cfs continuous minimum flow, and 98.7% of Conowingo's minimum flow on a daily average basis. Both conditions are on an "or net inflow[5]" basis, such that Holtwood is required to release the lesser of the two values. The agreement also specified that Holtwood must prorate both conditions as a percentage of Conowingo's baseline minimum flows if future operations result in different seasonal minimum flow requirements.

There are also several calibration-related operational constraints that were left in the Baseline run. The more notable constraints include:

1) Flow variation constraints of 40,000 cfs at Conowingo and 15,000 cfs at Muddy Run were maintained. These constraints were included for two reasons. First, Conowingo USGS gage records indicate that the river takes approximately 1.5 to 2 hours to fully respond to increased outflows. Secondly, the flow variation constraints prevented the model's optimization routine from rapidly cycling (sometimes hourly) Conowingo and Muddy Run on and off in response to subtle price changes, which is not how the Projects are typically operated. The flow variation constraint does not reflect any physical, operational or regulatory constraints. Flow variation constraints restrict the magnitude at which flows can change on an hourly basis. For example, if flow from Conowingo was 20,000 cfs at 9:00, then the flow at 10:00 can not exceed 60,000 cfs.

2) The regression equation used to approximate Conowingo's maximum daily peaking flow when Marietta flows are less than 55,000 cfs was maintained. This regression equation reduced the overall frequency and duration of flows at Conowingo's maximum generation capacity.

[5] Net inflow at Holtwood is calculated as the inflow from Safe Harbor plus local inflows minus evaporation.

3) The weekly pump/generation schedule preventing unrealistic pumping and/or generation at Muddy Run was maintained.

3. BASELINE MODEL RUN RESULTS

While the calibration model was run to match a short period of historic (2004-2007) data, the Baseline model was intended to be run over a much wider set of hydrologic conditions. This wider condition range was necessary to establish a thorough understanding of how operational changes may impact several project-related characteristics, including project energy and revenue outputs, downstream habitat and Conowingo Pond level variations. This section summarizes the Baseline model results, which will be used as benchmarks to which other production runs will be compared.

There was one noteworthy model response that shows Conowingo responding differently than it would be managed in reality. During extreme low flow events, there are a small number of instances when there is insufficient water to meet both minimum flow requirements and minimum pond levels particularly when the weekend recreation minimum pond of 107.2 ft is in effect. As stated in Section 3, the model was instructed to have minimum pond elevations take precedence over minimum flow releases. Since the optimization model has week-ahead foresight, it attempts to minimize the number of times it violates either requirement if it knows it will not be able to meet both of them 100% of the time. In other words, the model minimizes the number of hours in which it does not meet the minimum flow requirement. When such an event occurs, the model responds by completely shutting off turbine outflow from Conowingo Dam, such that leakage is the only flow leaving the dam. This allows the model to reduce the number of violations, though it disregards the magnitude of each violation, so that Conowingo can release the required minimum flow for the greatest number of hours. This contrasts to how the dam would operate in reality, which would likely result in Conowingo releasing as close to the required minimum flow as possible, even if it missed the minimum flow target for a greater number of hours. This model response occurred infrequently, with only 657 hours of this condition over the 78 years of modeled time. This phenomenon occurred in 17 of the 80 modeled years, and only when the Marietta flow was less than the seasonal minimum flow threshold. Each instance of unrealistic operations occurred between June 1 and September 14, when the seasonal minimum flow threshold was 5,000 cfs. Table 3-1 summarizes the number of occurrences and exceedance percentiles for the unrealistic operations. This translates to less than a 0.1% frequency occurrence. We have concluded, however, that the results occur so infrequently that they will not impact any of the analyses being run on the model output, such as habitat time series analyses or aggregate generation/flow/pond elevation statistics. Additionally, the relatively small benefit of excluding the years with small amounts of unrealistic operations outweights the risk of reducing the analyzed hydrologic period, particularly since the years with unrealistic operations were all low flow years (since Marietta flows dropped below 5,000 cfs). If future habitat or other analyses are used that are critically sensitive to this issue, we will address the consequences of using this data at that time.

The Baseline run's annual and monthly flow exceedance percentiles for Conowingo Dam outflow are shown in Table 3-2. Additional low-flow exceedance percentiles have been included in Table 3-3. The results show that Conowingo's seasonal minimum flow requirements and maximum turbine capacity influence which flows occur more frequently than others. Figure 3-1 compares the modeled baseline and USGS gage-observed flow data for Conowingo Dam, using a common period of record (water year 1989-2007). Annual and monthly flow exceedance curves are shown Appendix A.

The Baseline run's annual and monthly stage exceedance percentiles for Conowingo Pond are shown in Table 3-4. The model shows that Conowingo Pond spends a large amount of time at maximum pond (109.2 ft). Annual and monthly pond elevation exceedance curves are shown in Appendix B.

The Baseline run's annual and monthly average net energy output is shown in Table 3-5. The Baseline model results showed that from calendar year 1930 through 2007 the average annual generation at Conowingo was 1,669 GWh/yr, and average annual generation at Muddy Run was 1,739 GWh/yr generated, while 2,261 GWh/yr was used for Muddy Run pumping.

4. PRODUCTION RUN MODEL RESULTS

In consultation with relicensing stakeholders, Exelon completed three production runs that evaluate various minimum flows, peaking restrictions, ramping rates, and a run-of-river scenario. These three production runs were executed by Exelon as the first three of nine total production runs submitted to Exelon by relicensing stakeholders. The first run (SRBC-006) evaluated a new monthly minimum flow scheme and maximum flow (peaking) restrictions during the fish passage season. The second run (SRBC-007) was a run-of-river scenario where Conowingo Dam was required, on an hourly basis, to pass the daily average flow at Marietta plus intervening inflow between Marietta and Conowingo. The third run (SRBC-008) looked at habitat-based minimum flows, peaking restrictions similar to run SRBC-006 and included a 10,000 cfs per hour ramping rate at Conowingo Dam. Table 4-1 summarizes the modeling parameters used in the Baseline and production runs. Production runs were built using the baseline run as the original template. Thus, parameters that were not explicitly addressed in the production run changes were left as originally modeled in the baseline scenario. The following sub-sections describe the summary outputs of each executed production run. In addition to the descriptions provided in this report, several model parameters were provided to relicensing stakeholders. These output parameters are described in Table 4-2.

4.1 Production Run SRBC-006

Production Run SRBC-006 (Table 4-1) included a new monthly-varying minimum flow scheme and a seasonal peaking (maximum flow) restriction. Both of these flow restrictions were on an “or inflow” basis, such that if the Marietta flow plus intervening inflows was lesser (greater) than the seasonal minimum (maximum) flow, then flows the minimum (maximum) flow was adjusted to the lower (greater) flow. For example, if the seasonal minimum flow was 10,900 cfs but the sum of the Marietta flow plus intervening inflows was 9,800 cfs, then the minimum flow for that day was adjusted to 9,800 cfs. Conversely, if the seasonal maximum flow was 65,000 cfs but the sum of the Marietta flow plus intervening inflows was 70,000 cfs, then the maximum flow for that day was adjusted to 70,000 cfs. Additionally, the 800 cfs leakage credit was applied to minimum flows year-round at Conowingo.

Production Run SRBC-006’s annual and monthly flow exceedance percentiles for Conowingo Dam outflow are shown in Table 4.1-1. Additional low-flow exceedance percentiles have been included in Table 4.1-2. Annual and monthly stage exceedance percentiles for Conowingo Pond are shown in Table 4.2-3. Annual and monthly flow and pond elevation exceedance curves are compared to the Baseline results in Appendix B.

Production Run SRBC-006's annual and monthly average net energy output is shown in Table 4.1-4. The Baseline model results showed that from calendar year 1930 through 2007 the average annual generation at Conowingo was 1,668 GWh/yr, and average annual generation at Muddy Run was 1,702 GWh/yr generated, while 2,212 GWh/yr was used for Muddy Run pumping.

4.2 Production Run SRBC-007

Production Run SRBC-007 (Table 4-1) was a run-of-river scenario, where Conowingo was required to pass the Marietta flow plus intervening inflows at all times. No peaking was allowed, as the flow out of Conowingo was required to strictly follow the Marietta plus intervening inflows rule. Leakage was included as part of the required flow. Muddy Run was allowed to operate as long as Conowingo Pond remained within the allowable pool limits. During this run, Muddy Run storage was required in some situations to allow Conowingo to meet the strict run-of-river requirement, as Conowingo Pond inflows were highly irregular and different than Marietta flows due to Safe Harbor's and Holtwood's peaking operations.

Production Run SRBC-007's annual and monthly flow exceedance percentiles for Conowingo Dam outflow are shown in Table 4.2-1. Additional low-flow exceedance percentiles have been included in Table 4.2-2. Annual and monthly stage exceedance percentiles for Conowingo Pond are shown in Table 4.2-3. Annual and monthly flow and pond elevation exceedance curves are compared to the Baseline results in Appendix C.

Production Run SRBC-007's annual and monthly average net energy output is shown in Table 4.2-4. The Baseline model results showed that from calendar year 1930 through 2007 the average annual generation at Conowingo was 1,654 GWh/yr, and average annual generation at Muddy Run was 1,593 GWh/yr generated, while 2,068 GWh/yr was used for Muddy Run pumping.

4.3 Productrion Run SRBC-008

Production Run SRBC-008 (Table 4-1) included a new monthly-varying minimum flow scheme, a seasonal peaking (maximum flow) restriction and a ramping rate at Conowingo of 10,000 cfs/hr. Both of the flow restrictions were on an "or inflow" basis, such that if the Marietta flow plus intervening inflows was lesser (greater) than the seasonal minimum (maximum) flow, then the minimum (maximum) flow was adjusted to the lower (greater) flow. For example, if the seasonal minimum flow was 24,000 cfs but the sum of the Marietta flow plus intervening inflows was 9,800 cfs, then the minimum flow for that day was adjusted to 9,800 cfs. Conversely, if the seasonal maximum flow was 65,000 cfs but the sum of the Marietta flow plus intervening inflows was 70,000 cfs, then the maximum flow for that day was adjusted to 70,000 cfs. Additionally, the 800 cfs leakage credit was applied to minimum flows year-round. Thus, the minimum flows required downstream of Conowingo included Conowingo's estimated 800 cfs leakage. The 10,000 cfs/hr ramping rate was not applied during spill events (flow > 86,000 cfs), as high flows often change rapidly to the point that the model cannot meet the required ramping rate while passing the appropriate amount of water.

Production Run SRBC-008's annual and monthly flow exceedance percentiles for Conowingo Dam outflow are shown in Table 4.3-1. Additional low-flow exceedance percentiles have been included in Table 4.3-2. Annual and monthly stage exceedance percentiles for Conowingo Pond are shown in Table 4.3-3. Annual and monthly flow and pond elevation exceedance curves are compared to the Baseline results in Appendix D.

Production Run SRBC-008's annual and monthly average net energy output is shown in Table 4.3-4. The Baseline model results showed that from calendar year 1930 through 2007 the average annual generation at Conowingo was 1,666 GWh/yr, and average annual generation at Muddy Run was 1,638 GWh/yr generated, while 2,129 GWh/yr was used for Muddy Run pumping.

5. REFERENCES

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Kleinschmidt, “Initial Consultation Document,” for PPL. March 2006. (2006a).

Kleinschmidt, “Capacity-Related License Amendment, Holtwood Hydroelectric Expansion Volume 1 of 2 Technical Exhibits,” for PPL. November 2006. (2006b).

Normandeau Associates Inc., Personal Communication, September 2006.

Susquehanna River Basin Commission (SRBC). Conowingo Pond Management Plan. June 2006.

TABLE 2.2.3-1: SAFE HARBOR'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Turbine Capacity – hydraulic	110,000 cfs	Kleinschmidt 2006a
Turbine Capacity – reported maximum generation	417 MW	Kleinschmidt 2006a
Turbine/Generator Efficiency	Unavailable- Assumed an efficiency of 80%	None
Recreational Stage	Unknown- not modeled.	---
Normal Elevation Range	224.2 – 227.2 feet, the model will not drop the pool elevation below 224.2 feet throughout the year	SRBC 2006
Fish Passage Flows	4/15 – 6/15, daytime (7 am-7 pm) – 300 cfs, nighttime – 0 cfs, unavailable for power	Normandeau
Dam Leakage	500 cfs	Andrew Dehoff, SRBC
Discharge Rating Curve	Unavailable	---
Headloss Curve	Unavailable- none used.	---

TABLE 2.2.3-2: HOLTWOOD'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Turbine Capacity – hydraulic	31,500 cfs (existing), 61,460 cfs (post-expansion)	Kleinschmidt 2006a
Turbine Capacity – reported maximum generation	107 MW (existing), 195 MW (post-expansion)	Kleinschmidt 2006a Kleinschmidt 2006b
Turbine/Generator Efficiency	85%- a constant was used over the range of head and flow conditions.	Kleinschmidt 2006a
Recreational Stage	167.5 feet May 15 to Sep 15, the model will not drop the pool elevation below 167.5 ft during May 15-Sep 15.	Kleinschmidt 2006a
Normal Elevation Range	163.5 – 169.75 feet, the model will not drop the pool elevation below 163.5 feet throughout the year.	Kleinschmidt 2006a
Fish Passage Flows	4/15 – 6/15, daytime (7 am-7 pm) – 450 cfs, nighttime – 0 cfs, unavailable for power.	Kleinschmidt 2006b
Dam Leakage	Unavailable - Assumed 0 cfs	---
Headloss Rating Curve	Unavailable – none used	---
Minimum Flow Release Requirement	Continuous - 800 cfs or net inflow Daily Average - 98.7% of Conowingo's Seasonal Minimum Flow	

TABLE 2.2.3-3: MUDDY RUN'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Pump and Turbine Capacities – hydraulic	32,000 cfs – generation 28,000 cfs – pumping 25,600 cfs – pumping (alternative value)[6]	Exelon
Turbine Capacity – nameplate generation	800 MW	Exelon
Turbine/Generator Efficiency	A constant efficiency of 87% was used. This accounts for generator energy losses and other headlosses.	Exelon, based on calibration
Pump Efficiency	A constant pump efficiency of 90% was used.	Exelon
Normal Elevation Range	470 ft – 520 ft	Exelon
Headloss Curve	Headlosses are incorporated into turbine/generator efficiency	None

TABLE 2.2.3-4: CONOWINGO'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Turbine Capacity	Hydraulic - 86,000 cfs; Nameplate Generation – 573 MW	Exelon
Turbine Efficiency	Constant of 79% was used over the range of flow and head conditions.	Based on calibration process
Recreational Stage	107.2 ft, weekends May 22 – Sep 7, the model will not drop the pool elevation below 107.2 ft on weekends from May 22-Sep 7[7].	Exelon
Normal Elevation Range	104.7 ft – 109.2 ft, the model should not drop the pool elevation below 104.7 ft throughout the year.	SRBC-2002
Fish Passage Flows	4/1 – 6/15: daytime (7 am-7 pm) – 310 cfs, nighttime – 45 cfs, fish passage flows are unavailable for power.	Exelon
Dam Leakage	800 cfs, unavailable for power and not included in the fish passage flows	SRBC-2002
Minimum Flow Release Requirement	12/1-2/28: 3,500 cfs intermittent[8] 3/1 – 3/31: 3,500 cfs 4/1 – 4/30: 10,000 cfs 5/1 – 5/31: 7,500 cfs 6/1 – 9/14: 5,000 cfs 9/15 – 11/30: 3,500 cfs	
Headloss Curve	Headlosses are incorporated into turbine/generator efficiency	----

[6] The published pump capacity is 28,000 cfs, but operations data show that 25,600 cfs is a more accurate representation of typical operations.

[7] The weekend recreation limit was incorrectly reported as extending until September 30 in SRBC (2002)

[8] Conowingo's intermittent wintertime minimum flow of 3,500 cfs refers to a maximum of 6 hours with no generation, followed by at least 6 hours of at least 3,500 cfs.

TABLE 3-1: BASELINE OPERATIONS MODEL UNREALISTIC OPERATIONS SUMMARY. SOURCE: MODELED BASELINE RUN, PERIOD OF RECORD: JAN 1930 – DECEMBER 2007.

Year	Total Hours of 800 cfs Occurrences	Exceedance Percentile (%)
1930	78	99.11
1936	12	99.86
1944	9	99..90
1954	5	99.94
1954	16	99.82
1955	53	99.39
1957	28	99.68
1962	32	99.63
1963	36	99.59
1964	54	99.38
1965	36	99.59
1966	142	98.38
1980	8	99.91
1981	20	99.77
1983	1	99.99
1991	2	99.98
1995	20	99.77
1999	75	99.14

TABLE 3-2: ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW EXCEEDENCE PERCENTILES, IN CFS. SOURCE: MODELED BASELINE RUN, PERIOD OF RECORD: JAN 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,195,559	583,801	438,283	654,062	537,270	362,387	1,195,559	263,883	388,629	553,941	303,572	320,404	377,636
5	122,586	128,256	122,008	191,995	202,765	124,676	86,845	75,325	55,952	72,883	85,622	86,800	117,694
10	86,845	86,800	86,800	147,773	155,921	87,110	81,036	53,105	37,636	42,648	63,583	81,618	86,800
15	86,800	86,800	86,800	125,248	131,200	87,110	74,818	41,104	22,593	24,863	44,345	76,250	86,800
20	80,764	81,414	81,636	106,017	110,765	86,845	61,135	29,864	5,860	13,035	30,715	63,095	81,065
25	71,191	78,229	79,592	86,800	88,604	81,953	50,611	14,897	5,800	5,800	20,369	60,362	77,054
30	61,446	66,054	70,881	86,800	87,110	81,093	41,104	5,800	5,800	5,800	8,420	47,006	64,567
35	47,514	59,952	62,643	86,800	87,110	78,483	29,142	5,800	5,800	5,800	4,300	36,556	60,362
40	36,563	49,694	60,157	86,800	86,845	69,038	8,300	5,800	5,800	5,800	4,300	22,619	51,531
45	19,887	42,550	49,694	81,695	86,845	59,642	5,800	5,800	5,800	5,000	4,300	5,273	42,550
50	8,300	35,128	42,550	80,706	81,995	48,300	5,800	5,800	5,800	4,561	4,300	4,300	35,642
55	5,800	19,664	32,223	74,036	81,110	30,724	5,800	5,800	5,800	4,300	4,300	4,300	18,611
60	5,800	2,550	13,833	62,692	77,645	8,300	5,800	5,800	5,800	4,300	4,300	4,300	4,300
65	5,800	2,550	2,550	62,130	63,013	8,300	5,800	5,800	5,800	4,300	4,300	4,300	2,550
70	5,000	2,550	2,550	46,800	55,721	8,300	5,800	5,800	5,000	4,300	4,300	4,300	2,550
75	4,300	2,550	2,550	34,075	36,913	8,300	5,800	5,800	5,000	4,300	4,300	4,300	2,550
80	4,300	2,550	2,550	4,300	10,800	8,300	5,800	5,800	4,817	3,500	4,300	4,300	2,550
85	4,158	2,550	2,550	4,300	10,800	8,300	5,800	5,800	4,306	3,500	4,300	4,300	2,550
90	2,550	2,550	2,550	4,300	10,800	8,300	5,800	5,000	3,776	3,233	3,500	4,300	2,550
95	2,550	2,550	2,550	4,300	10,800	8,300	5,800	4,128	3,233	2,788	2,966	3,500	2,550
100	800	2,550	2,550	2,550	4,300	8,300	4,496	800	800	800	1,781	2,117	1,750

TABLE 3-3: BASELINE OPERATIONS MODEL RESULTS SHOWING LOW-FLOW EXCEEDANCE PERCENTILES. SOURCE: MODELED BASELINE RUN, PERIOD OF RECORD: JAN 1930 – DECEMBER 2007.

Exceedance Percentile	Conowingo Dam Outflow (cfs)												
	Annual	January	February	March	April	May	June	July	August	September	October	November	December
92.5	2,550	2,550	2,550	4,300	10,800	8,300	5,800	4,625	3,548	2,962	3,278	4,300	2,550
95	2,550	2,550	2,550	4,300	10,800	8,300	5,800	4,128	3,233	2,788	2,966	3,500	2,550
96	2,550	2,550	2,550	4,300	10,800	8,300	5,800	3,872	3,108	2,732	2,878	3,500	2,550
97	2,550	2,550	2,550	4,300	10,800	8,300	5,800	3,660	2,988	2,647	2,843	3,462	2,550
97.5	2,550	2,550	2,550	4,300	10,800	8,300	5,800	3,502	2,947	2,546	2,821	3,235	2,550
98	2,550	2,550	2,550	4,300	10,800	8,300	5,800	3,316	2,890	2,473	2,776	3,011	2,550
98.5	2,550	2,550	2,550	4,300	10,800	8,300	5,800	3,193	2,833	2,418	2,744	2,873	2,550
99	2,550	2,550	2,550	4,300	10,800	8,300	5,800	3,024	2,743	2,341	2,706	2,785	2,550
99.25	2,550	2,550	2,550	4,300	10,800	8,300	5,800	2,895	2,704	2,282	2,646	2,736	2,550
99.5	2,550	2,550	2,550	4,300	10,800	8,300	5,800	2,705	800	2,224	2,549	2,460	2,550
99.75	2,393	2,550	2,550	4,300	10,800	8,300	5,800	800	800	2,188	2,423	2,313	2,550
99.9	1,781	2,550	2,550	4,300	10,800	8,300	4,810	800	800	800	2,250	2,185	2,550
99.95	800	2,550	2,550	2,550	10,800	8,300	4,635	800	800	800	2,112	2,155	1,750

TABLE 3-4: CONOWINGO POND ANNUAL AND MONTHLY ELEVATION EXCEEDENCE PERCENTILES, IN FEET NGVD 1929. SOURCE: MODELED BASELINE RUN, PERIOD OF RECORD: JAN 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
5	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
10	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
15	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
20	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.1	109.1	109.1	109.2	109.2	109.2
25	109.2	109.2	109.2	109.2	109.2	109.2	109.1	109.0	109.0	109.0	109.1	109.2	109.2
30	109.2	109.2	109.2	109.2	109.2	109.1	109.0	108.9	108.9	108.9	109.0	109.1	109.2
35	109.1	109.1	109.2	109.2	109.2	109.1	108.9	108.7	108.7	108.7	108.8	109.0	109.1
40	109.0	109.1	109.2	109.2	109.2	109.0	108.7	108.5	108.5	108.5	108.7	109.0	109.1
45	108.9	109.0	109.1	109.2	109.2	108.9	108.6	108.3	108.3	108.3	108.5	108.9	109.0
50	108.8	109.0	109.1	109.2	109.2	108.9	108.4	108.2	108.1	108.1	108.3	108.7	108.9
55	108.7	108.9	109.0	109.1	109.1	108.7	108.2	107.9	107.9	107.9	108.2	108.6	108.8
60	108.5	108.8	109.0	109.1	109.1	108.6	108.1	107.7	107.6	107.6	107.9	108.5	108.7
65	108.3	108.6	108.9	109.0	109.0	108.4	107.8	107.5	107.4	107.4	107.8	108.3	108.6
70	108.1	108.5	108.8	109.0	108.9	108.3	107.6	107.3	107.3	107.3	107.6	108.2	108.5
75	107.9	108.4	108.6	108.9	108.8	108.1	107.4	107.2	107.2	107.1	107.4	108.0	108.4
80	107.6	108.1	108.5	108.8	108.6	107.8	107.2	107.0	107.0	106.9	107.2	107.9	108.2
85	107.3	107.9	108.4	108.6	108.4	107.5	107.1	106.7	106.6	106.7	107.0	107.7	108.0
90	107.0	107.5	108.1	108.4	108.1	107.2	106.7	106.3	106.3	106.5	106.7	107.4	107.7
95	106.5	107.0	107.7	108.0	107.5	106.8	106.4	106.0	106.0	106.2	106.4	106.9	107.2
100	104.7	104.7	104.7	104.8	105.3	105.1	104.7	104.7	104.7	104.7	104.7	104.7	104.7

TABLE 3-5: CONOWINGO AND MUDDY RUN ANNUAL AVERAGE GENERATION. SOURCE: MODELED BASELINE RUN, PERIOD OF RECORD: JAN 1930 – DECEMBER 2007.

Month	Conowingo Annual Average Generation (GWh/yr)	Muddy Run Average Annual Generation (GWh/yr)	Muddy Run Annual Average Pumping Energy Consumption (GWh/yr)
January	161.0	122.9	160.2
February	157.1	80.0	103.3
March	254.0	111.1	143.3
April	261.6	140.7	182.6
May	193.5	164.0	212.7
June	111.4	180.5	237.2
July	71.0	201.3	261.8
August	52.4	195.8	254.5
September	53.3	172.2	225.0
October	74.3	154.9	200.1
November	117.8	100.5	131.3
December	161.9	115.3	148.5
Annual	1669.3	1739.2	2260.6

TABLE 4-1: DESCRIPTION OF PRODUCTION RUN PARAMETERS VERSUS THE BASELINE RUN

Run Name	Leakage Credit/Trigger	Hourly Minimum Flow (cfs)	Hourly Maximum Flow (cfs)	Minimum Pond Level (ft NGVD 1929)	Hourly Flow Change (cfs/hr)
Baseline	800 cfs if $Q_{mar} < Q_{FERC}$ + 1000 cfs	12/1 – 2/29: 1,750 cfs 3/1 – 3/31: 3,500 cfs 4/1 – 4/30: 10,000 cfs 5/1 – 5/31: 7,500 cfs 6/1 – 9/14: 5,000 cfs 9/15 – 11/30: 3,500 cfs	Year-Round: 86,000	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: 40,000 Muddy Run: 15,000
SRBC-006	800 cfs always	1/1 – 1/31: 10,900 2/1 – 2/31: 12,500 3/1 – 3/31: 24,100 4/1 – 4/30: 29,300 5/1 – 5/31: 17,100 6/1 – 6/30: 9,700 7/1 – 7/31: 5,400 8/1 – 8/31: 4,300 9/1 – 9/30: 3,500 10/1 – 10/31: 4,200 11/1 – 11/30: 6,100 12/1 – 12/31: 10,500	4/1 – 11/30: 65,000 12/1 – 3/31: 86,000	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: 40,000 Muddy Run: 15,000
SRBC-007	800 cfs always	Marietta flow + intervening inflow	Marietta flow + intervening inflow	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: N/A Muddy Run: 15,000
SRBC-008	800 cfs always	3/1 – 6/14: 24,000 6/15 – 9/14: 14,100 9/15 – 2/29: 4,000	4/1 – 11/30: 65,000 12/1 – 3/31: 86,000	Year-Round: 104.7 Weekends Mem Day to lab Day: 107.2	Conowingo: 10,000 Muddy Run: 15,000

TABLE 4-2: ADDITIONAL PRODUCTION RUN OUTPUTS PROVIDED TO RELICENSING STAKEHOLDERS

Output Parameter	Description
Max. daily flow at Conowingo	The maximum daily average flow at Conowingo for the entire model run period.
Avg. daily flow at Conowingo	The average daily average flow at Conowingo for the entire model run period.
Min. daily flow at Conowingo	The minimum daily average flow at Conowingo for the entire model run period.
Max. hourly flow at Conowingo	The maximum hourly flow at Conowingo for the entire model run period.
Avg. hourly flow at Conowingo	The average hourly flow at Conowingo for the entire model run period.
Min. hourly flow at Conowingo	The minimum hourly flow at Conowingo for the entire model run period.
Hourly flow at Conowingo	Hourly discharges (in cfs) though Conowingo Dam
Hourly Conowingo Pond levels	Hourly Conowingo Pond elevations, in ft NGVD 1929.
Hourly Muddy Run Pump/Generation Flow	Hourly Muddy Run pump and generation flows, in cfs
Habitat time series outputs	Post-processed habitat values using model flows for the reach downstream of Conowingo Dam.

TABLE 4.1-1: ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW EXCEEDENCE PERCENTILES, IN CFS. SOURCE: PRODUCTION RUN SRBC-006, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,195,559	583,801	438,283	654,062	537,270	362,387	1,195,559	263,883	388,629	553,941	303,572	320,404	377,636
5	122,924	128,256	121,899	191,995	202,765	125,243	74,531	65,800	61,987	65,800	65,800	86,800	117,692
10	86,800	86,800	86,800	147,722	156,002	87,110	66,110	56,809	41,880	46,857	65,800	65,800	86,800
15	81,414	86,800	86,800	125,146	131,405	83,138	65,800	44,161	28,103	28,516	48,524	65,800	86,800
20	66,110	81,358	81,619	105,858	113,420	71,111	65,657	33,401	17,301	18,500	32,885	65,800	80,897
25	65,800	77,054	78,556	86,800	95,218	66,110	52,274	20,696	4,300	10,843	22,218	62,389	75,648
30	60,929	62,652	66,121	86,800	86,845	66,110	40,100	5,400	4,300	3,500	10,843	51,531	62,532
35	44,658	53,771	62,358	86,800	84,879	66,110	16,382	5,400	4,300	3,500	4,200	38,722	55,952
40	29,300	44,410	52,500	86,800	80,061	65,845	9,700	5,400	4,300	3,500	4,200	21,814	47,136
45	22,758	25,633	38,684	81,648	70,955	65,166	9,700	5,400	4,300	3,500	4,200	6,100	30,934
50	17,100	10,900	14,083	79,329	66,110	46,845	9,700	5,400	4,300	3,500	4,200	6,100	10,500
55	12,500	10,900	12,500	63,216	66,110	17,100	9,700	5,400	4,300	3,500	4,200	6,100	10,500
60	10,565	10,900	12,500	62,177	66,110	17,100	9,700	5,400	4,300	3,500	4,200	6,100	10,500
65	9,700	10,900	12,500	37,042	65,845	17,100	9,700	5,400	4,300	3,500	4,200	6,100	10,500
70	7,450	10,900	12,500	24,100	53,619	17,100	9,700	5,400	4,300	3,500	4,200	6,100	10,500
75	5,400	10,900	12,500	24,100	29,300	17,100	9,700	5,400	4,300	3,500	4,200	6,100	10,500
80	5,291	10,900	12,500	24,100	29,300	17,100	9,700	5,400	4,300	3,500	4,200	6,100	10,500
85	4,300	10,900	12,500	24,100	29,300	17,100	9,700	5,400	4,300	3,500	4,200	6,100	10,500
90	4,200	10,900	12,500	23,893	29,300	17,100	9,493	5,192	3,752	3,278	3,686	5,670	10,500
95	3,500	9,218	9,993	16,650	26,715	15,483	7,903	4,079	3,211	2,751	3,069	4,411	8,358
100	800	3,287	3,874	6,147	2,538	8,784	4,450	800	800	800	1,750	800	3,151

TABLE 4.1-2: PRODUCTION RUN SRBC-006 MODEL RESULTS SHOWING LOW-FLOW EXCEEDANCE PERCENTILES. SOURCE: PRODUCTION RUN SRBC-006, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Exceedance Percentile	Conowingo Dam Outflow (cfs)												
	Annual	January	February	March	April	May	June	July	August	September	October	November	December
92.5	3,500	10,502	11,347	21,204	29,300	16,842	8,803	4,613	3,486	2,982	3,361	5,057	9,622
95	3,500	9,218	9,993	16,650	26,715	15,483	7,903	4,079	3,211	2,751	3,069	4,411	8,358
96	3,500	8,356	9,279	14,558	25,513	14,932	7,590	3,777	3,060	2,645	2,981	4,120	7,843
97	3,500	7,320	8,575	13,066	23,777	14,456	7,277	3,579	2,933	2,511	2,896	3,543	6,703
97.5	3,389	6,993	8,015	12,542	22,948	14,138	7,040	3,416	2,889	2,461	2,834	3,273	6,144
98	3,193	6,748	7,680	12,264	22,209	13,621	6,709	3,319	2,837	2,419	2,797	3,151	5,884
98.5	3,009	6,520	6,726	11,842	21,132	13,041	6,446	3,211	2,764	2,356	2,733	3,007	5,381
99	2,842	5,911	6,192	10,964	20,355	12,355	6,062	3,076	2,701	2,260	2,632	2,857	4,874
99.25	2,747	5,290	5,705	10,310	19,881	12,011	5,715	3,026	2,669	2,206	2,574	2,777	4,661
99.5	2,605	4,441	5,535	9,835	18,530	11,474	5,325	2,848	2,619	2,106	2,502	2,536	4,245
99.75	2,436	3,668	4,585	9,349	17,004	10,731	4,798	2,625	2,521	1,972	2,323	2,332	3,753
99.9	2,222	3,516	4,064	8,219	16,495	9,346	4,626	2,431	2,420	1,898	2,114	2,173	3,571
99.95	2,104	3,416	4,023	6,345	16,170	8,970	4,464	2,412	2,331	1,891	2,095	2,166	3,534

TABLE 4.1-3: CONOWINGO POND ANNUAL AND MONTHLY ELEVATION EXCEEDENCE PERCENTILES, IN FEET NGVD 1929. SOURCE: PRODUCTION RUN SRBC-006, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
5	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
10	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
15	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
20	109.2	109.2	109.2	109.2	109.2	109.2	109.1	109.1	109.1	109.2	109.2	109.2	109.2
25	109.2	109.2	109.2	109.2	109.2	109.2	109.1	109.0	109.1	109.1	109.1	109.1	109.2
30	109.1	109.1	109.2	109.2	109.2	109.1	108.9	108.9	108.9	108.9	108.9	109.1	109.1
35	109.0	109.0	109.1	109.2	109.2	109.0	108.8	108.7	108.7	108.7	108.8	109.0	109.0
40	108.9	109.0	109.1	109.2	109.2	108.9	108.6	108.5	108.5	108.5	108.6	108.8	109.0
45	108.8	108.9	109.0	109.2	109.2	108.7	108.3	108.3	108.3	108.3	108.4	108.7	108.9
50	108.6	108.8	108.9	109.1	109.1	108.5	108.2	108.1	108.1	108.1	108.3	108.6	108.8
55	108.5	108.7	108.9	109.1	109.0	108.3	107.9	107.9	107.9	107.9	108.1	108.4	108.6
60	108.3	108.5	108.8	109.0	108.8	108.1	107.7	107.6	107.7	107.7	107.9	108.3	108.5
65	108.0	108.3	108.6	108.9	108.7	107.9	107.5	107.4	107.4	107.5	107.7	108.2	108.3
70	107.8	108.2	108.5	108.8	108.5	107.7	107.3	107.3	107.3	107.3	107.6	108.0	108.2
75	107.6	107.9	108.3	108.6	108.3	107.4	107.2	107.2	107.2	107.2	107.4	107.8	107.9
80	107.3	107.6	108.0	108.3	108.0	107.2	107.0	107.0	107.0	107.0	107.2	107.7	107.7
85	107.1	107.2	107.8	107.9	107.7	106.8	106.7	106.7	106.8	106.9	107.0	107.5	107.3
90	106.7	106.9	107.4	107.3	107.1	106.5	106.4	106.4	106.5	106.6	106.7	107.2	106.9
95	106.3	106.4	106.9	106.7	106.2	106.0	106.0	106.1	106.2	106.4	106.4	106.7	106.5
100	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7

TABLE 4.1-4: CONOWINGO AND MUDDY RUN ANNUAL AVERAGE GENERATION. SOURCE: PRODUCTION RUN SRBC-006, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Month	Conowingo Annual Average Generation (GWh/yr)	Muddy Run Average Annual Generation (GWh/yr)	Muddy Run Annual Average Pumping Energy Consumption (GWh/yr)
January	161.3	118.7	155.0
February	157.2	75.6	98.8
March	254.6	110.0	139.8
April	260.5	131.8	171.5
May	192.9	155.9	202.5
June	111.5	172.8	226.3
July	70.8	201.9	262.7
August	52.2	197.8	257.1
September	52.9	174.0	227.6
October	74.0	154.7	200.1
November	117.2	96.1	126.5
December	162.5	112.5	144.3
Annual	1667.6	1701.8	2212.2

TABLE 4.2-1: ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW EXCEEDENCE PERCENTILES, IN CFS. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,195,557	753,617	633,493	687,528	743,244	512,169	1,195,557	371,287	388,629	725,196	483,293	538,342	509,248
5	119,760	129,959	120,335	192,406	202,683	118,708	73,984	46,071	35,910	47,180	68,529	88,104	118,110
10	88,194	93,567	91,954	146,352	153,802	92,321	55,366	33,449	24,564	28,050	44,620	63,048	87,882
15	70,706	75,252	79,078	122,692	129,033	80,334	45,970	27,411	19,116	20,785	31,523	52,795	71,872
20	59,166	62,673	67,865	104,163	108,554	70,354	39,515	23,765	16,894	17,370	24,950	44,470	60,764
25	50,348	54,599	57,545	94,711	96,203	63,325	34,302	20,546	14,645	14,105	19,444	38,146	52,464
30	43,171	47,910	51,110	88,210	89,341	57,694	31,056	18,336	12,844	12,053	16,128	34,061	47,026
35	36,955	42,536	45,580	79,574	82,828	52,247	27,658	16,559	11,415	10,544	13,601	30,687	41,482
40	31,908	36,883	40,919	73,326	76,720	47,618	24,864	14,824	10,302	9,281	11,964	27,699	37,362
45	27,551	32,583	36,185	67,492	70,439	43,653	22,560	13,460	9,506	8,040	10,713	24,846	33,563
50	23,928	28,608	32,407	62,123	65,837	39,492	20,735	12,354	8,626	7,164	9,572	21,970	30,343
55	20,778	25,795	29,230	56,884	61,790	35,798	19,128	11,181	7,775	6,593	8,639	19,954	27,170
60	17,959	23,252	26,861	52,302	56,945	32,971	17,510	10,232	7,073	5,978	7,771	17,283	24,318
65	15,418	20,932	24,146	47,478	52,843	30,253	16,158	9,430	6,396	5,514	6,977	14,829	22,092
70	13,041	18,491	21,516	43,117	48,763	27,792	14,553	8,547	5,856	5,017	6,248	12,991	19,795
75	11,021	16,430	19,286	37,996	44,394	25,310	13,135	7,725	5,319	4,620	5,535	10,997	17,925
80	9,165	14,715	17,632	33,164	40,066	22,699	11,977	6,827	4,825	4,177	4,932	8,955	16,005
85	7,323	12,843	15,553	27,774	36,068	20,329	10,793	5,899	4,303	3,748	4,284	7,236	13,526
90	5,702	11,351	12,743	23,616	31,923	17,813	9,397	5,159	3,740	3,219	3,669	5,645	10,893
95	4,209	9,210	9,902	16,294	26,641	15,452	7,829	4,063	3,210	2,678	3,034	4,411	8,331
100	1,550	3,287	3,874	6,147	16,144	8,784	4,450	2,196	2,196	1,691	1,550	1,966	3,151

TABLE 4.2-2: PRODUCTION RUN SRBC-006 MODEL RESULTS SHOWING LOW-FLOW EXCEEDANCE PERCENTILES. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Exceedance Percentile	Conowingo Dam Outflow (cfs)												
	Annual	January	February	March	April	May	June	July	August	September	October	November	December
92.5	4,968	10,489	11,255	21,014	29,151	16,704	8,741	4,594	3,477	2,973	3,340	5,039	9,574
95	4,209	9,210	9,902	16,294	26,641	15,452	7,829	4,063	3,210	2,678	3,034	4,411	8,331
96	3,865	8,356	9,186	14,425	25,441	14,907	7,531	3,770	3,059	2,501	2,922	4,104	7,843
97	3,512	7,313	8,409	13,062	23,651	14,447	7,235	3,560	2,932	2,327	2,787	3,538	6,733
97.5	3,360	6,967	7,916	12,542	22,753	14,072	6,978	3,413	2,874	2,268	2,712	3,273	6,150
98	3,167	6,746	7,613	12,245	22,076	13,534	6,699	3,311	2,834	2,236	2,639	3,075	5,884
98.5	2,985	6,520	6,726	11,835	21,073	12,914	6,427	3,176	2,738	2,161	2,597	2,946	5,381
99	2,794	5,911	6,192	10,905	20,282	12,355	5,998	3,076	2,682	2,073	2,502	2,830	4,874
99.25	2,668	5,290	5,705	10,306	19,873	12,011	5,686	3,026	2,649	2,006	2,400	2,664	4,661
99.5	2,501	4,441	5,535	9,835	18,305	11,474	5,137	2,848	2,570	1,906	2,322	2,347	4,245
99.75	2,256	3,668	4,585	9,349	17,004	10,731	4,798	2,521	2,515	1,772	2,124	2,132	3,753
99.9	2,034	3,516	4,064	8,219	16,495	9,346	4,626	2,326	2,420	1,713	1,918	1,995	3,571
99.95	1,918	3,416	4,023	6,345	16,170	8,970	4,464	2,273	2,331	1,698	1,915	1,973	3,534

TABLE 4.2-3: CONOWINGO POND ANNUAL AND MONTHLY ELEVATION EXCEEDENCE PERCENTILES, IN FEET NGVD 1929. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
5	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
10	109.2	109.1	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.1	109.1
15	109.1	109.0	109.0	109.2	109.2	109.0	109.1	109.1	109.1	109.1	109.1	108.9	108.9
20	108.9	108.8	108.9	109.1	109.1	108.9	109.0	109.0	109.0	108.9	108.8	108.7	108.7
25	108.8	108.6	108.8	109.0	109.0	108.7	108.8	108.8	108.8	108.6	108.6	108.5	108.5
30	108.6	108.4	108.6	108.9	108.9	108.5	108.6	108.6	108.6	108.3	108.3	108.3	108.2
35	108.3	108.2	108.4	108.8	108.8	108.3	108.3	108.4	108.4	108.1	108.0	108.0	108.0
40	108.1	107.9	108.2	108.6	108.6	108.1	108.1	108.1	108.1	107.9	107.8	107.8	107.7
45	107.8	107.7	108.0	108.5	108.5	107.8	107.8	107.8	107.8	107.6	107.6	107.5	107.4
50	107.6	107.5	107.8	108.3	108.3	107.5	107.5	107.6	107.6	107.4	107.4	107.3	107.2
55	107.4	107.2	107.6	108.0	108.0	107.2	107.2	107.3	107.4	107.2	107.1	107.1	107.0
60	107.2	107.0	107.4	107.8	107.8	107.1	107.2	107.2	107.2	107.1	106.9	106.9	106.8
65	106.9	106.8	107.1	107.6	107.5	106.8	107.0	107.1	107.2	106.8	106.7	106.6	106.6
70	106.7	106.6	106.9	107.3	107.2	106.4	106.6	106.8	106.9	106.6	106.5	106.4	106.4
75	106.4	106.4	106.7	107.0	106.9	106.1	106.2	106.4	106.5	106.4	106.3	106.2	106.2
80	106.1	106.1	106.4	106.6	106.6	105.7	105.8	106.1	106.2	106.2	106.0	105.9	106.0
85	105.8	105.9	106.2	106.3	106.2	105.4	105.5	105.7	105.8	105.9	105.8	105.6	105.7
90	105.5	105.6	105.8	105.9	105.7	105.1	105.3	105.4	105.5	105.5	105.5	105.3	105.5
95	105.1	105.3	105.4	105.5	105.3	104.8	104.9	105.0	105.2	105.2	105.2	105.0	105.2
100	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7

TABLE 4.2-4: CONOWINGO AND MUDDY RUN ANNUAL AVERAGE GENERATION. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Month	Conowingo Annual Average Generation (GWh/yr)	Muddy Run Average Annual Generation (GWh/yr)	Muddy Run Annual Average Pumping Energy Consumption (GWh/yr)
January	159.2	102.3	132.4
February	154.9	62.1	80.6
March	250.5	100.6	129.4
April	258.4	129.5	169.7
May	191.9	154.2	199.6
June	111.9	153.8	199.5
July	71.4	181.4	234.9
August	52.5	190.2	246.7
September	53.1	169.0	220.8
October	73.4	154.5	201.0
November	116.7	94.6	122.2
December	159.7	100.5	130.6
Annual	1653.6	1592.7	2067.5

TABLE 4.3-1: ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW EXCEEDENCE PERCENTILES, IN CFS. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,195,559	583,801	438,283	654,062	537,270	362,387	1,195,559	263,883	388,629	553,941	303,572	320,404	377,636
5	122,933	128,667	122,099	191,995	202,765	125,243	73,309	64,100	44,650	65,541	65,800	86,800	117,992
10	86,800	86,800	86,800	147,736	156,002	87,110	65,845	42,903	17,924	37,319	62,389	65,800	86,800
15	79,804	86,800	86,800	125,151	131,445	82,924	60,157	25,233	14,100	23,152	44,000	65,800	85,786
20	66,110	79,649	80,574	106,421	113,728	70,480	45,040	14,100	14,100	14,100	32,381	64,000	77,895
25	63,440	67,410	71,473	86,800	96,073	66,110	33,934	14,100	14,100	13,809	24,000	54,000	66,800
30	51,554	58,495	62,740	86,800	86,845	66,110	24,000	14,100	13,084	10,868	16,751	44,410	59,427
35	40,589	51,313	55,787	86,800	84,866	65,845	24,000	14,100	11,591	8,588	10,843	35,800	52,882
40	30,571	44,000	49,228	85,225	79,789	55,845	23,217	14,100	10,444	6,878	4,000	29,811	45,249
45	24,000	37,704	44,000	79,176	70,828	44,265	19,648	13,754	9,589	5,864	4,000	23,959	38,722
50	22,890	33,337	36,665	69,954	66,110	33,031	16,270	12,523	8,715	5,017	4,000	14,645	34,000
55	15,378	24,964	32,128	62,546	66,110	24,000	14,100	11,337	7,825	4,000	4,000	7,079	24,822
60	14,100	19,555	24,000	54,473	66,110	24,000	14,100	10,359	7,124	4,000	4,000	4,000	18,552
65	12,017	14,000	18,177	44,072	64,881	24,000	14,100	9,467	6,431	4,000	4,000	4,000	13,123
70	8,892	4,000	12,671	34,000	54,265	24,000	14,100	8,590	5,897	4,000	4,000	4,000	4,000
75	5,969	4,000	4,000	24,000	42,913	24,000	13,244	7,777	5,357	4,000	4,000	4,000	4,000
80	4,000	4,000	4,000	24,000	25,845	22,840	12,071	6,882	4,840	4,000	4,000	4,000	4,000
85	4,000	4,000	4,000	24,000	24,000	20,365	10,836	5,934	4,330	3,792	4,000	4,000	4,000
90	4,000	4,000	4,000	24,000	24,000	17,839	9,406	5,188	3,746	3,271	3,688	4,000	4,000
95	4,000	4,000	4,000	16,934	24,000	15,465	7,840	4,063	3,211	2,746	3,069	4,000	4,000
100	800	3,287	3,874	4,000	9,957	4,919	4,450	800	800	800	1,750	800	3,151

TABLE 4.3-2: PRODUCTION RUN SRBC-006 MODEL RESULTS SHOWING LOW-FLOW EXCEEDANCE PERCENTILES. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Exceedance Percentile	Conowingo Dam Outflow (cfs)												
	Annual	January	February	March	April	May	June	July	August	September	October	November	December
92.5	4,000	4,000	4,000	21,578	24,000	16,711	8,744	4,594	3,486	2,980	3,353	4,000	4,000
95	4,000	4,000	4,000	16,934	24,000	15,465	7,840	4,063	3,211	2,746	3,069	4,000	4,000
96	3,897	4,000	4,000	14,724	24,000	14,907	7,534	3,777	3,035	2,639	2,981	4,000	4,000
97	3,543	4,000	4,000	13,252	23,912	14,447	7,249	3,579	2,932	2,496	2,896	3,557	4,000
97.5	3,388	4,000	4,000	12,630	22,974	14,109	7,037	3,413	2,872	2,456	2,829	3,287	4,000
98	3,193	4,000	4,000	12,290	22,226	13,534	6,699	3,319	2,823	2,413	2,797	3,151	4,000
98.5	3,006	4,000	4,000	11,830	21,312	12,913	6,427	3,211	2,743	2,345	2,733	2,997	4,000
99	2,837	4,000	4,000	10,905	20,405	12,325	5,998	3,071	2,692	2,259	2,632	2,860	4,000
99.25	2,743	4,000	4,000	10,310	19,881	11,984	5,686	3,012	2,654	2,144	2,574	2,785	4,000
99.5	2,594	4,000	4,000	9,834	18,588	11,464	5,137	2,837	2,558	2,085	2,502	2,547	4,000
99.75	2,415	3,668	4,000	9,207	17,004	10,703	4,798	2,526	2,462	1,928	2,324	2,332	3,765
99.9	2,166	3,516	4,000	6,345	16,495	9,346	4,626	2,412	800	800	2,115	2,173	3,629
99.95	2,009	3,416	4,000	6,147	16,170	8,970	4,464	2,396	800	800	2,095	2,166	3,534

TABLE 4.3-3: CONOWINGO POND ANNUAL AND MONTHLY ELEVATION EXCEEDENCE PERCENTILES, IN FEET NGVD 1929. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
5	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
10	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
15	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2	109.2
20	109.2	109.2	109.2	109.2	109.2	109.2	109.1	109.1	109.1	109.1	109.1	109.1	109.2
25	109.1	109.1	109.2	109.2	109.2	109.1	109.0	109.0	109.0	109.0	109.0	109.0	109.1
30	109.1	109.1	109.1	109.2	109.2	109.0	108.8	108.8	108.8	108.8	108.8	108.9	109.0
35	109.0	109.0	109.1	109.2	109.2	108.9	108.6	108.6	108.6	108.5	108.7	108.8	108.9
40	108.8	108.9	109.0	109.2	109.2	108.8	108.4	108.4	108.4	108.3	108.5	108.7	108.9
45	108.7	108.8	108.9	109.1	109.1	108.6	108.2	108.2	108.1	108.1	108.4	108.6	108.8
50	108.5	108.7	108.9	109.1	109.1	108.4	107.9	107.9	107.9	107.9	108.2	108.5	108.7
55	108.4	108.6	108.8	109.0	109.0	108.2	107.7	107.6	107.6	107.7	108.0	108.4	108.6
60	108.2	108.5	108.7	108.9	108.8	108.0	107.5	107.4	107.4	107.5	107.9	108.3	108.5
65	108.0	108.3	108.6	108.8	108.7	107.7	107.3	107.3	107.3	107.3	107.7	108.1	108.3
70	107.8	108.2	108.5	108.7	108.5	107.4	107.2	107.2	107.2	107.2	107.5	108.0	108.2
75	107.5	108.0	108.4	108.5	108.3	107.2	107.0	107.0	107.0	107.0	107.3	107.8	108.1
80	107.3	107.8	108.2	108.3	108.1	106.9	106.6	106.7	106.7	106.8	107.1	107.7	107.9
85	107.0	107.6	108.1	107.9	107.8	106.5	106.3	106.4	106.3	106.6	106.9	107.5	107.6
90	106.6	107.3	107.8	107.4	107.3	106.1	106.0	106.1	106.0	106.4	106.7	107.2	107.4
95	106.1	106.8	107.5	106.7	106.5	105.7	105.7	105.7	105.7	106.0	106.4	106.8	106.9
100	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7

TABLE 4.3-4: CONOWINGO AND MUDDY RUN ANNUAL AVERAGE GENERATION. SOURCE: PRODUCTION RUN SRBC-007, PERIOD OF RECORD: JANUARY 1930 – DECEMBER 2007.

Month	Conowingo Annual Average Generation (GWh/yr)	Muddy Run Average Annual Generation (GWh/yr)	Muddy Run Annual Average Pumping Energy Consumption (GWh/yr)
January	160.8	121.4	158.2
February	156.5	77.3	102.0
March	254.5	109.0	137.9
April	260.1	132.3	173.0
May	192.6	149.5	196.1
June	111.8	152.8	199.5
July	71.4	177.7	230.3
August	52.4	183.7	239.3
September	53.2	170.0	221.5
October	73.9	155.0	200.3
November	116.8	96.4	126.6
December	161.8	112.5	144.2
Annual	1665.8	1637.6	2128.9

FIGURE 2.2.3-1: CONOWINGO DAM SEASONALLY-VARYING MINIMUM FLOW RELEASES[9].

Date	Minimum Flow (cfs)
1-Jan	1,750
28-Feb	1,750
1-Mar	3,500
31-Mar	3,500
1-Apr	10,000
30-Apr	10,000
1-May	7,500
30-May	7,500
1-Jun	5,000
14-Sep	5,000
15-Sep	3,500
30-Nov	3,500
1-Dec	1,750
31-Dec	1,750

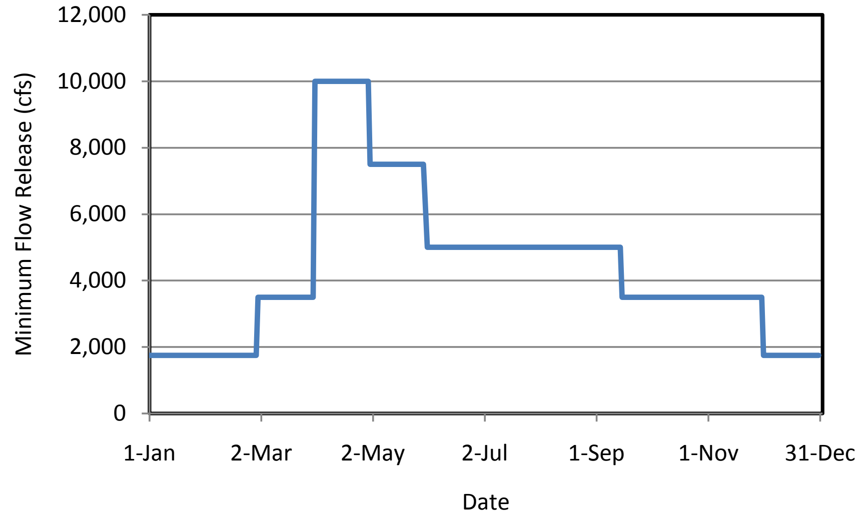
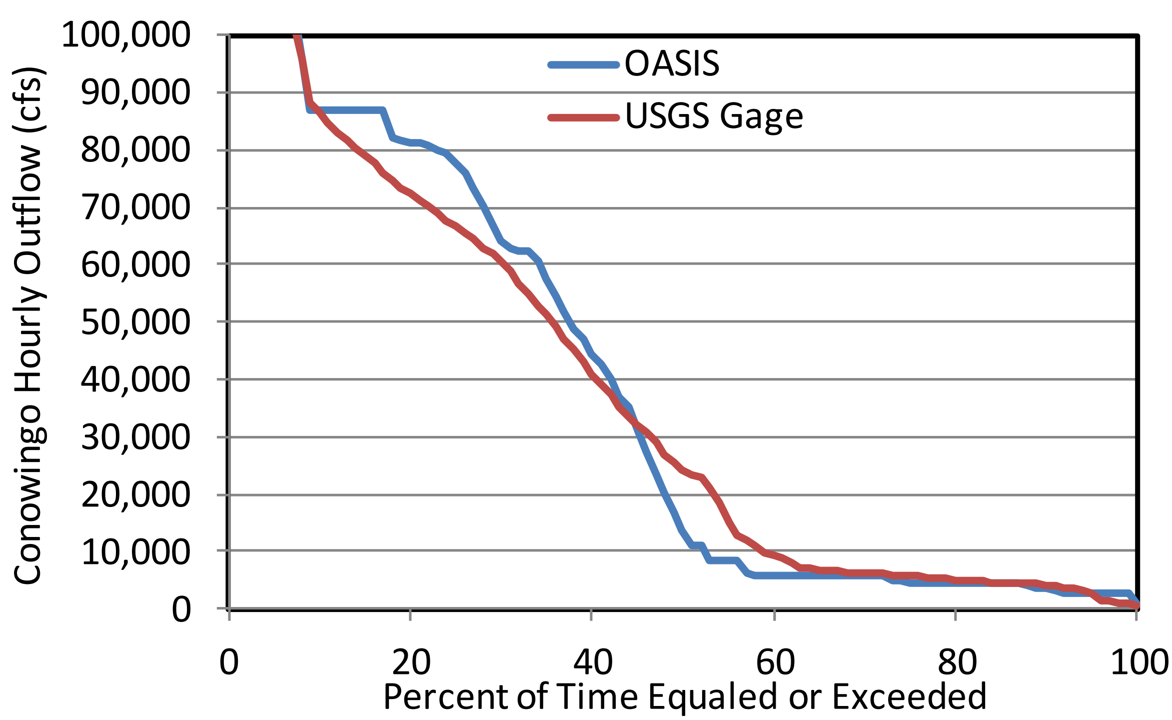
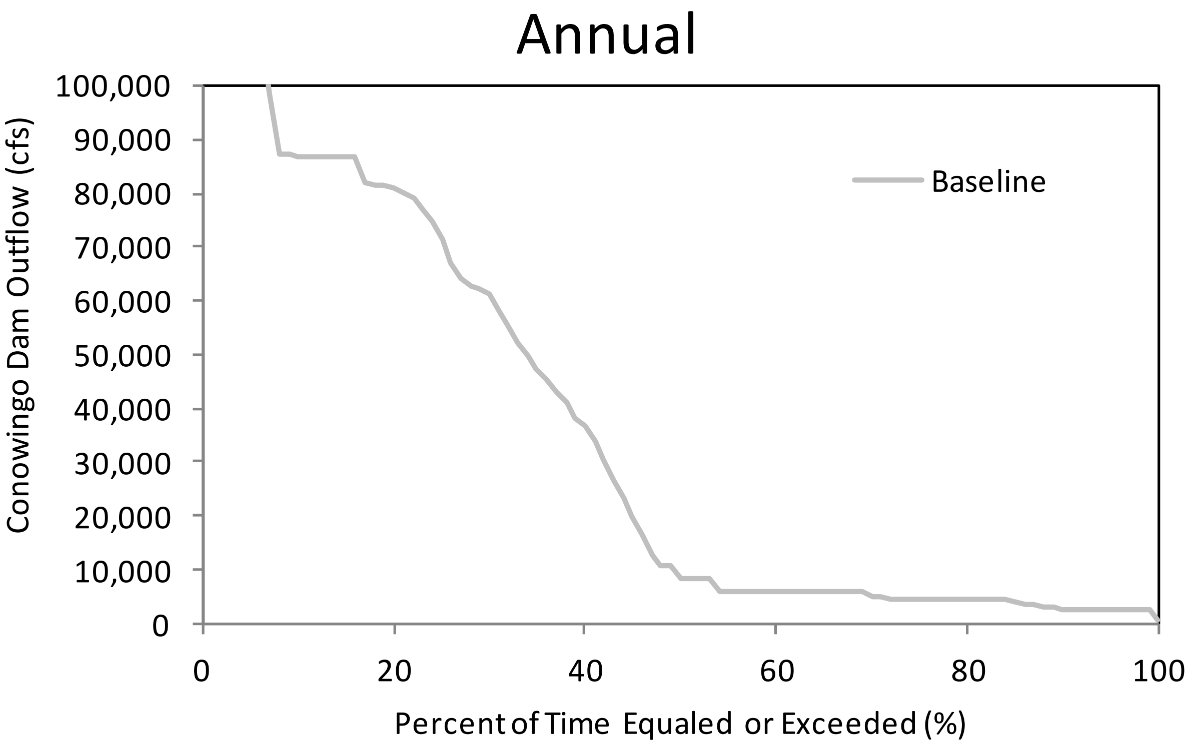


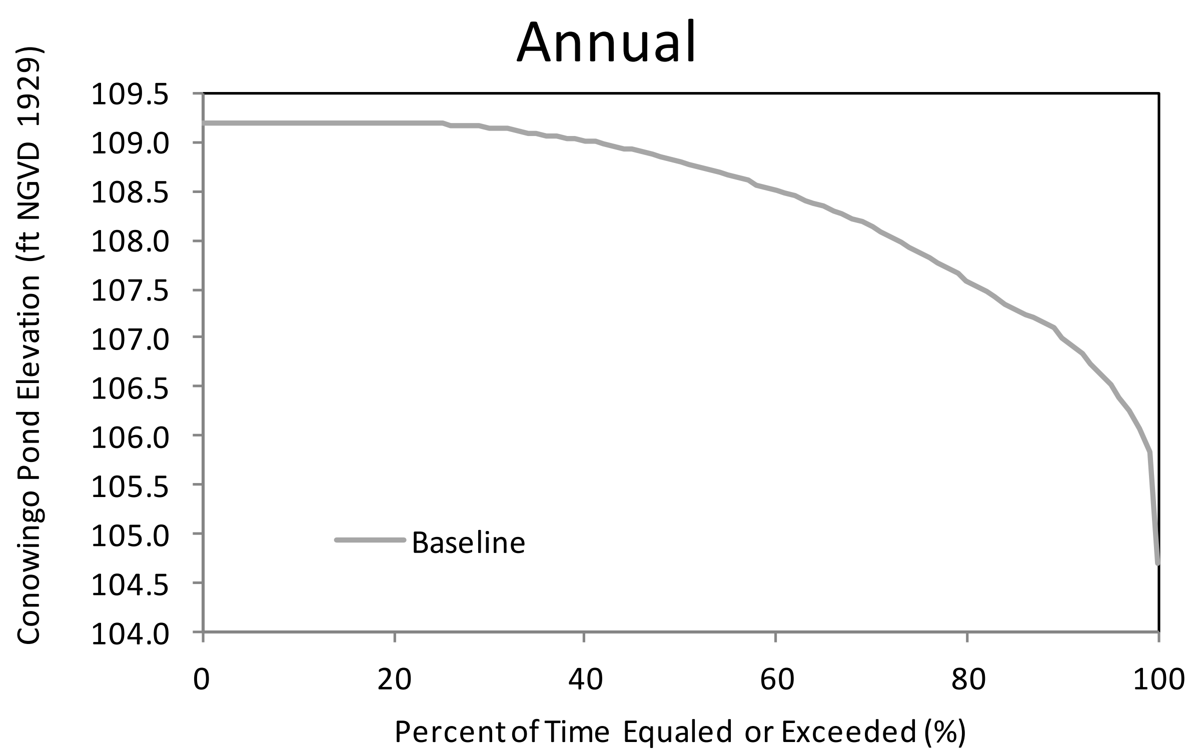
FIGURE 3-1: ANNUAL HOURLY FLOW DURATION CURVE COMPARING MODELED AND OBSERVED CONOWINGO DAM OUTFLOWS. THE PERIOD OF RECORD IS WATER YEAR 1989-2007.

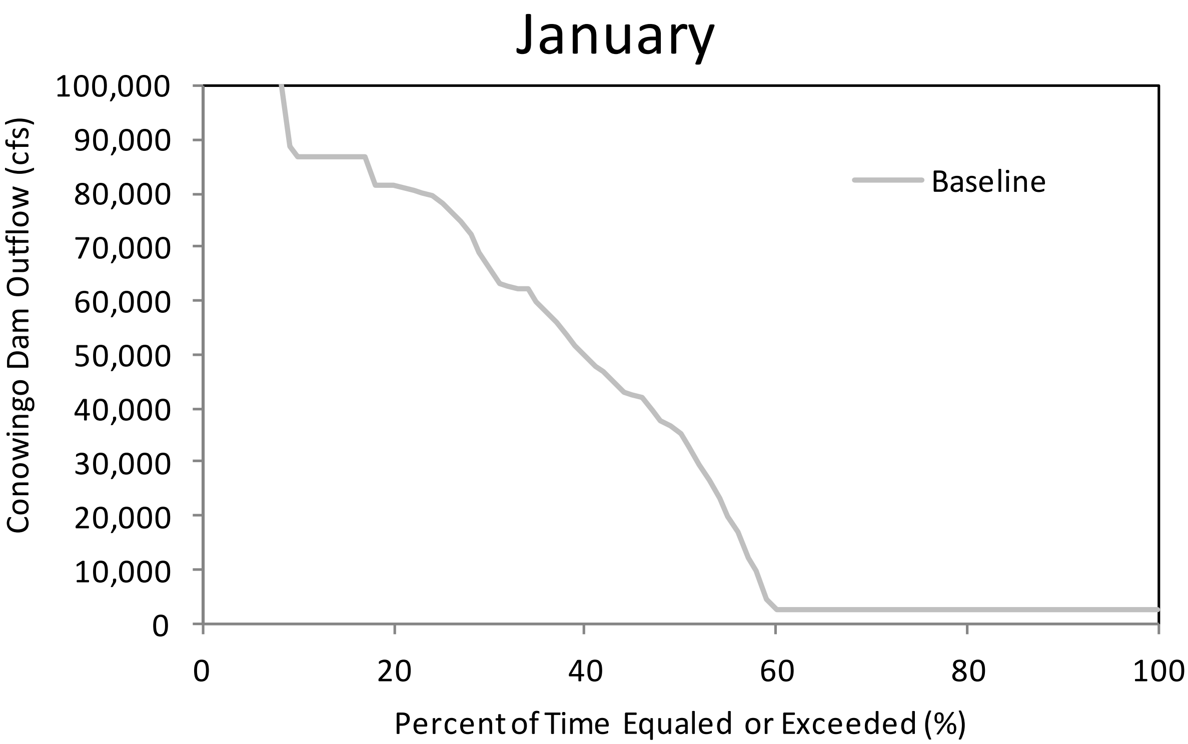


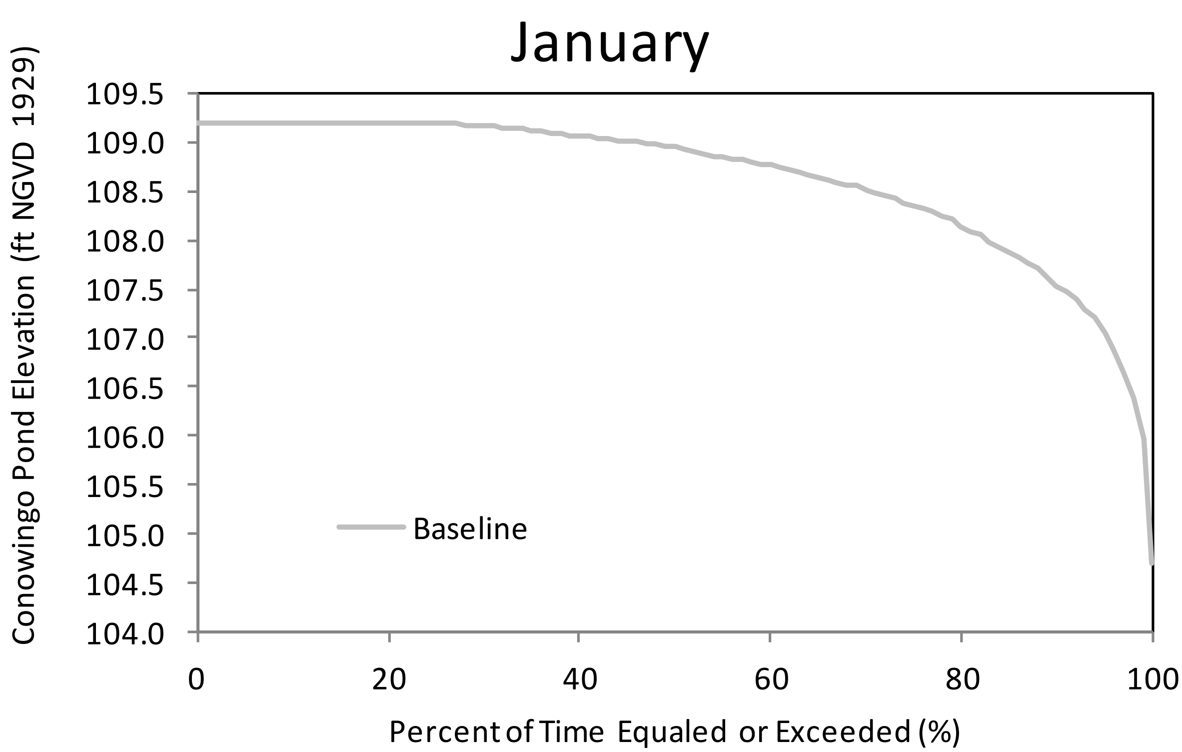
[9] The 1,750 cfs minimum flow for the period December 1-February 28 reflects an average of the 6 hours on, 6 hours off at 3,500 cfs, as stipulated in the minimum flow agreement.

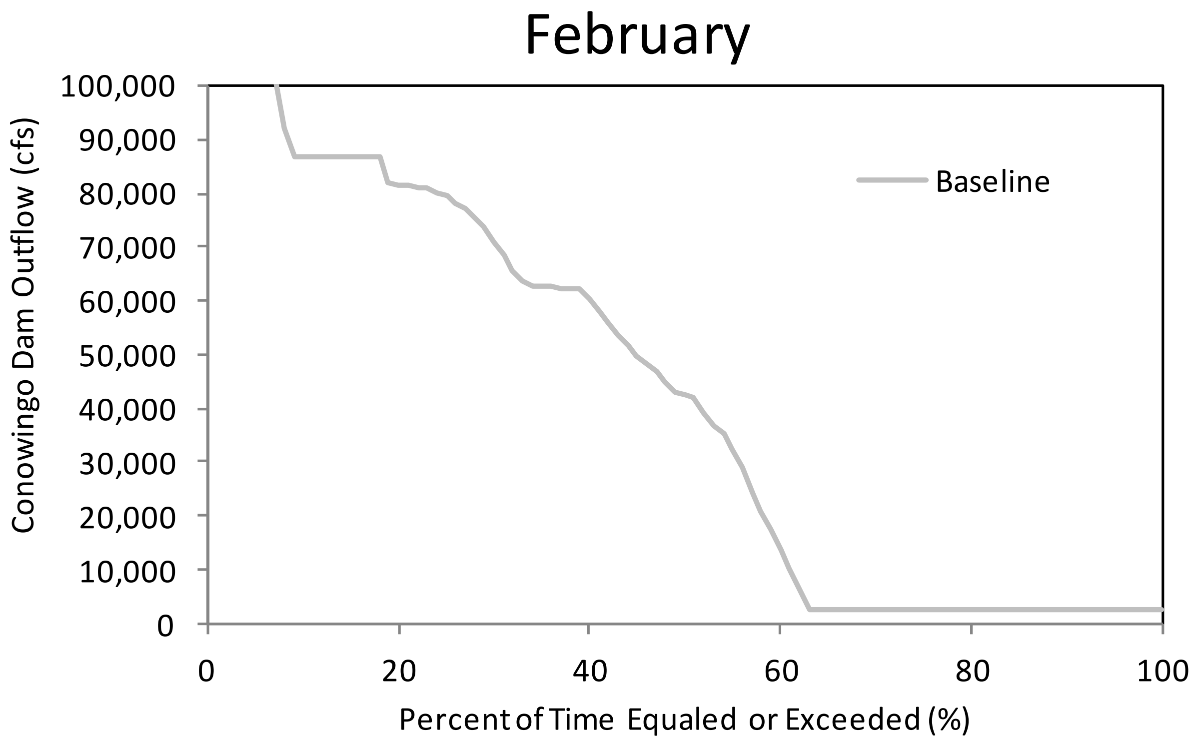
APPENDIX A: BASELINE RUN'S ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW AND POND ELEVATION EXCEEDENCE CURVES

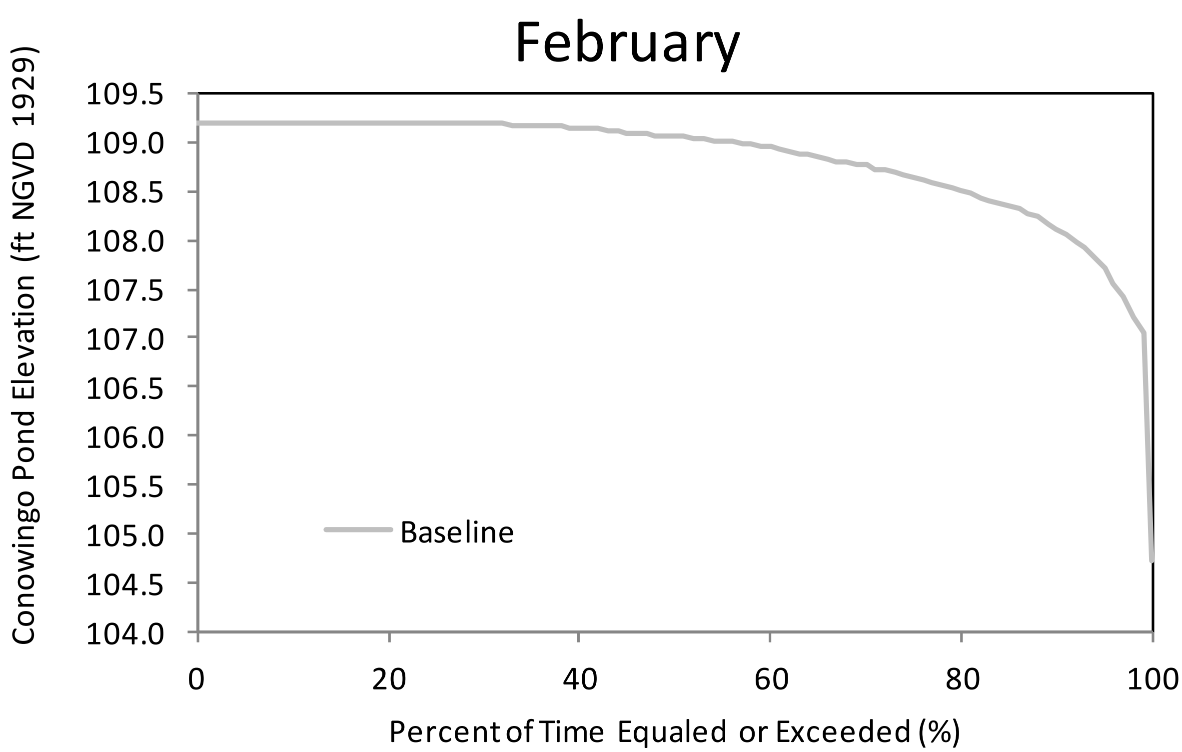

Annual
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

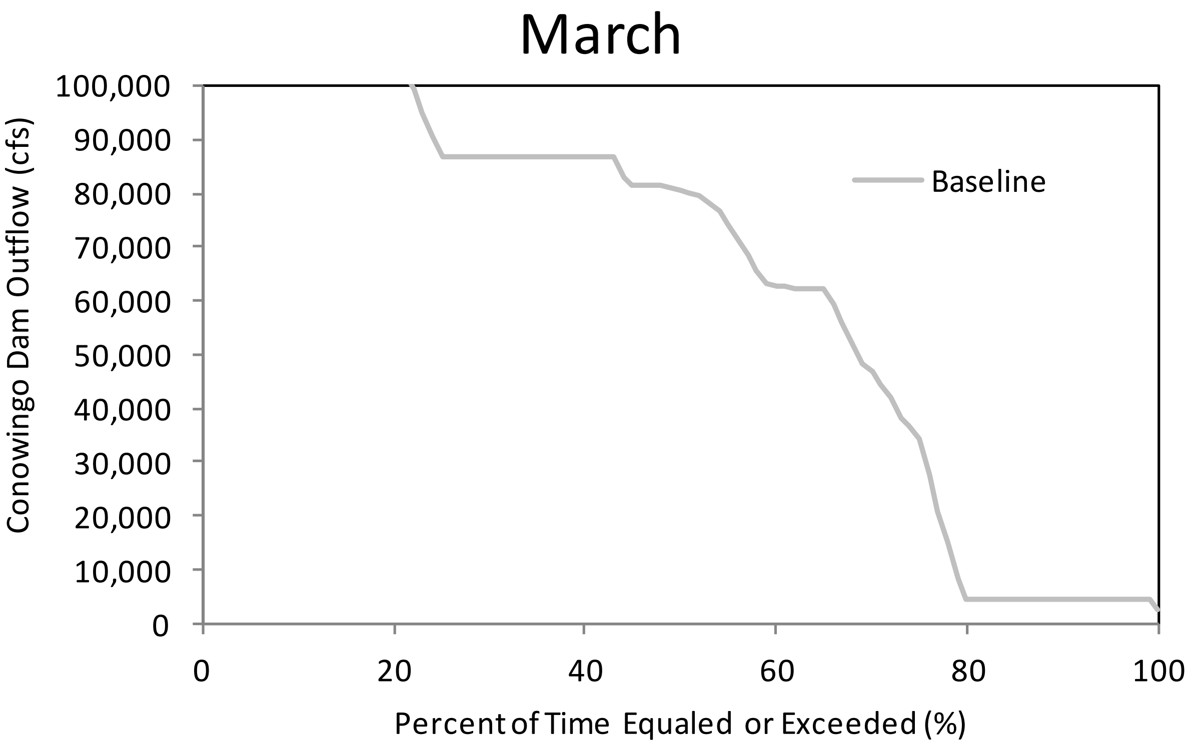

Annual
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

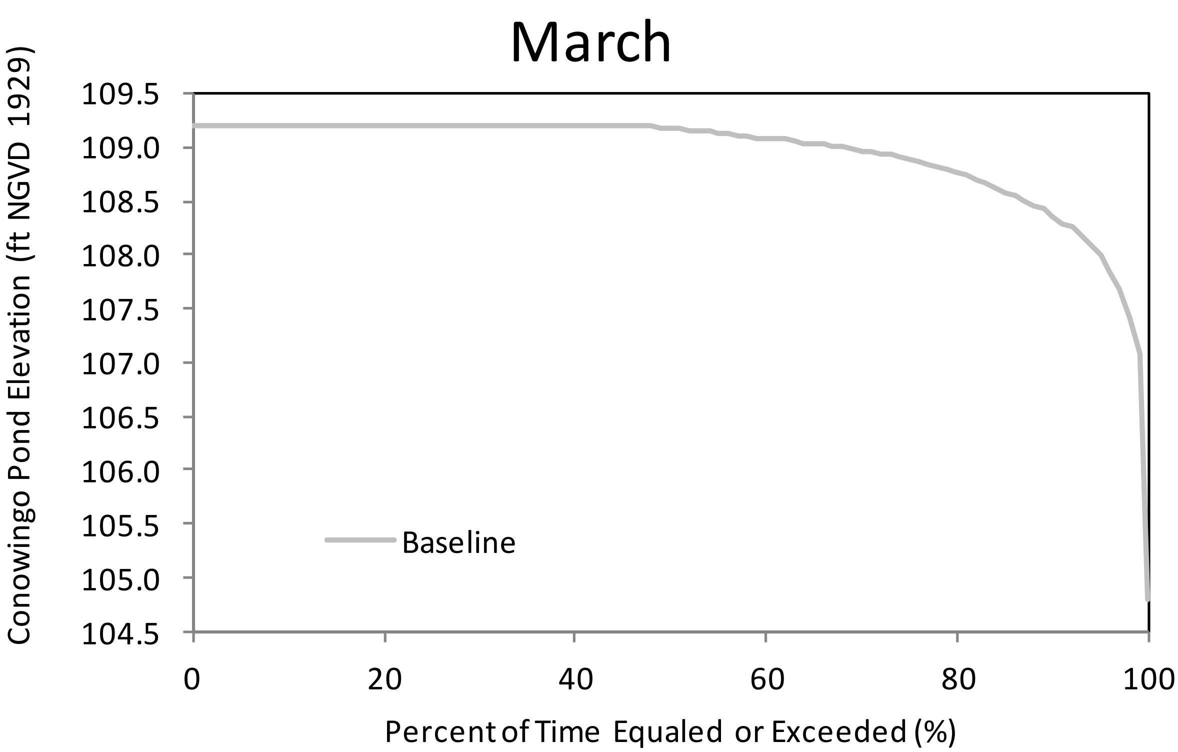

January
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

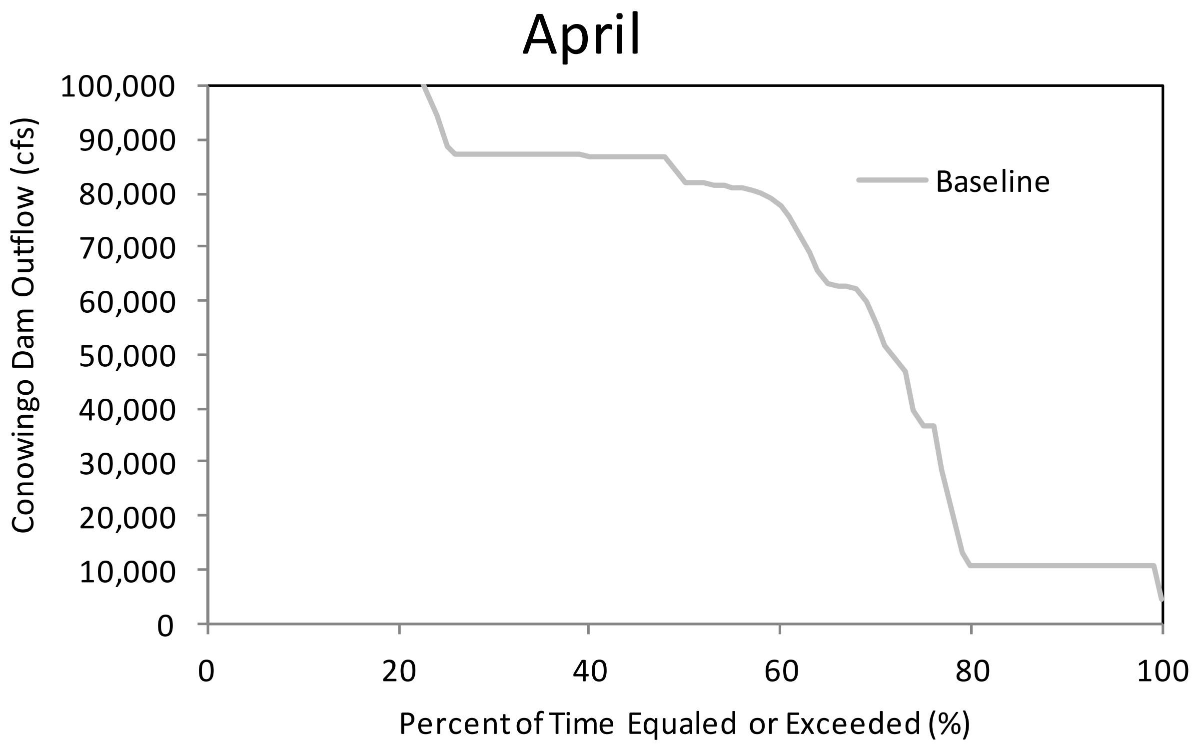

January
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

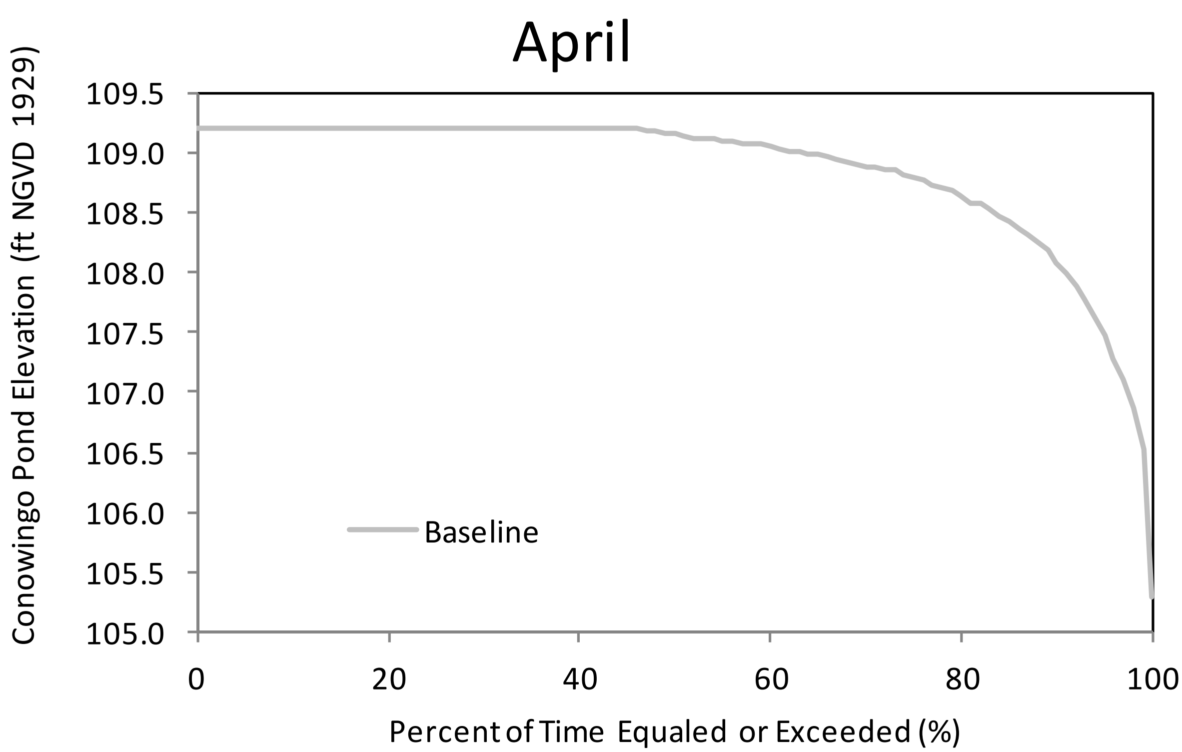

February
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

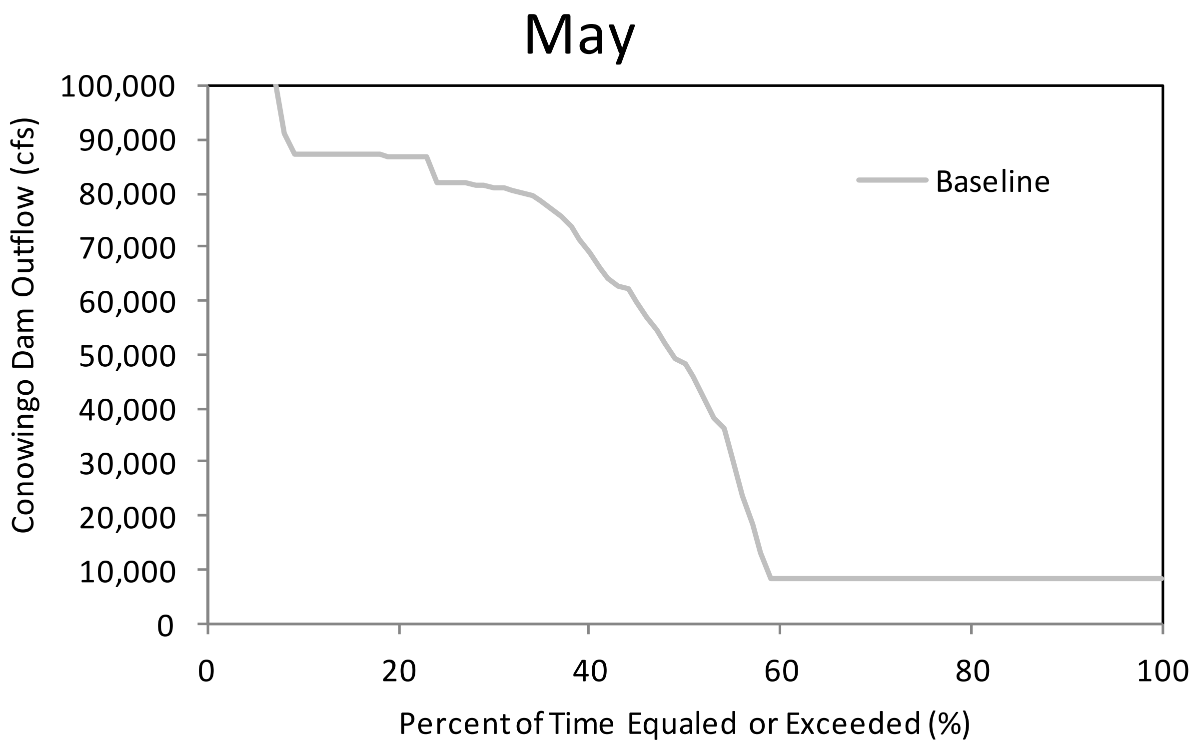

February
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

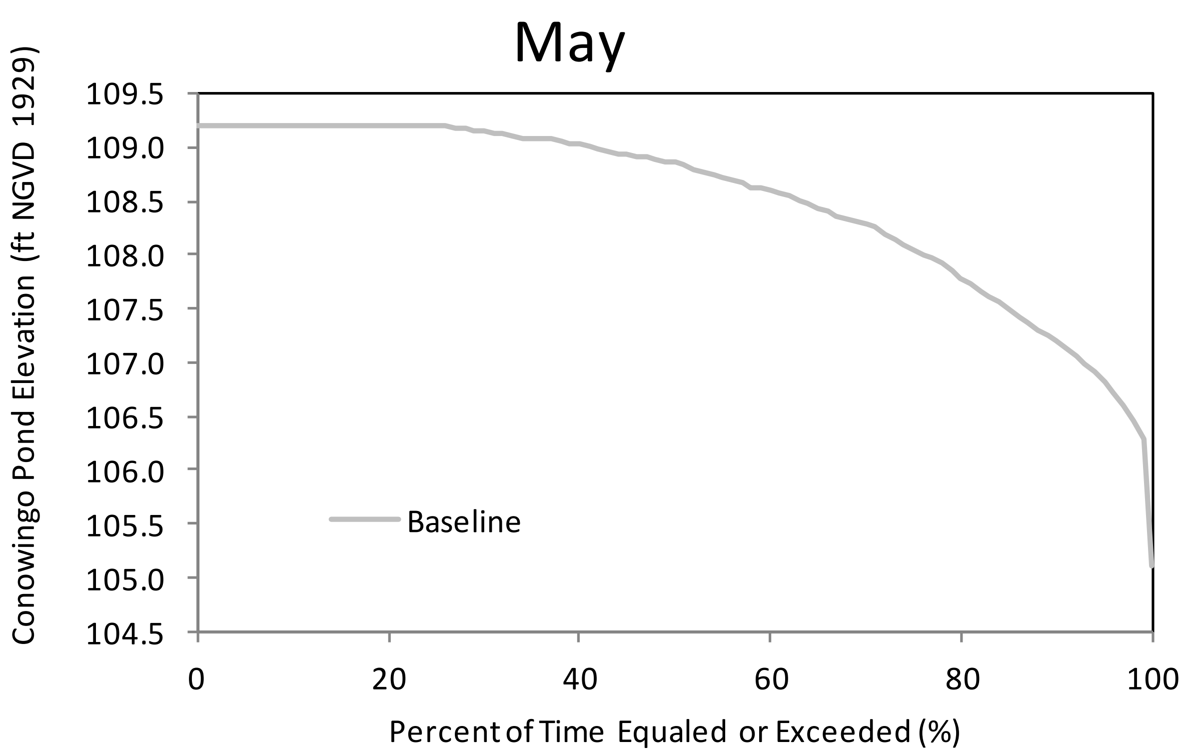

March
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

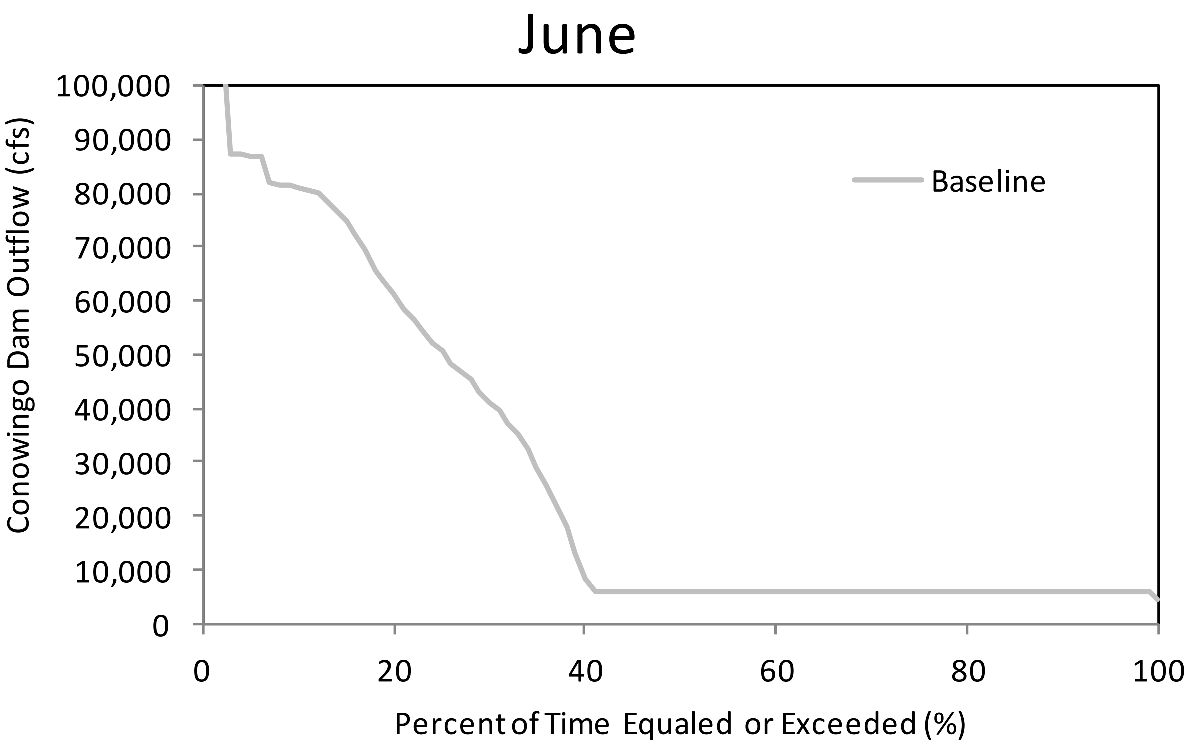

March
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

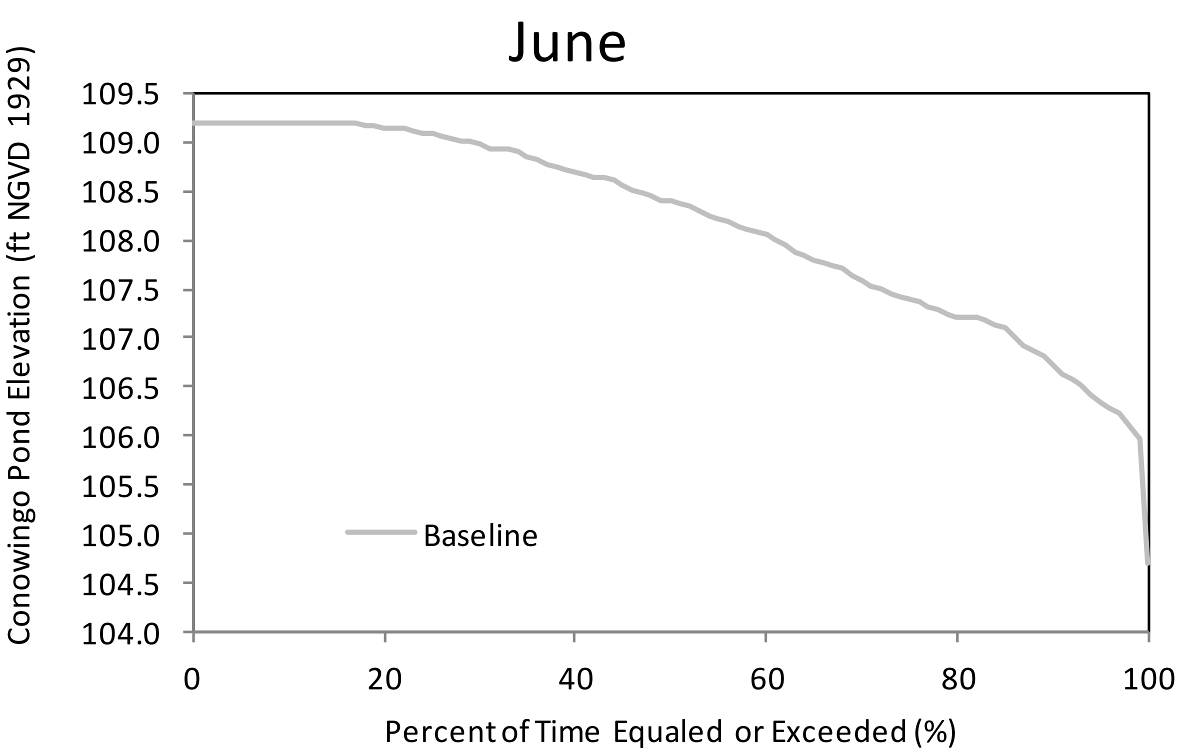

April
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

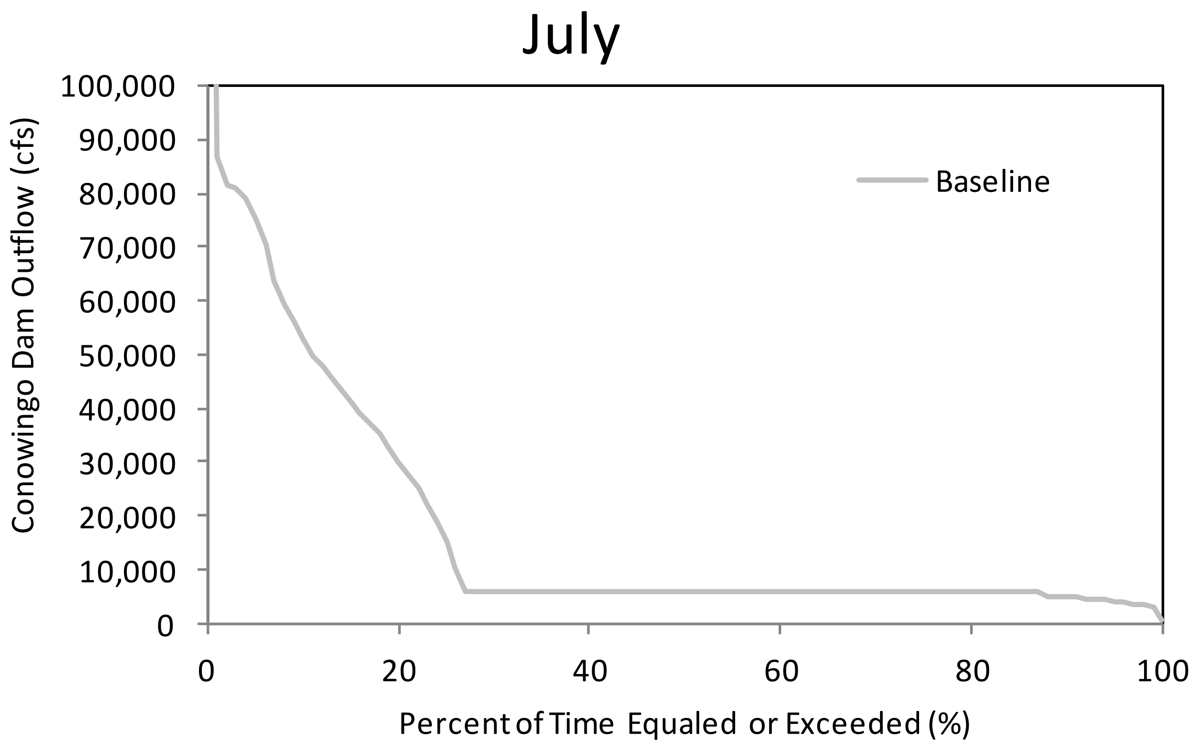

April
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

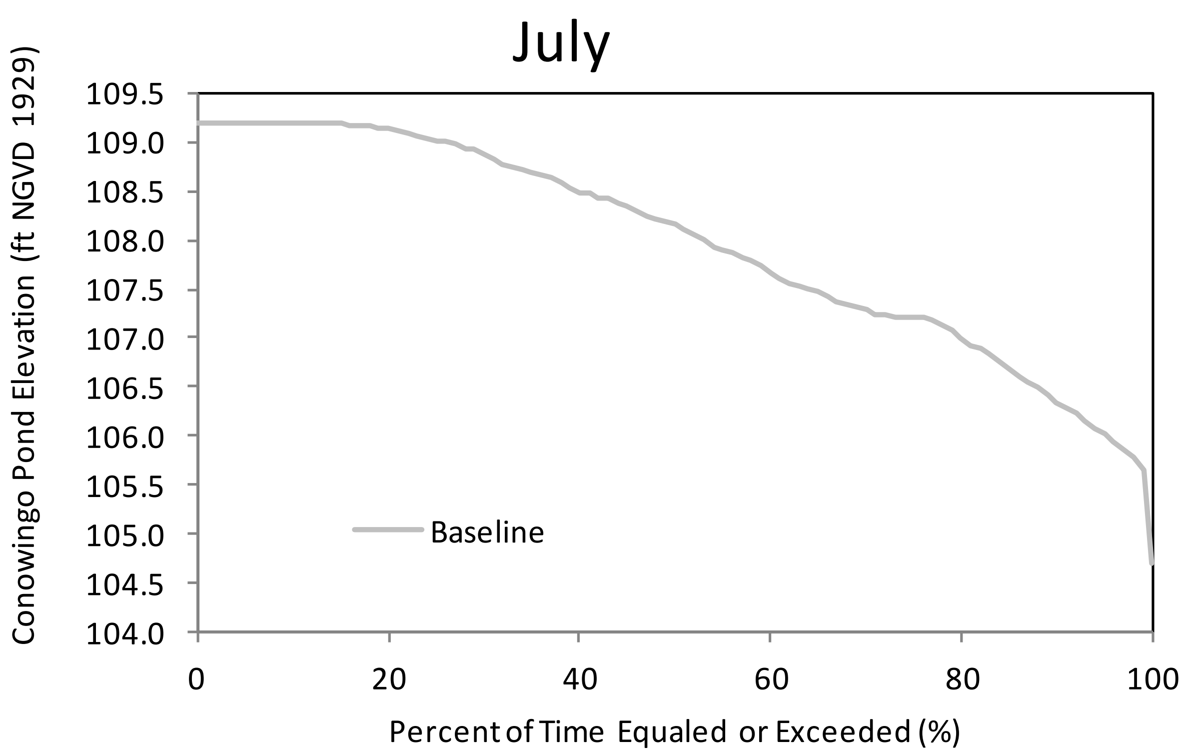

May
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

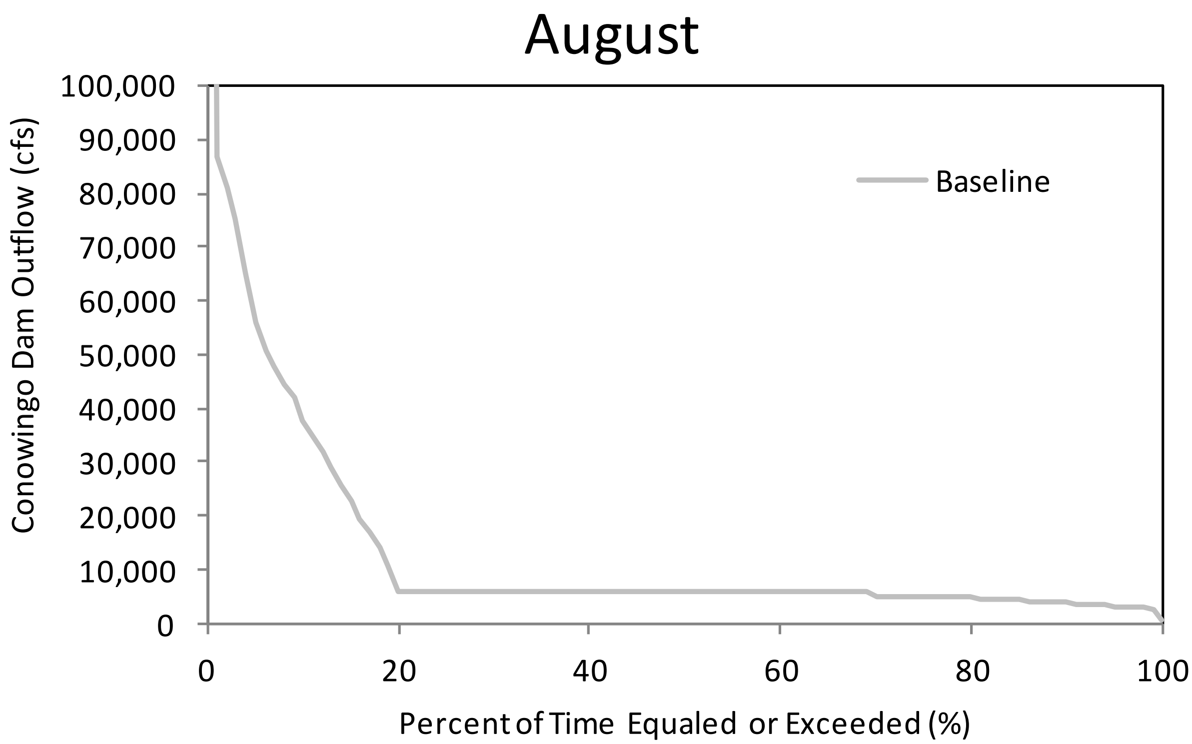

May
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

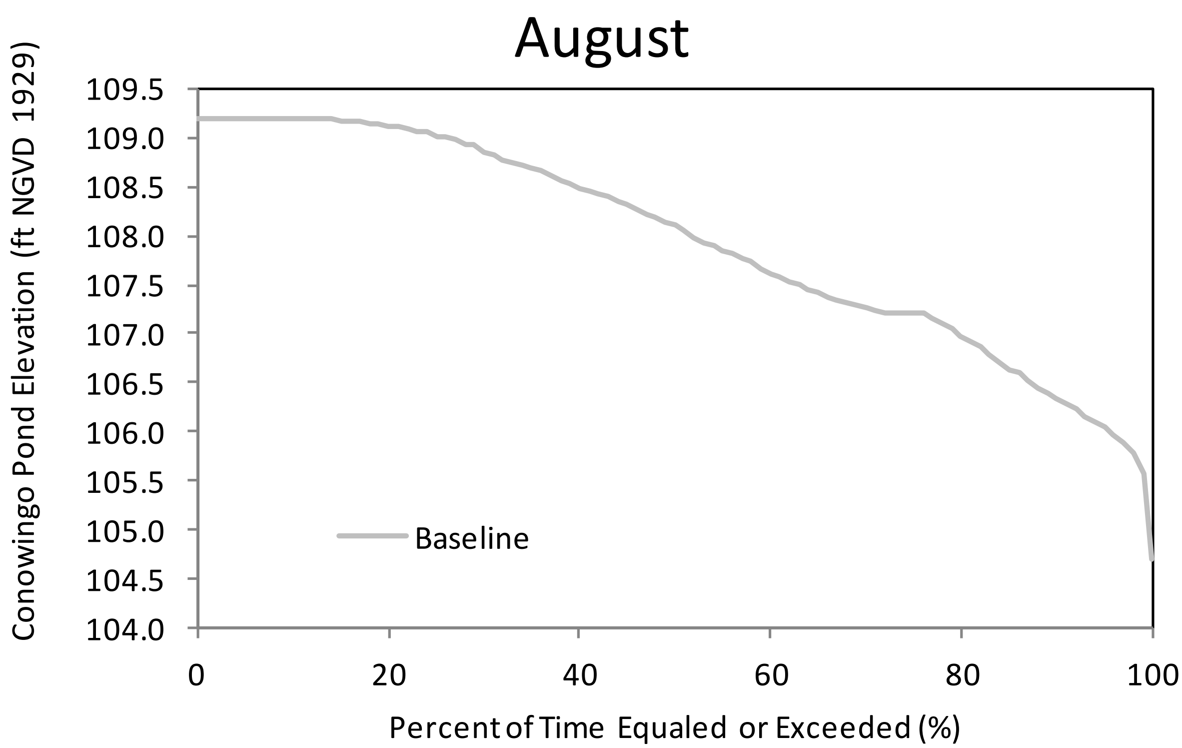

June
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline

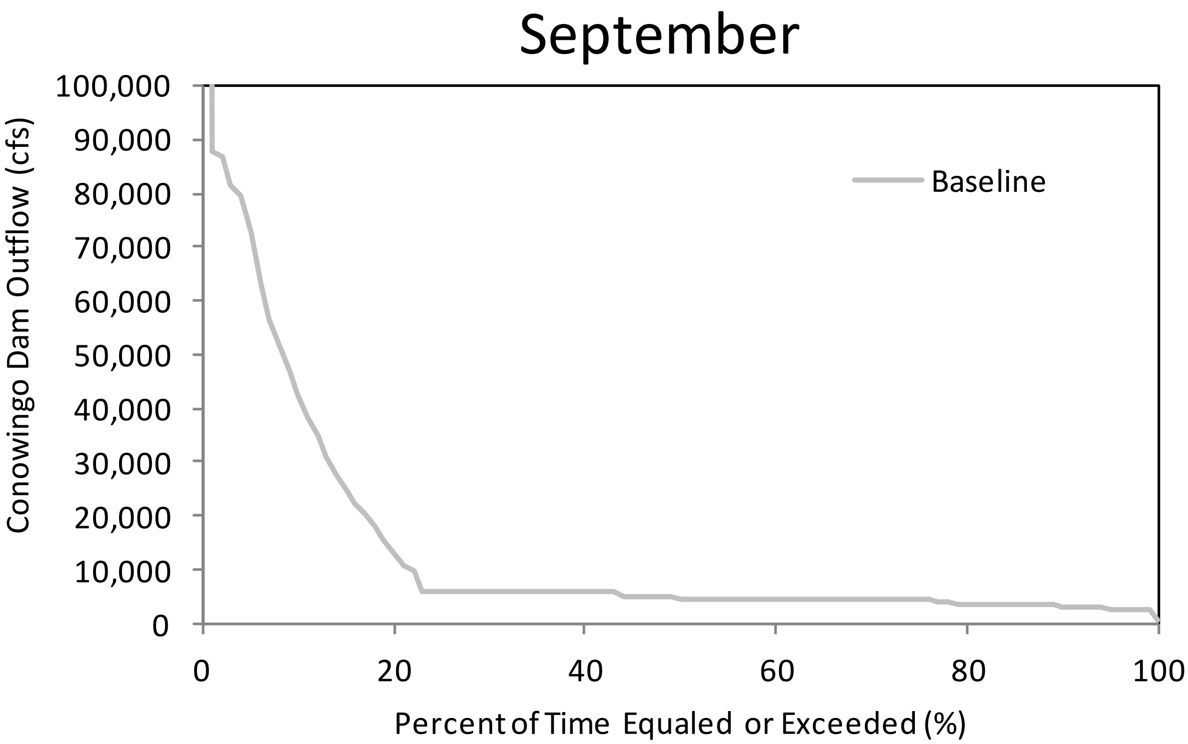

June
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline

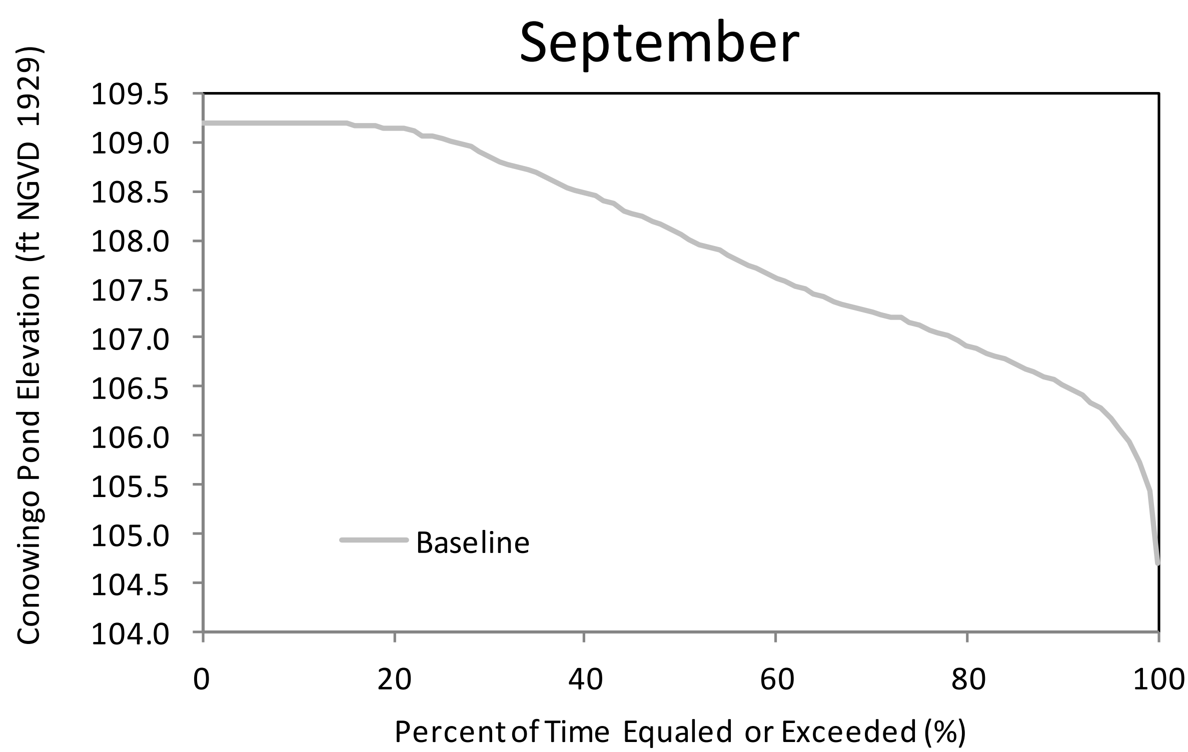

July
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

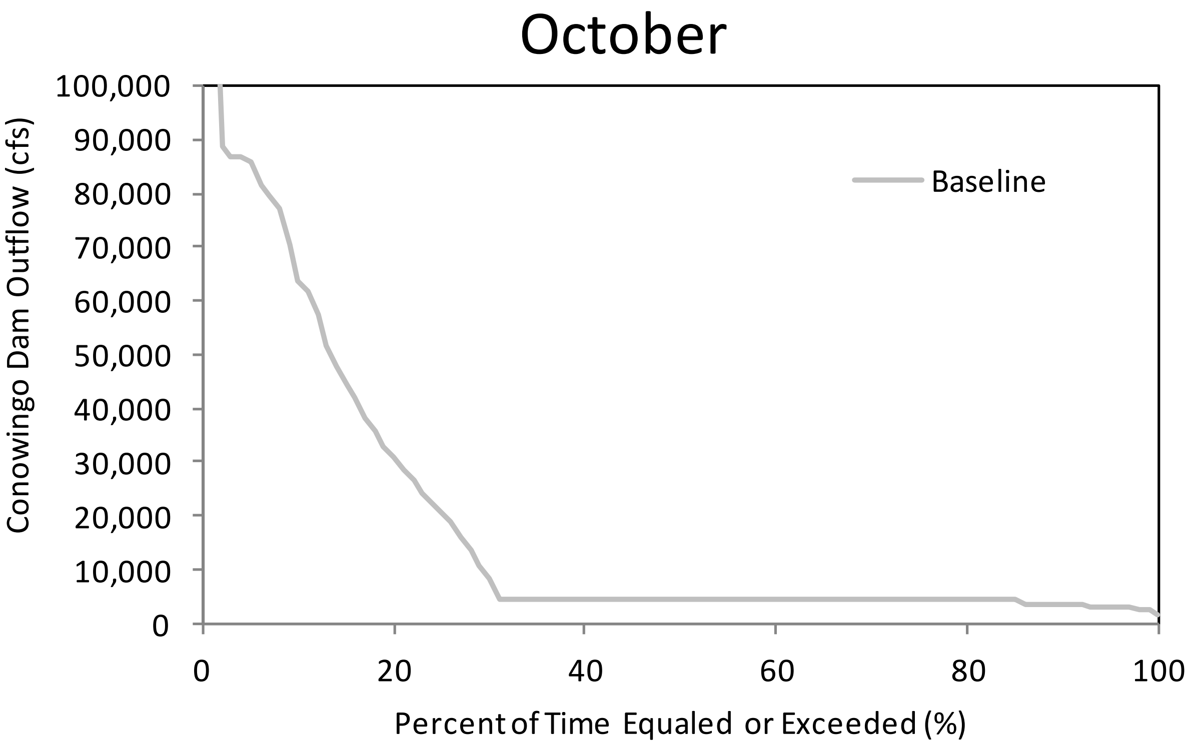

July
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

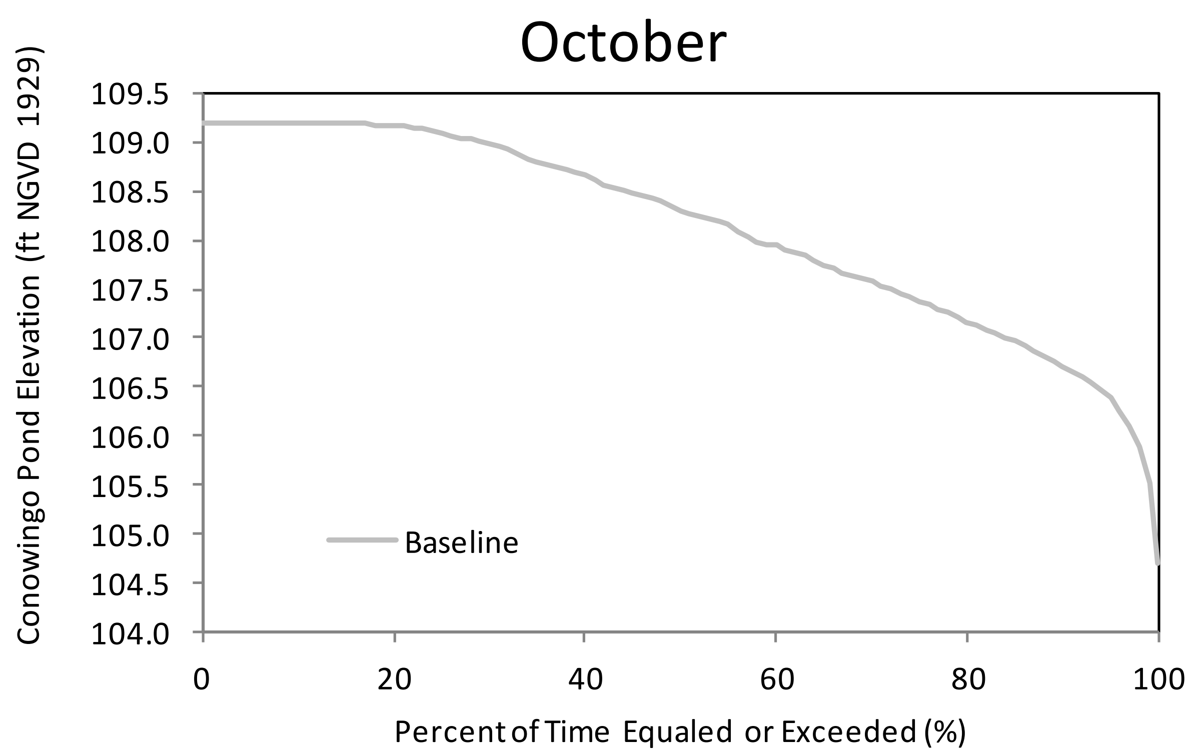

August
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

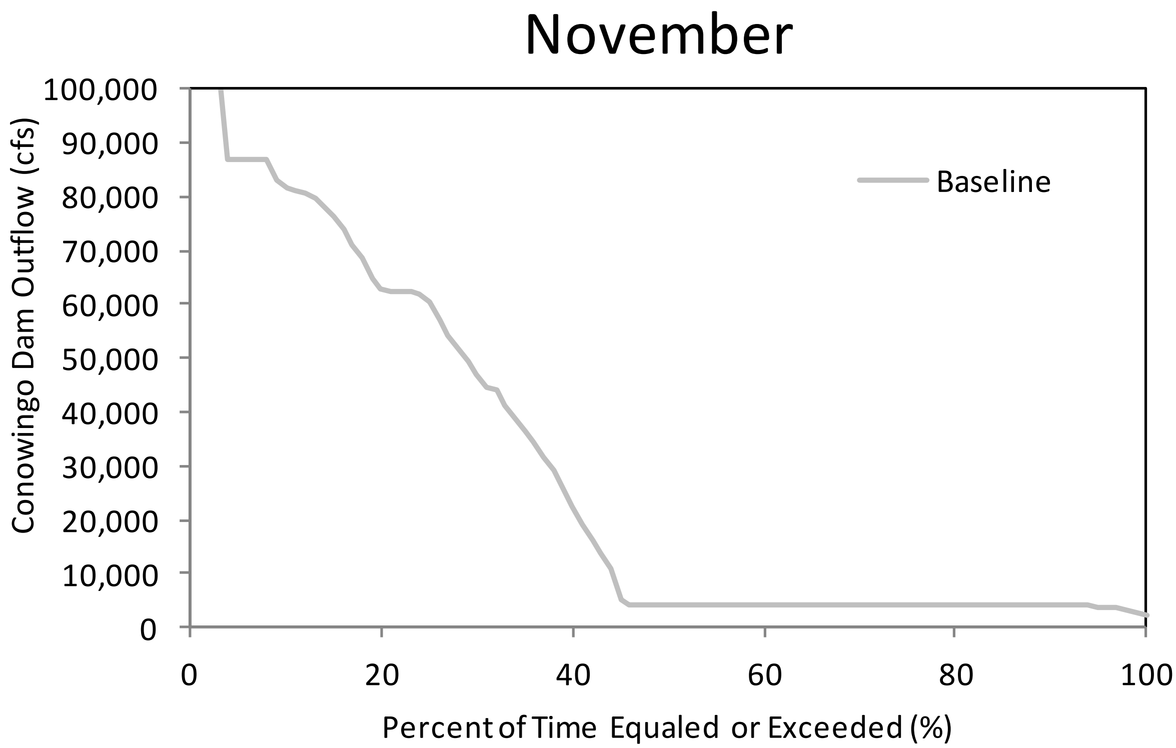

August
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

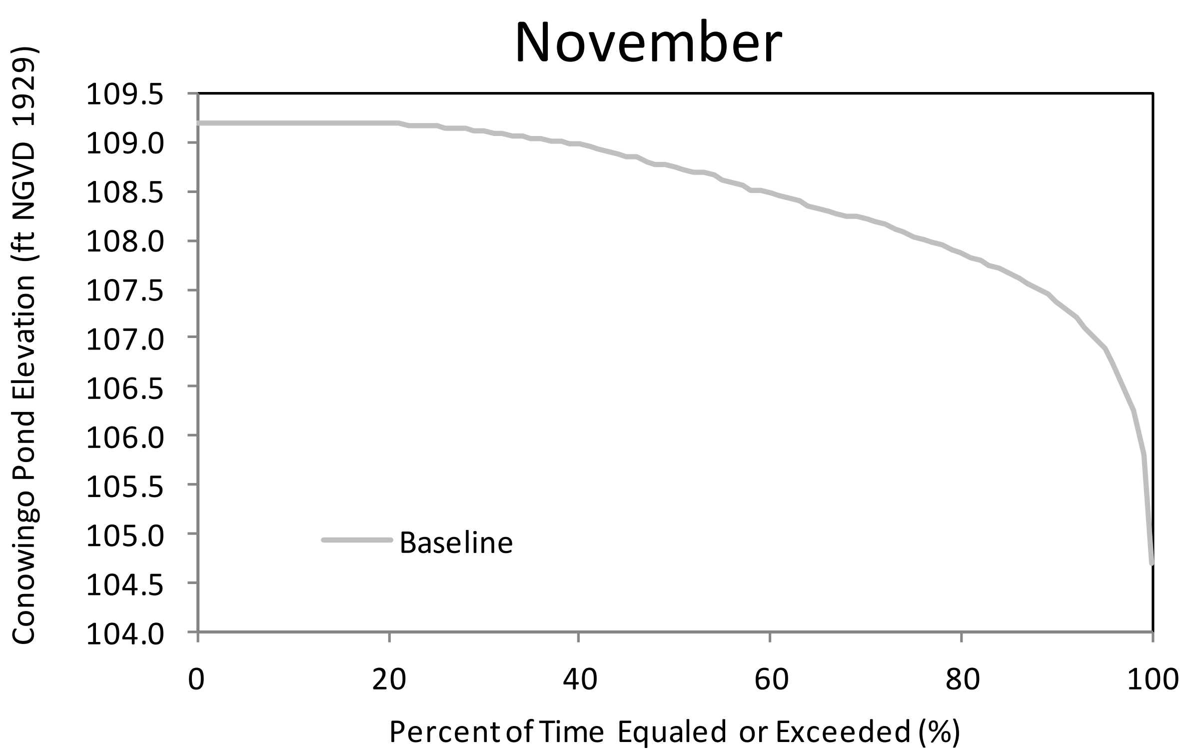

September
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

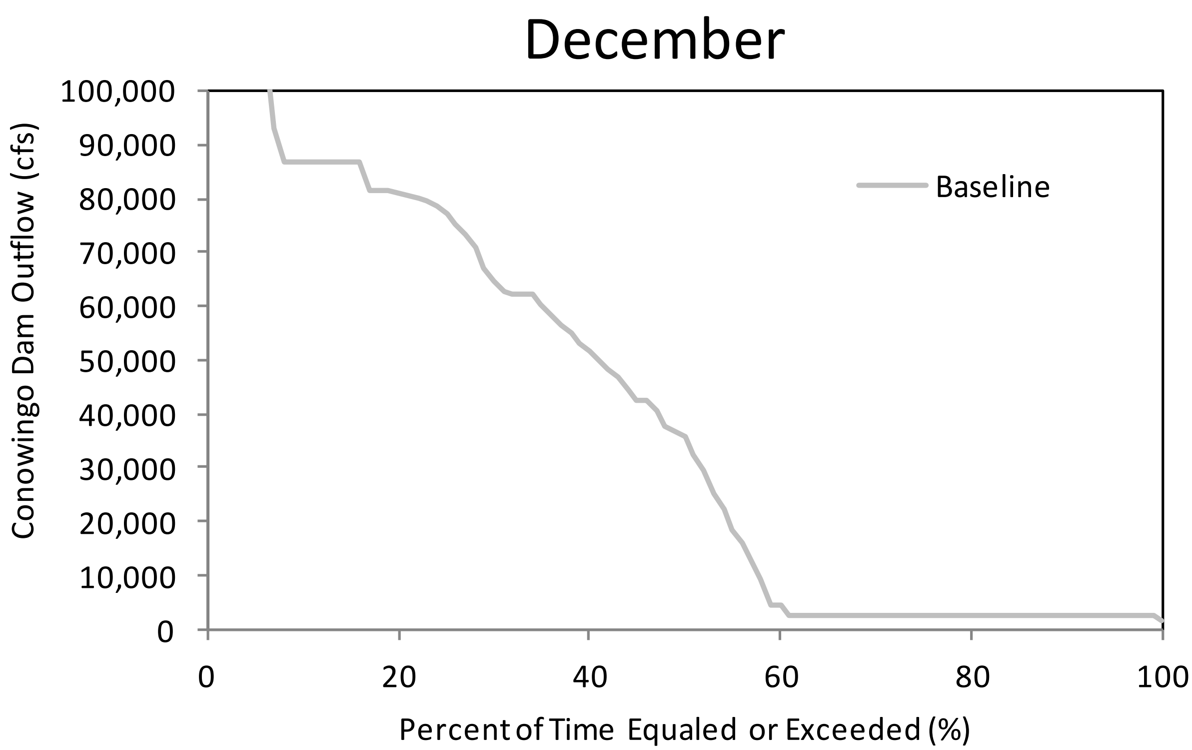

September
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

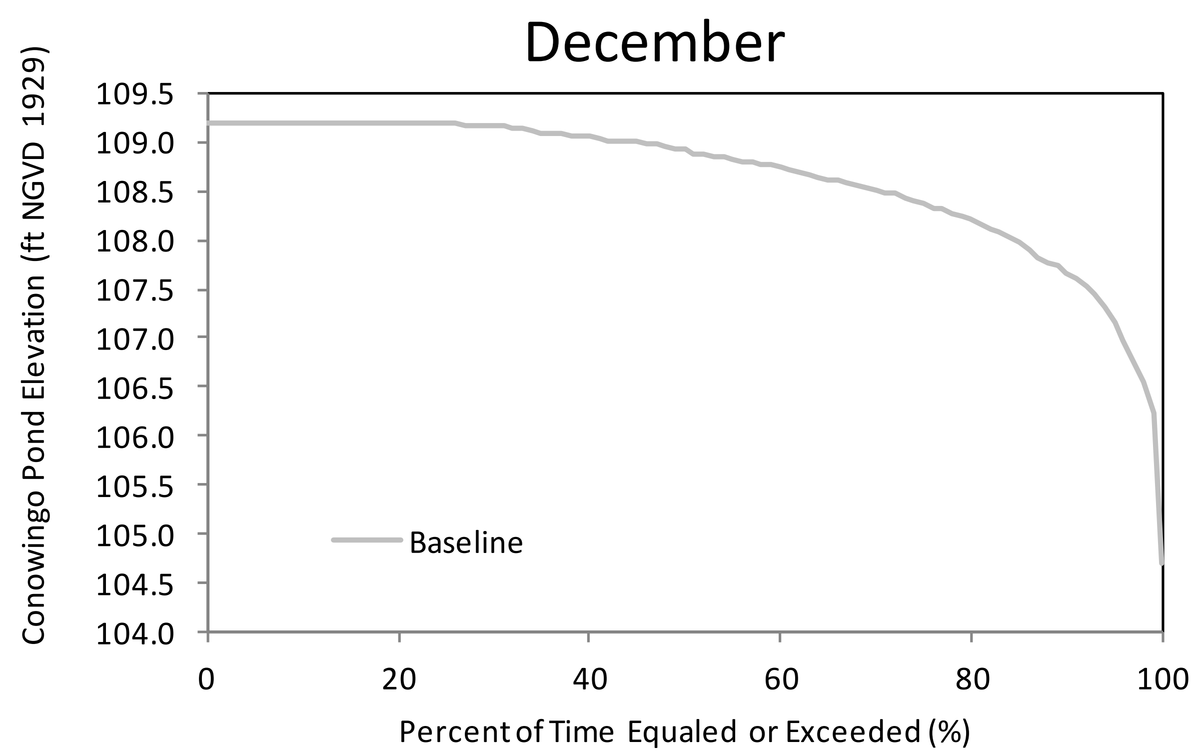

October
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline


October
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline

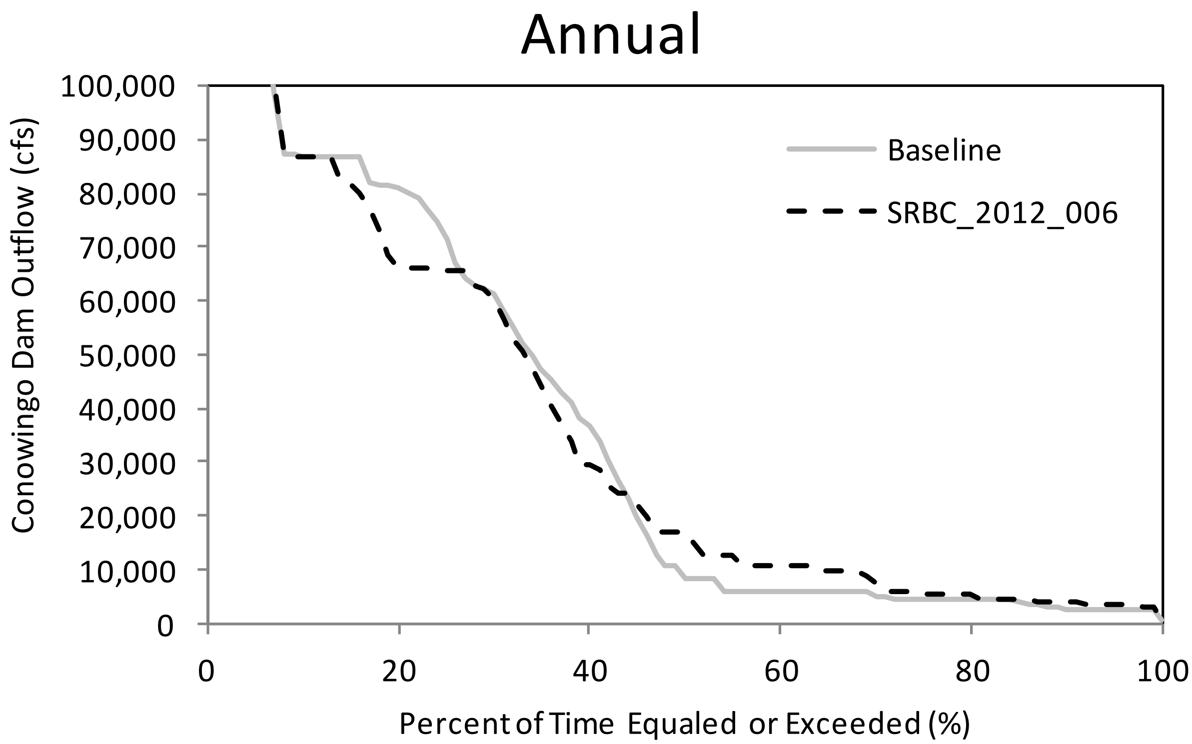

November
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Conowingo Dam Outflow (cfs)
Percent of Time Equaled or Exceeded (%)
Baseline

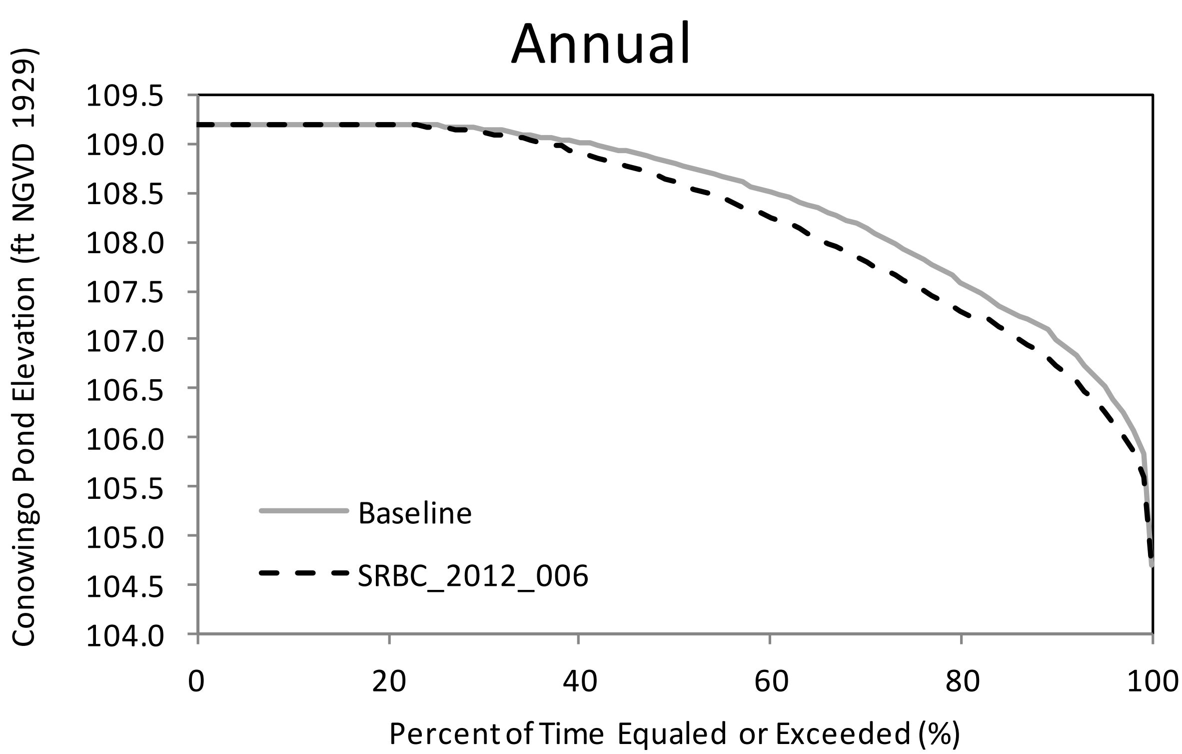

November
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Conowingo Pond Elevation (ft NGVD 1929)
Percent of Time Equaled or Exceeded (%)
Baseline

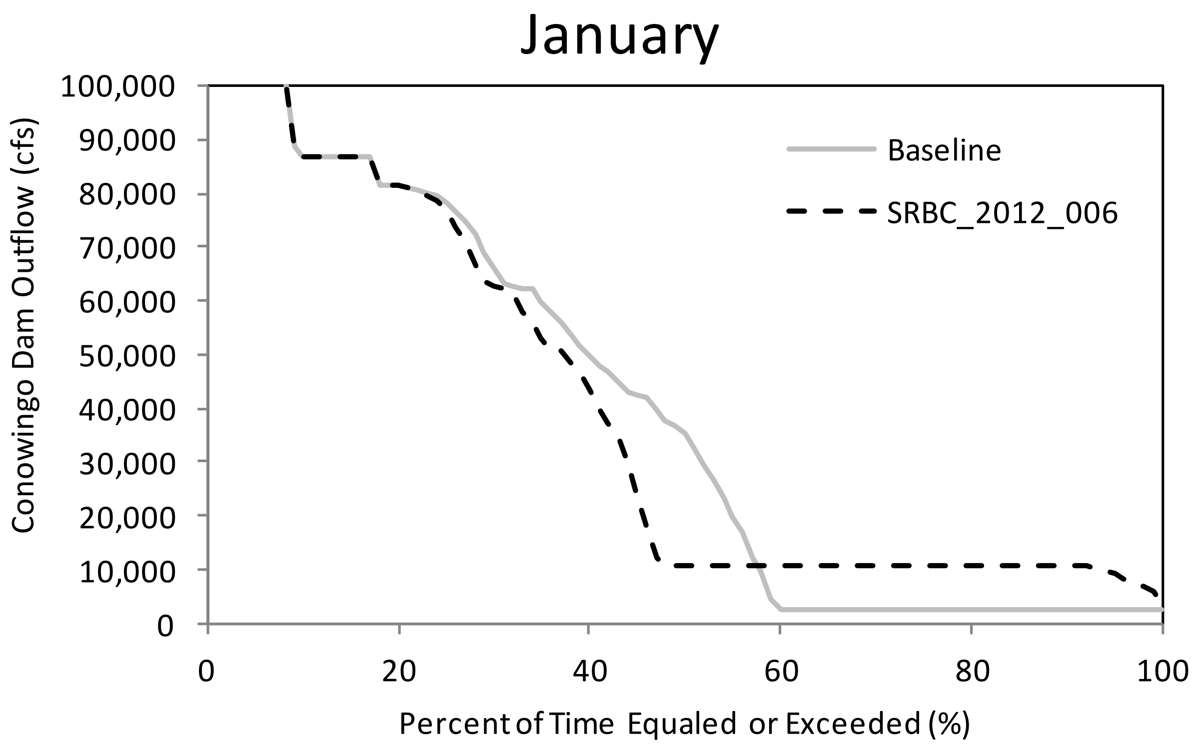

December
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

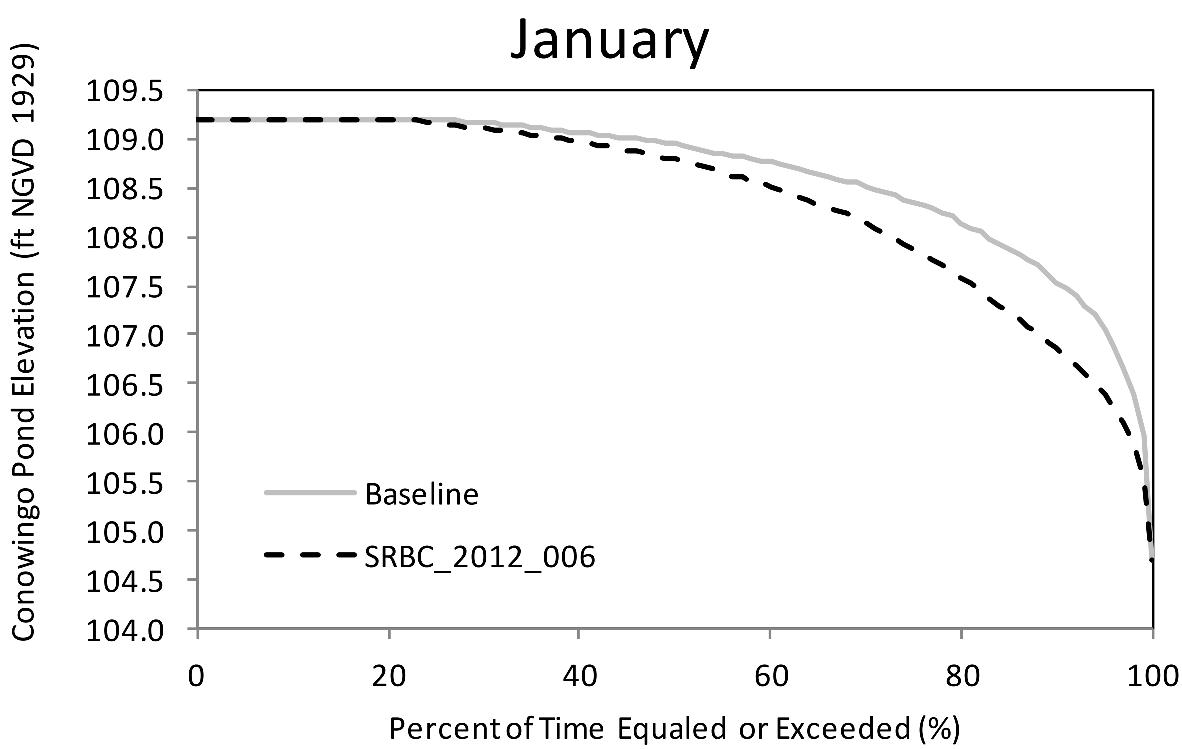

December
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Baseline
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

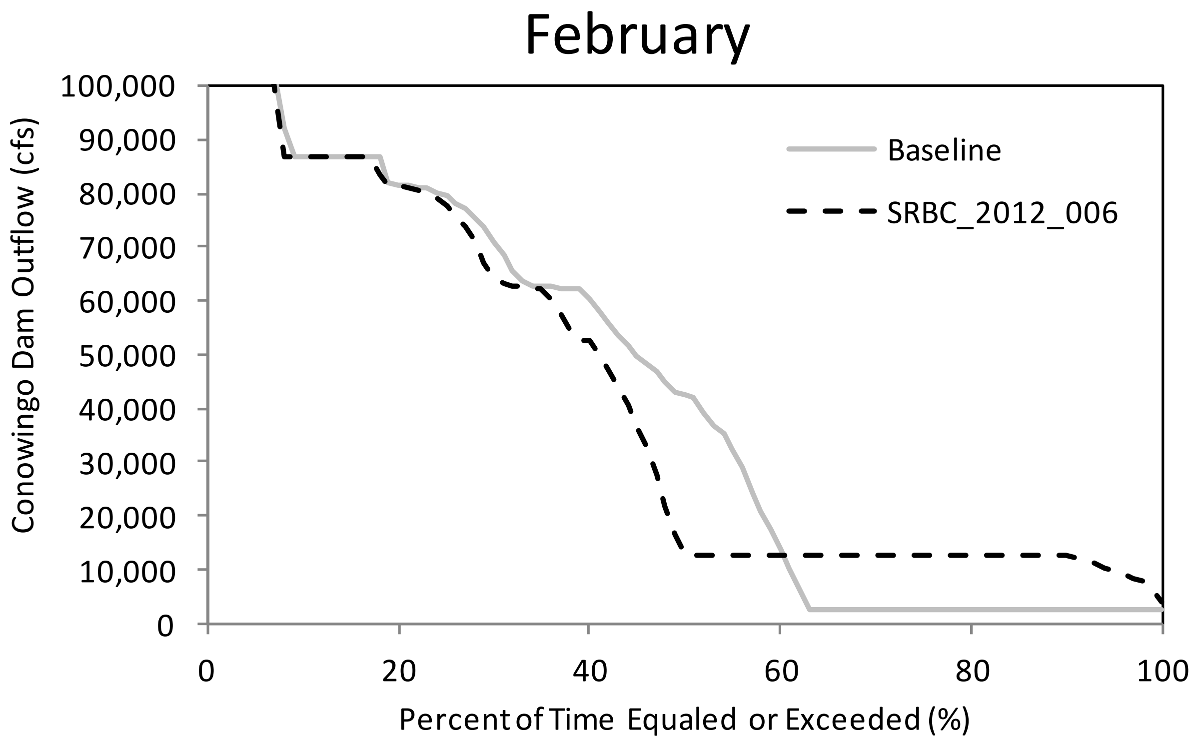
APPENDIX B: PRODUCTION RUN SRBC-006 ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW AND POND ELEVATION EXCEEDENCE CURVES

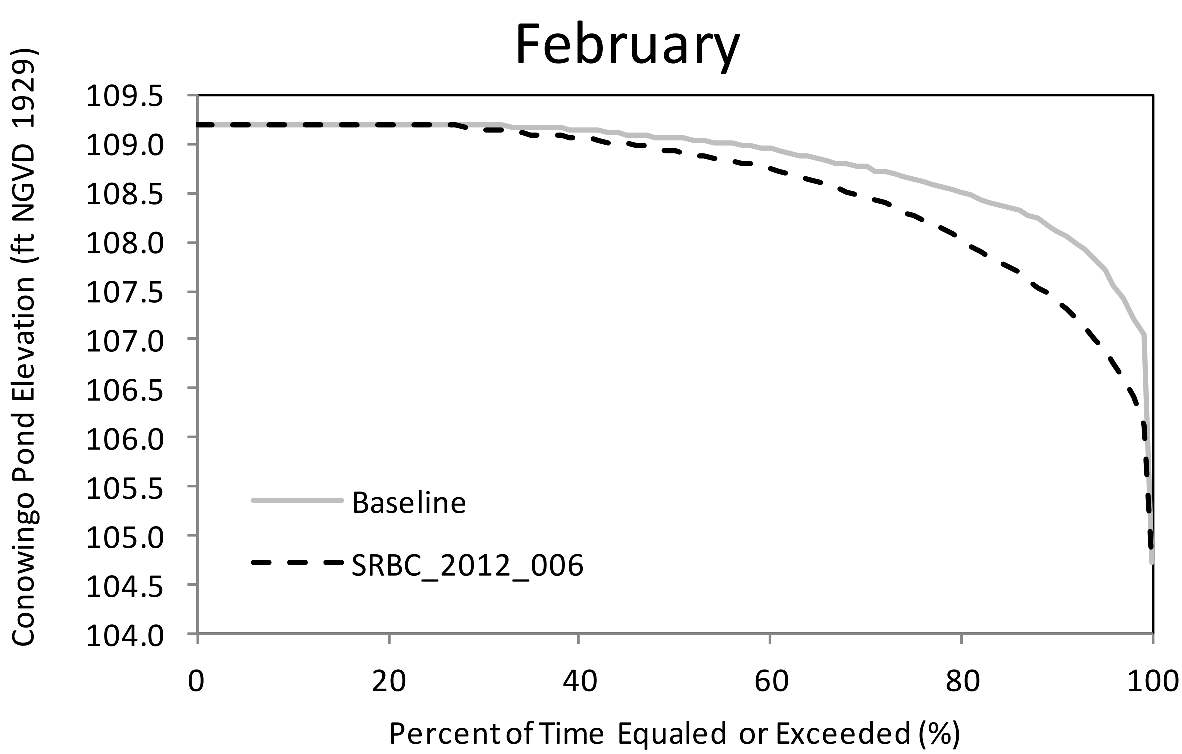

Annual
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

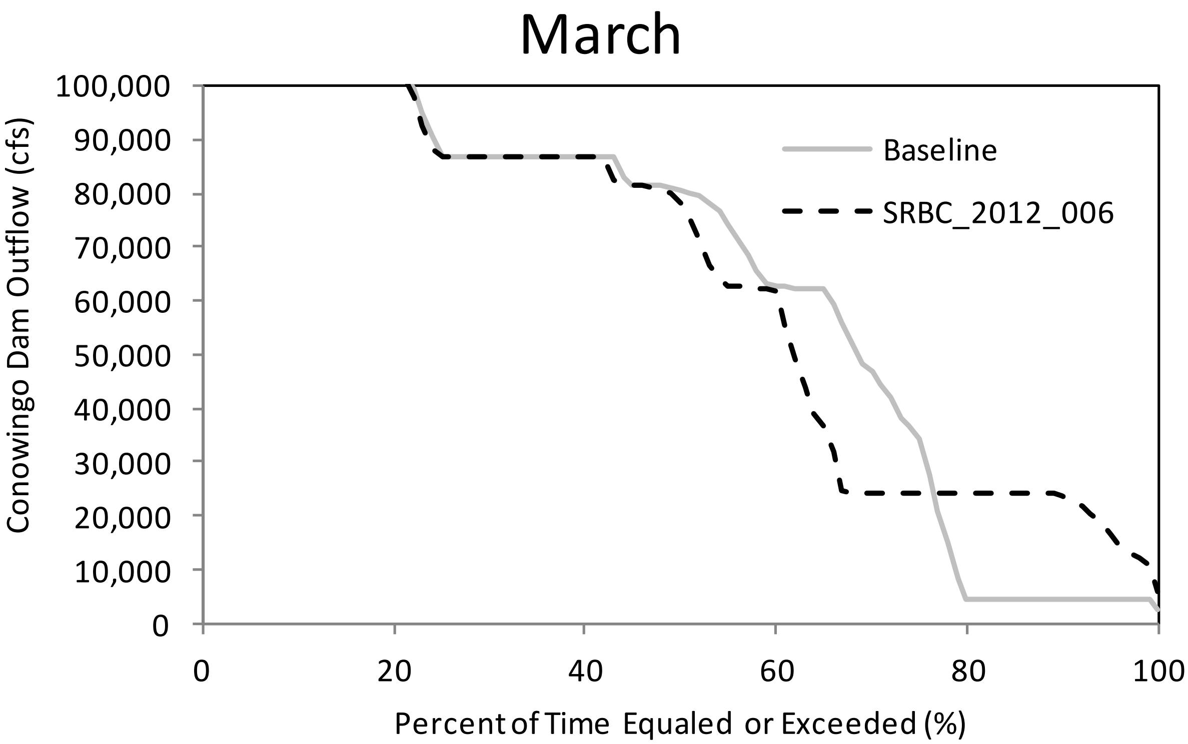

Annual
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006


January
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

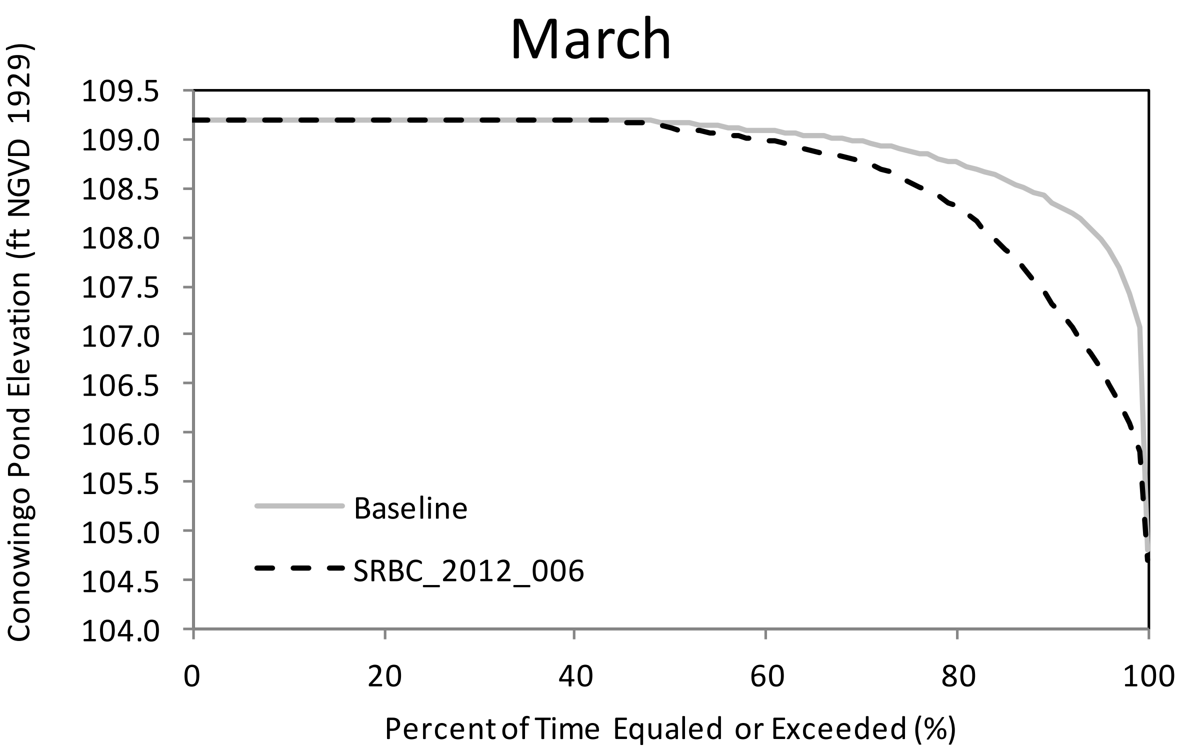

January
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006


February
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

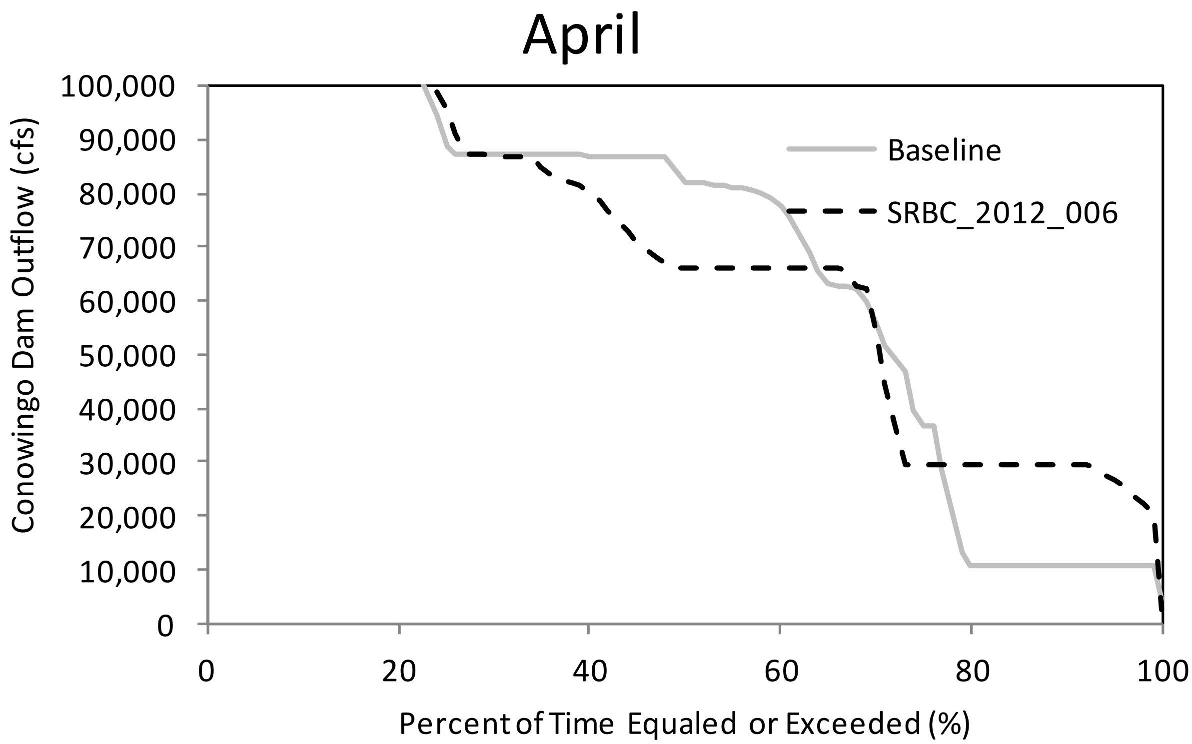

February
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

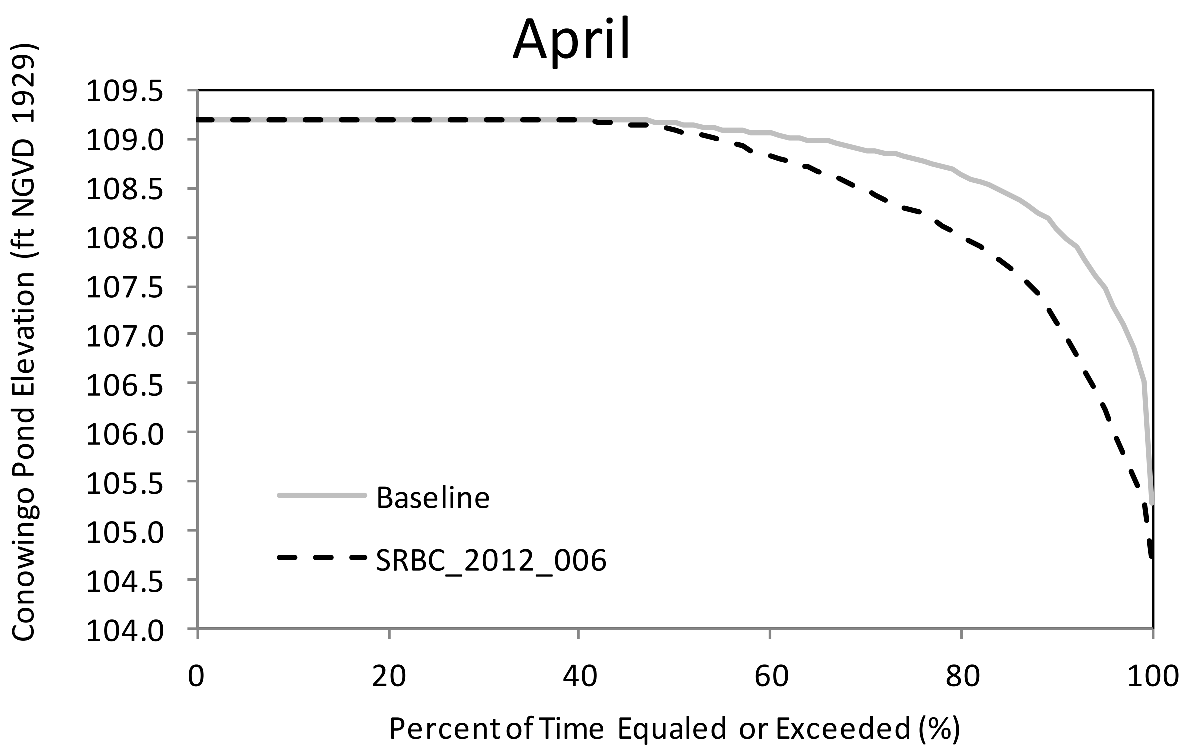


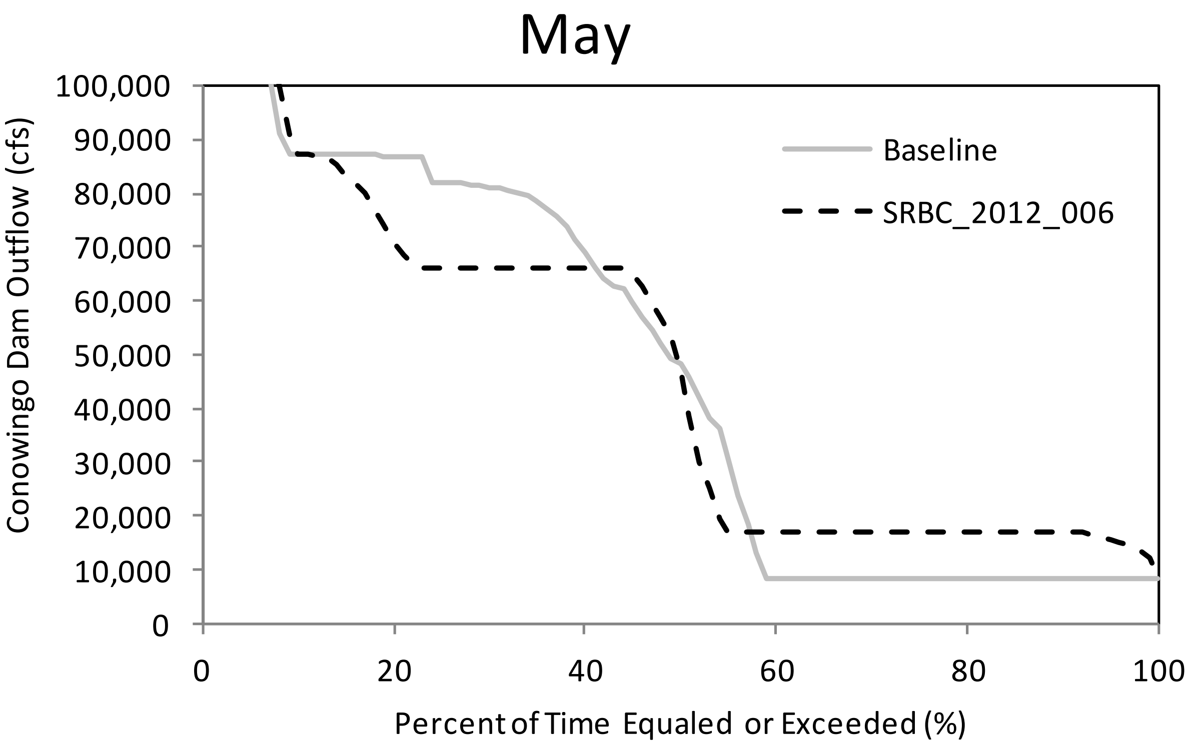
March
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

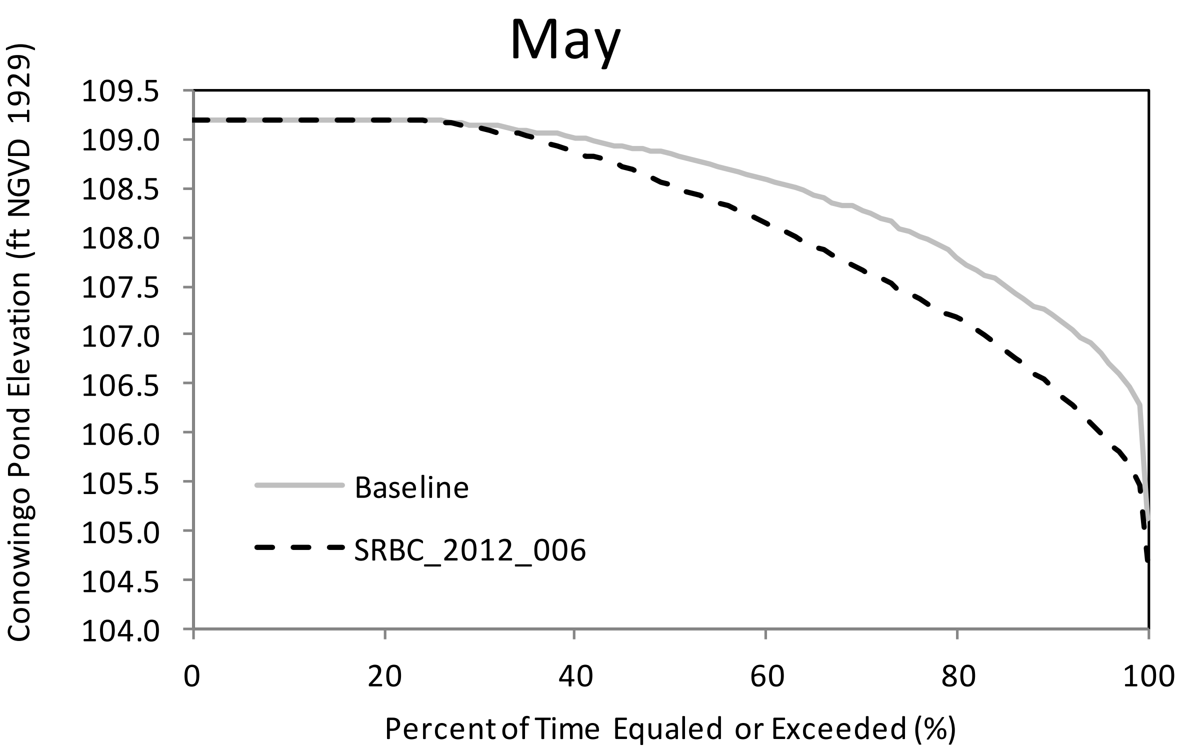


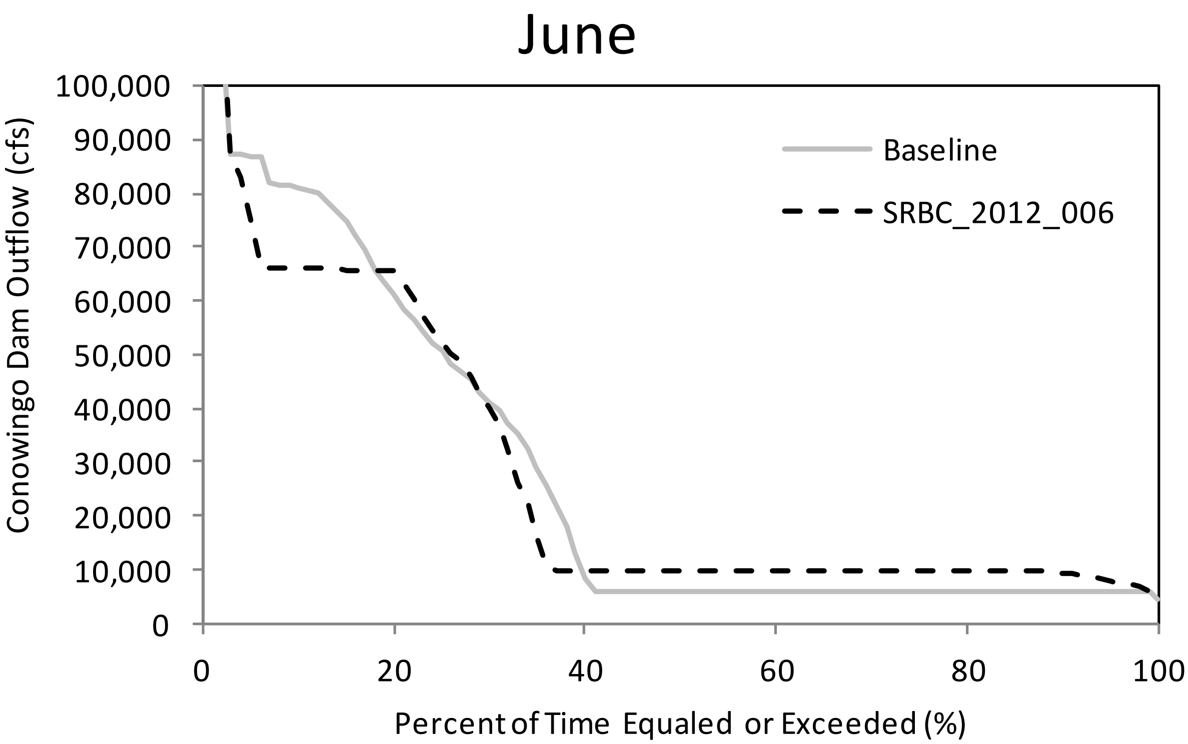
March
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

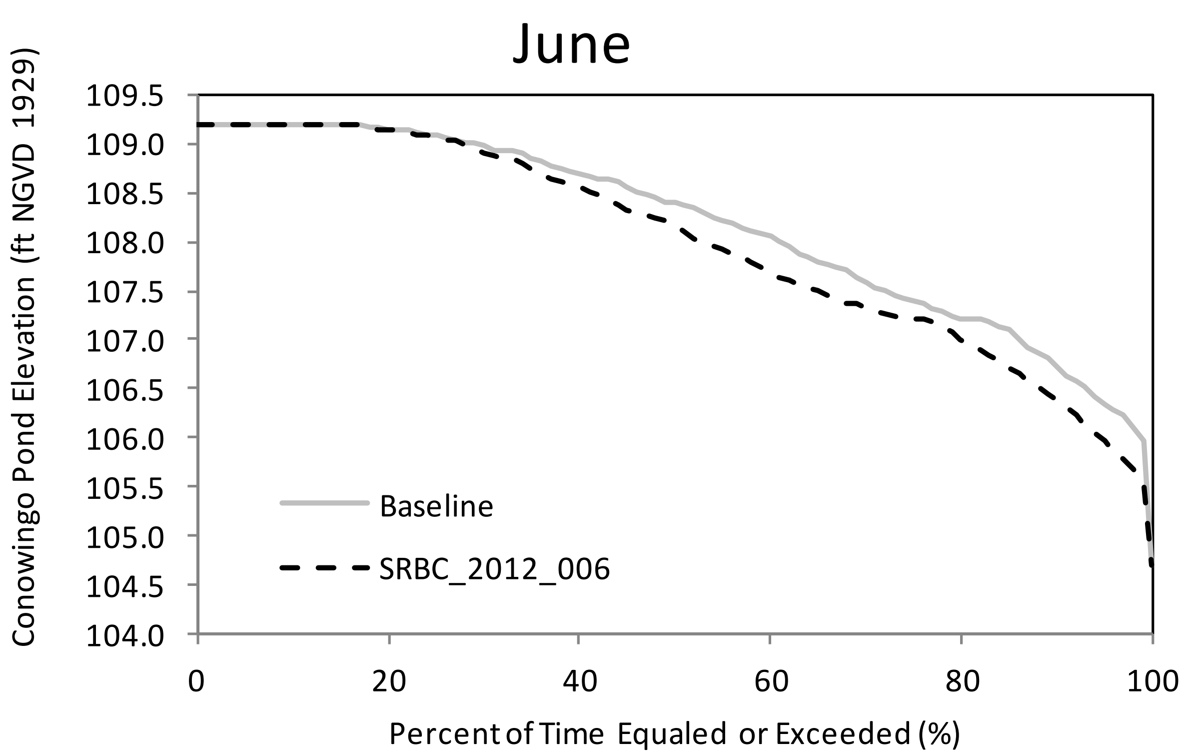

April
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

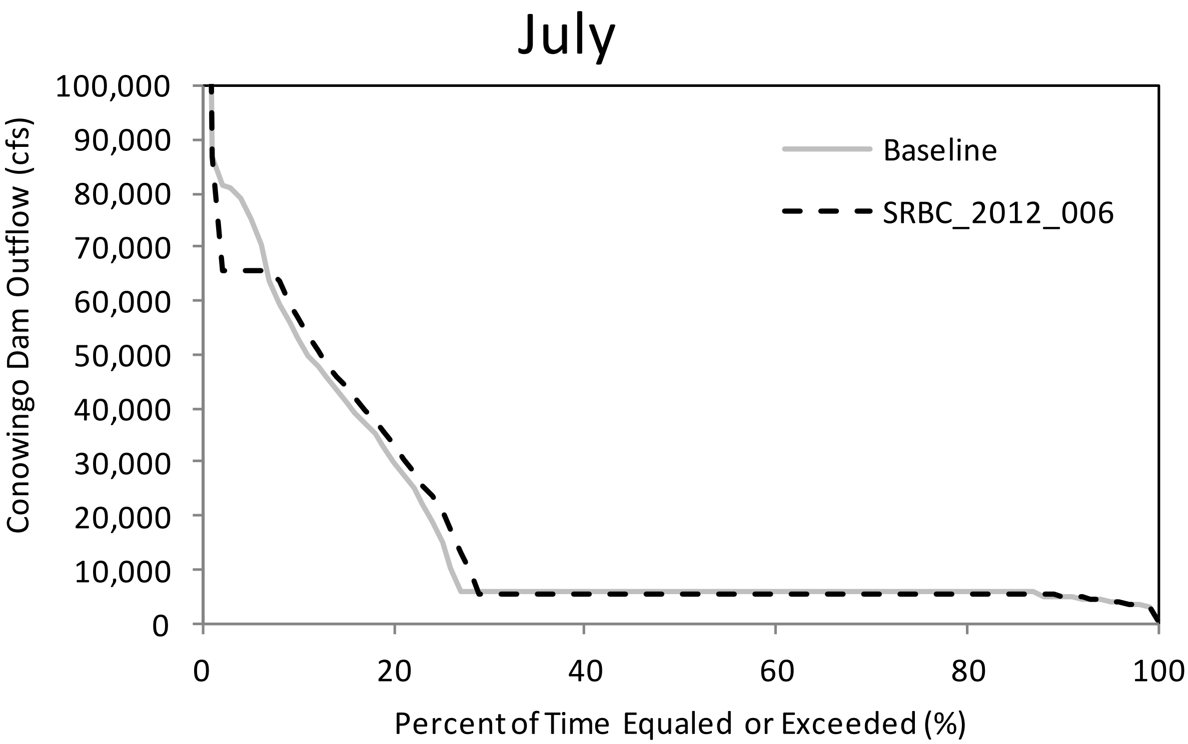

April
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

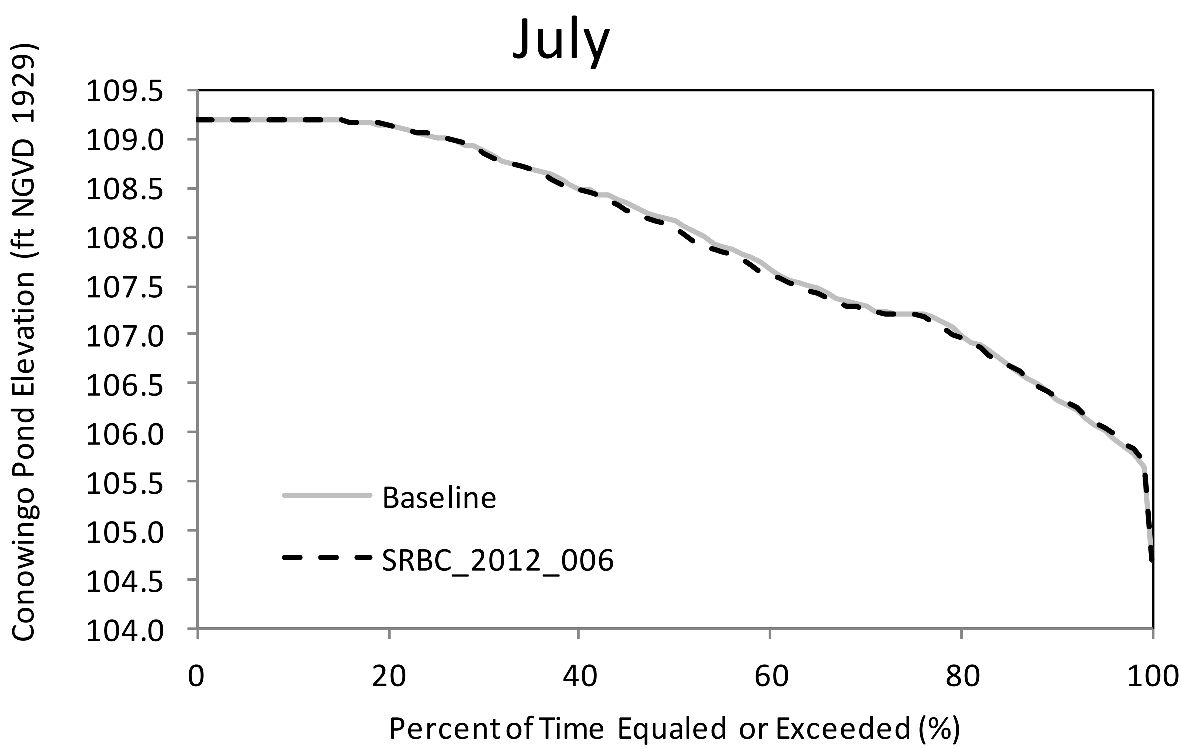

May
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
Baseline
SRBC_2012_006
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

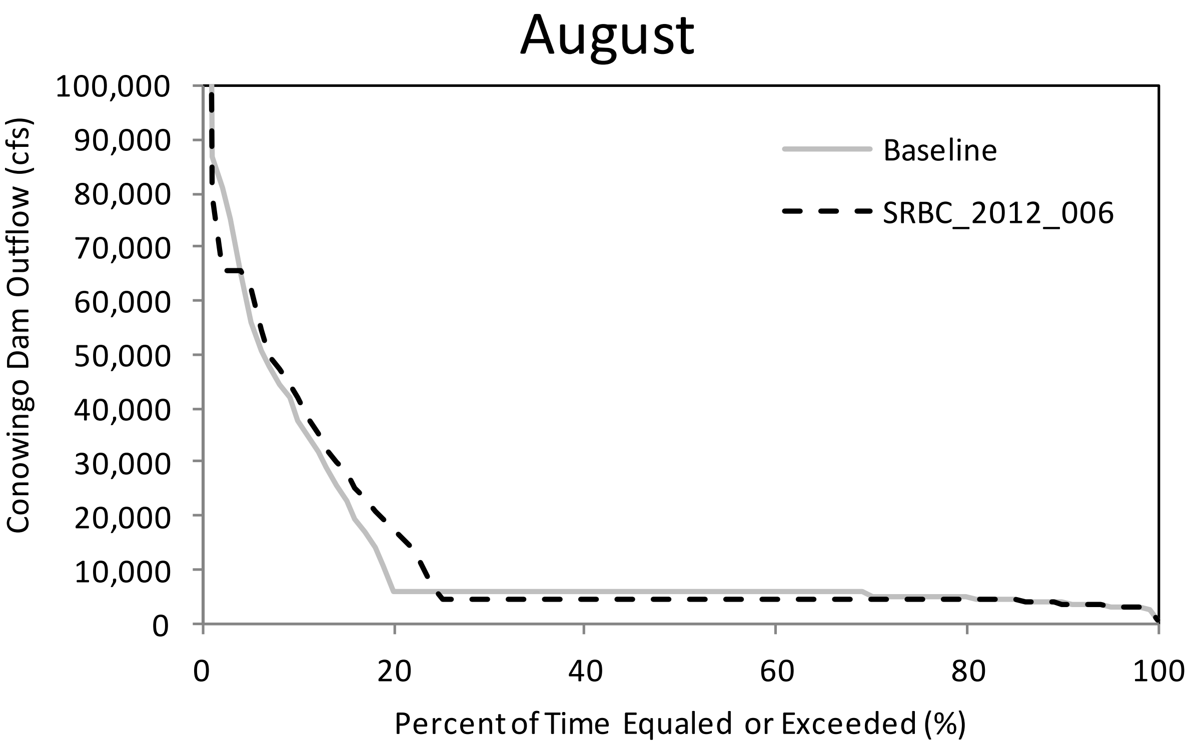

May
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
Baseline
SRBC_2012_006
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

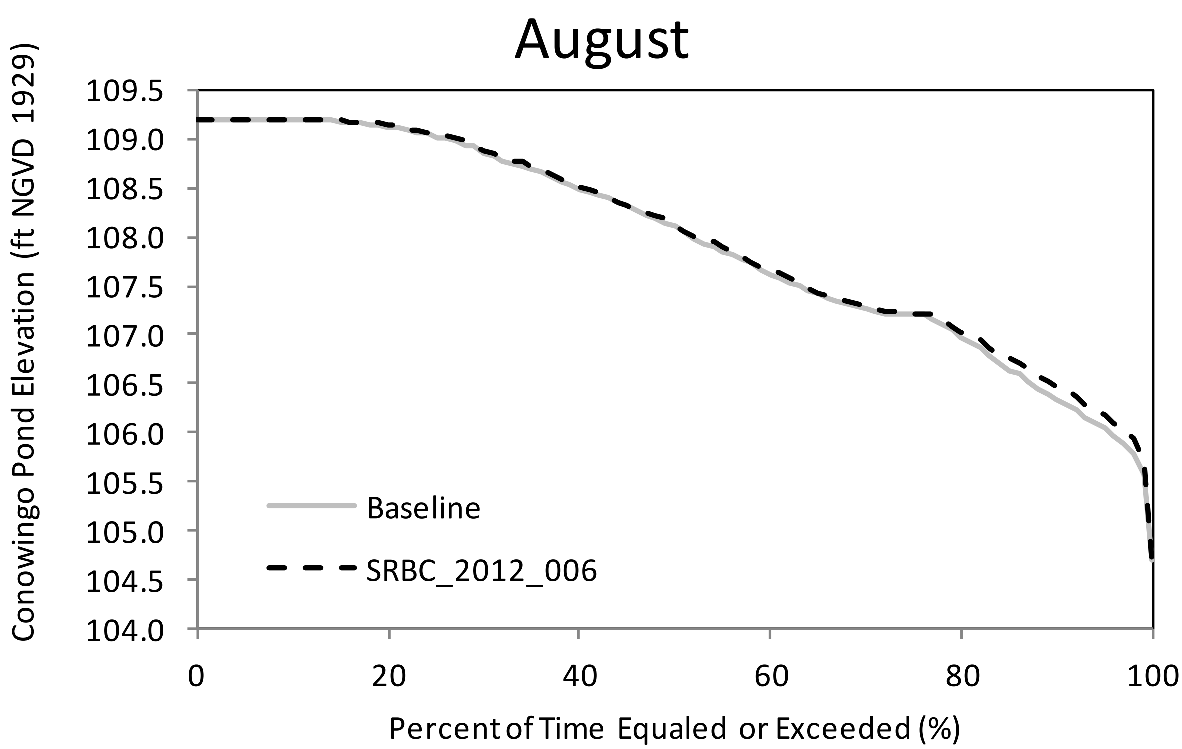

June
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

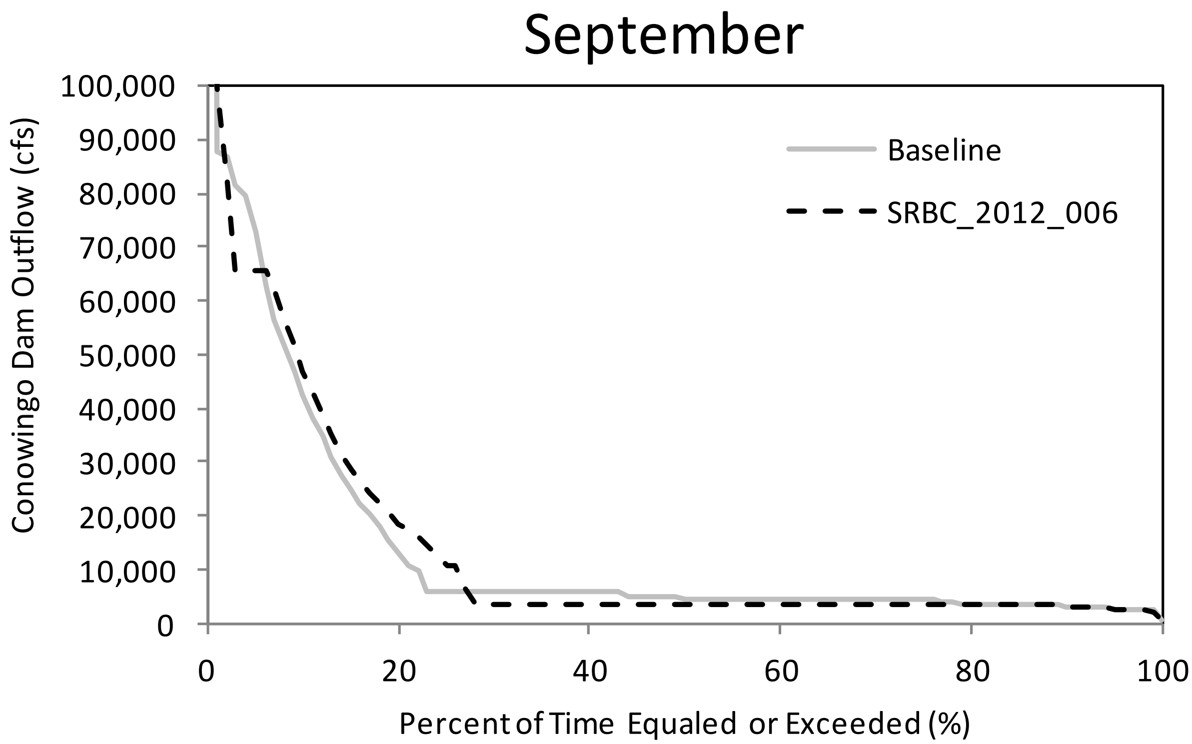

June
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

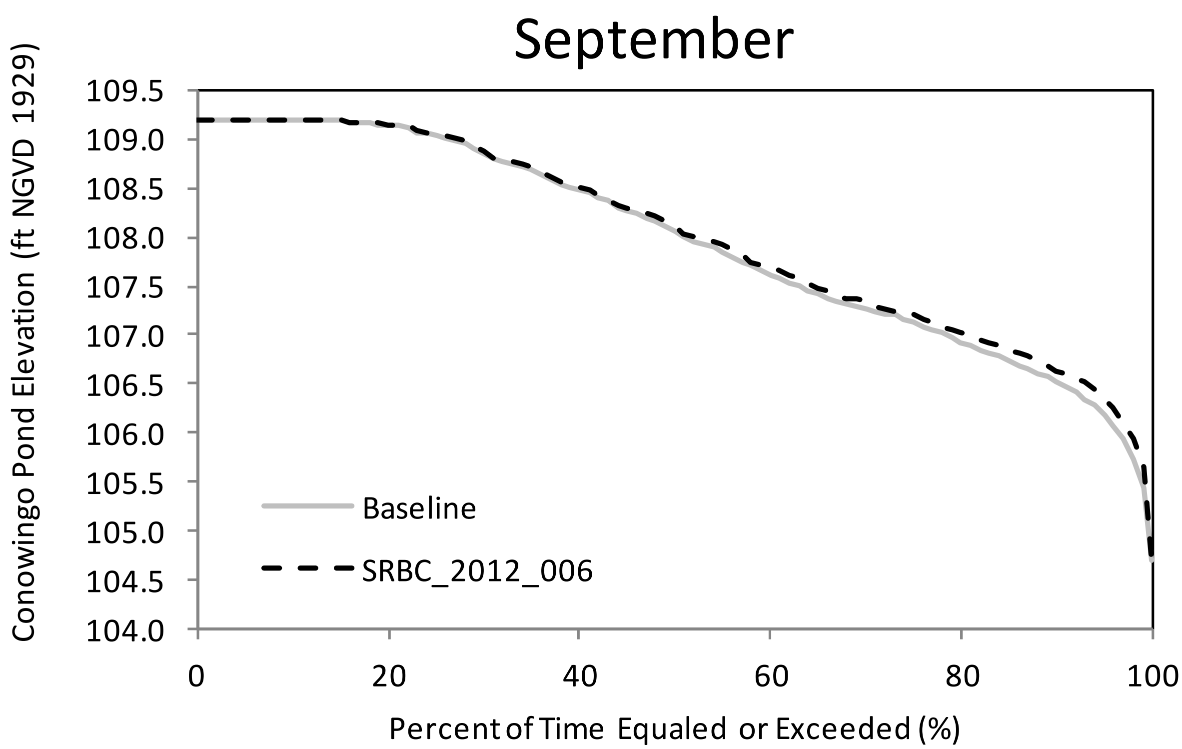

July
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

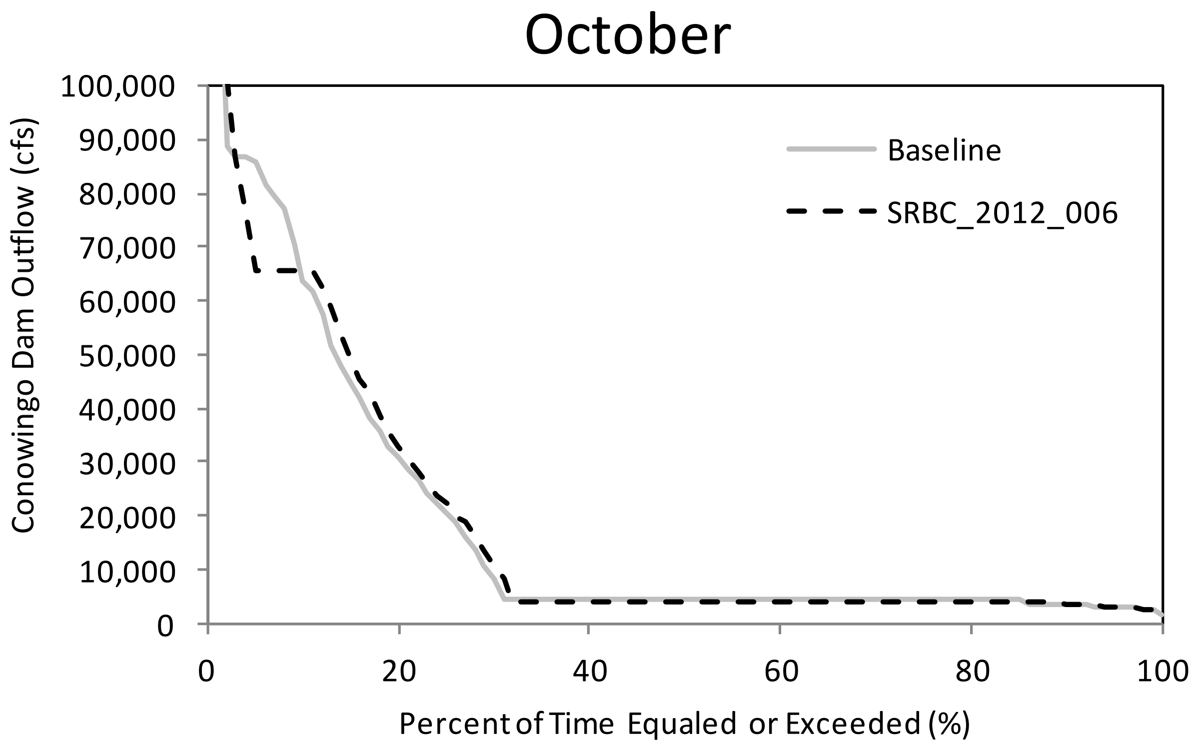

July
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

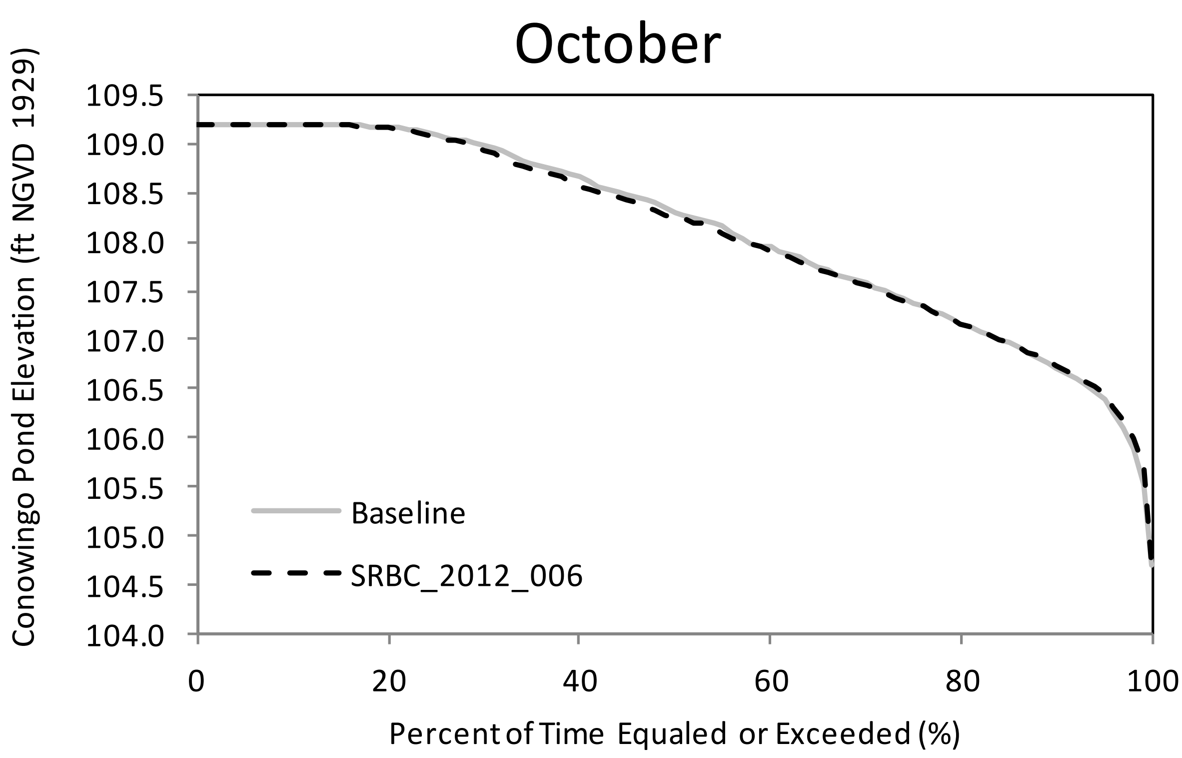

August
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

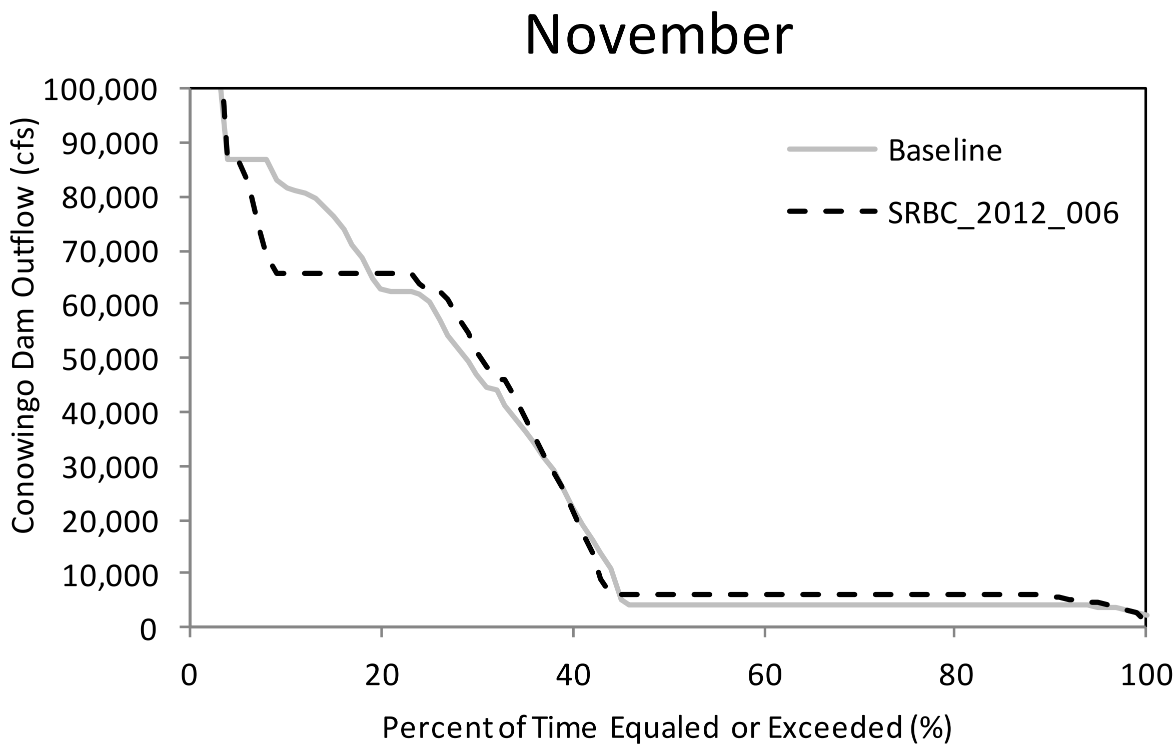

August
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

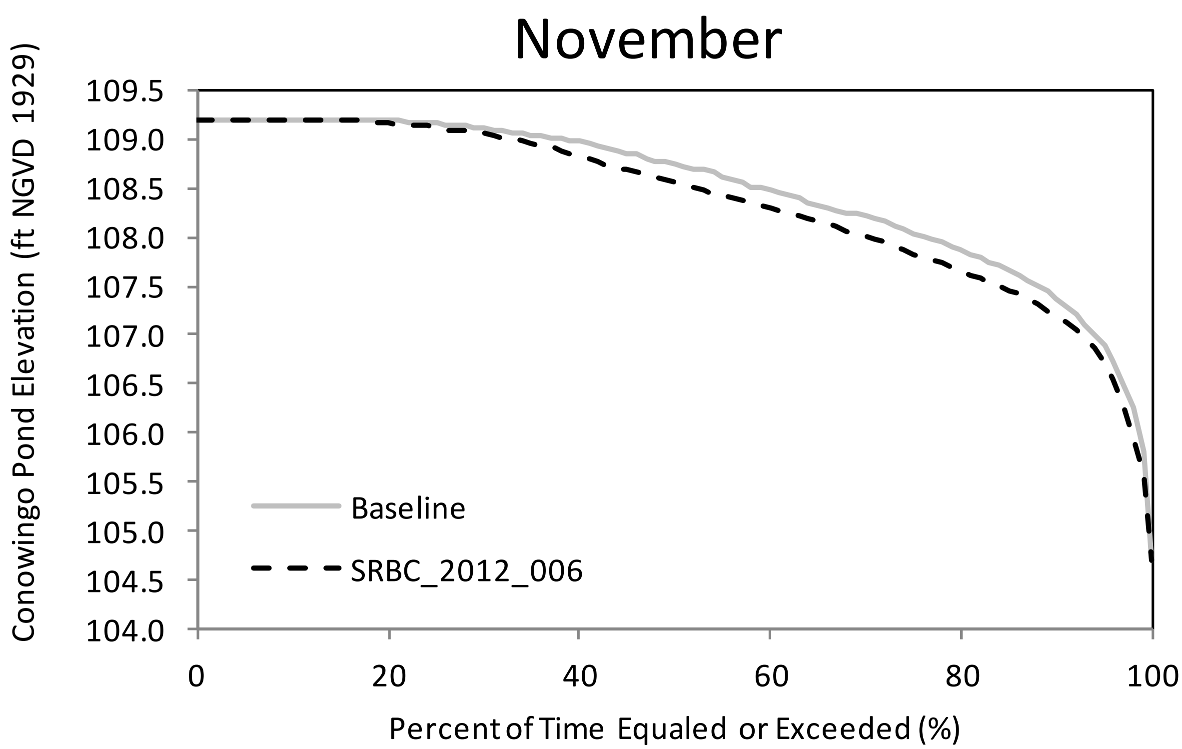

September
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Baseline
SRBC_2012_006
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

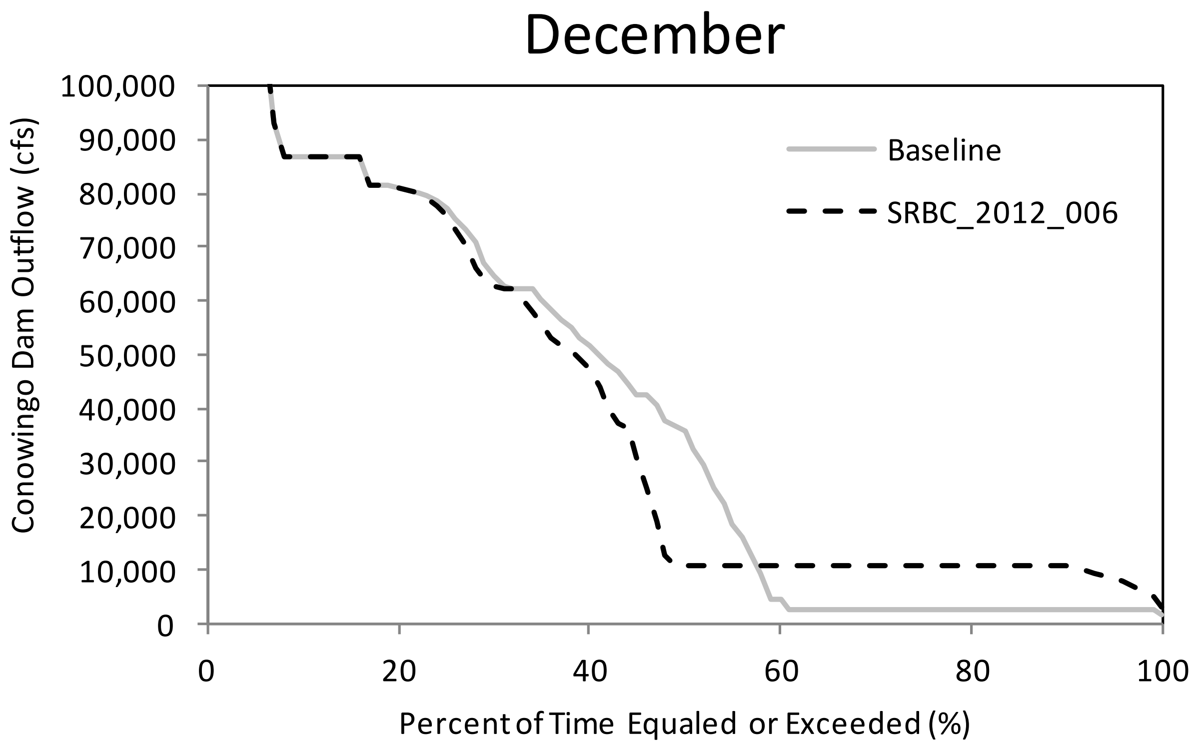

September
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Baseline
SRBC_2012_006
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

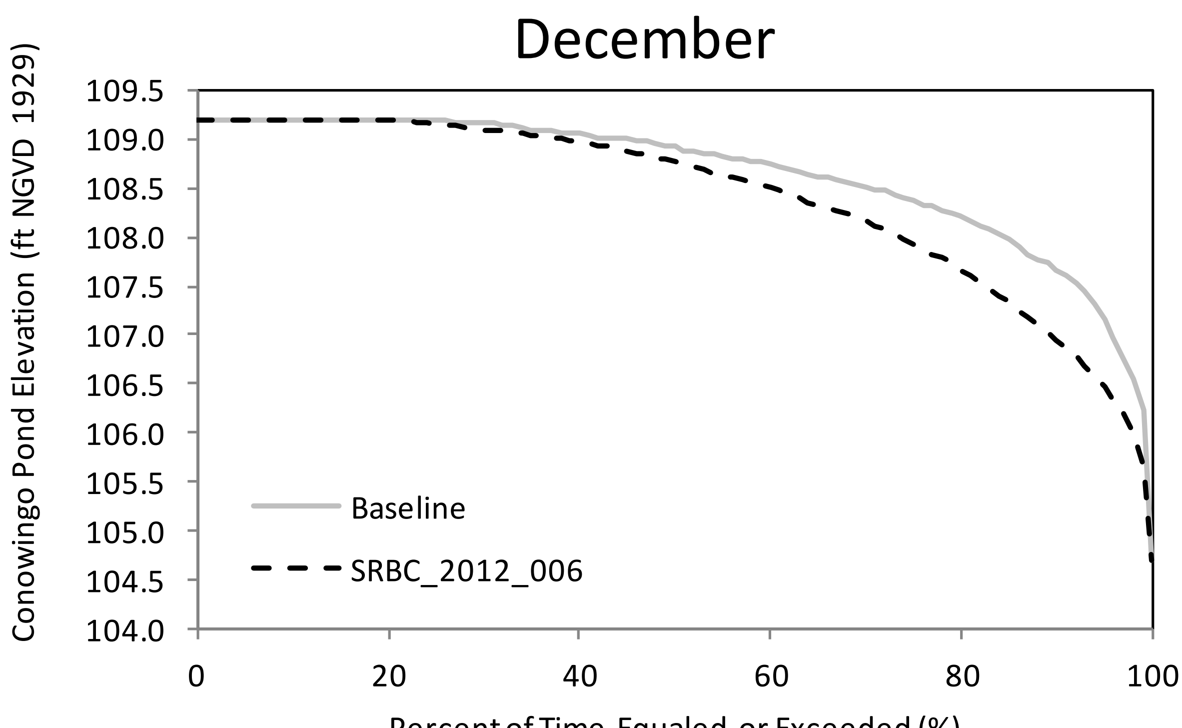

October
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
Baseline
SRBC_2012_006
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)


October
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
Baseline
SRBC_2012_006
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

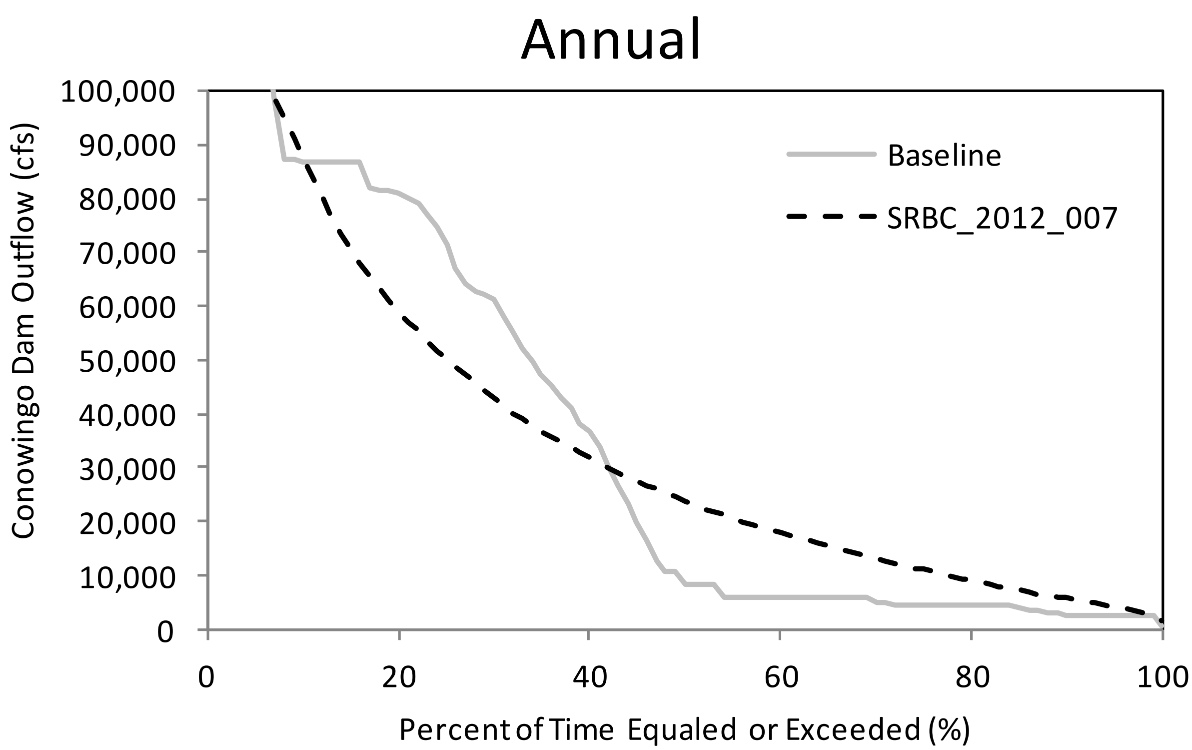

November
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

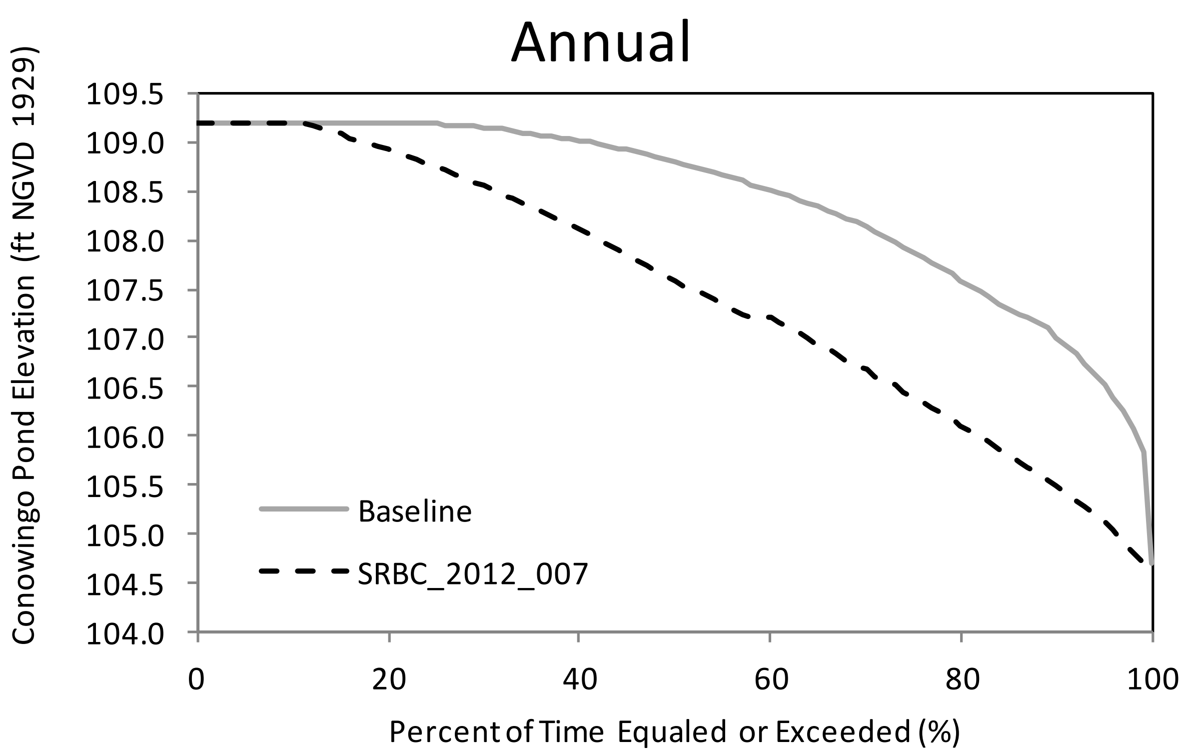

November
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

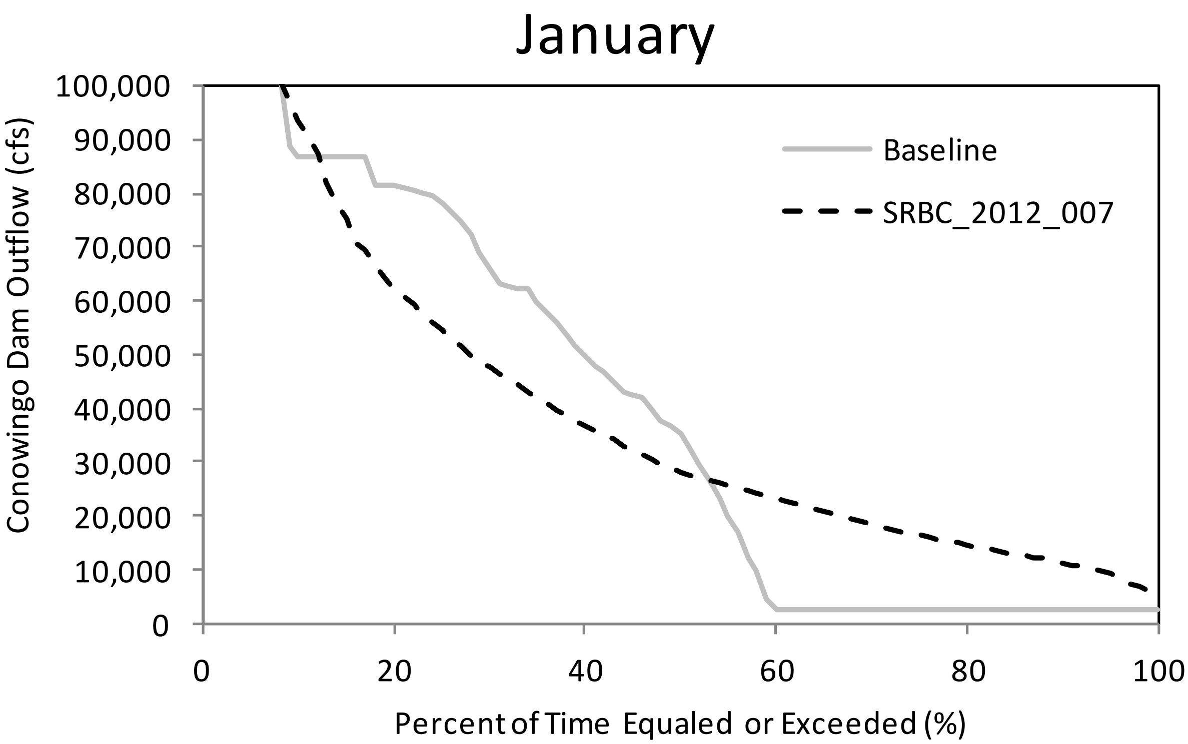

December
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

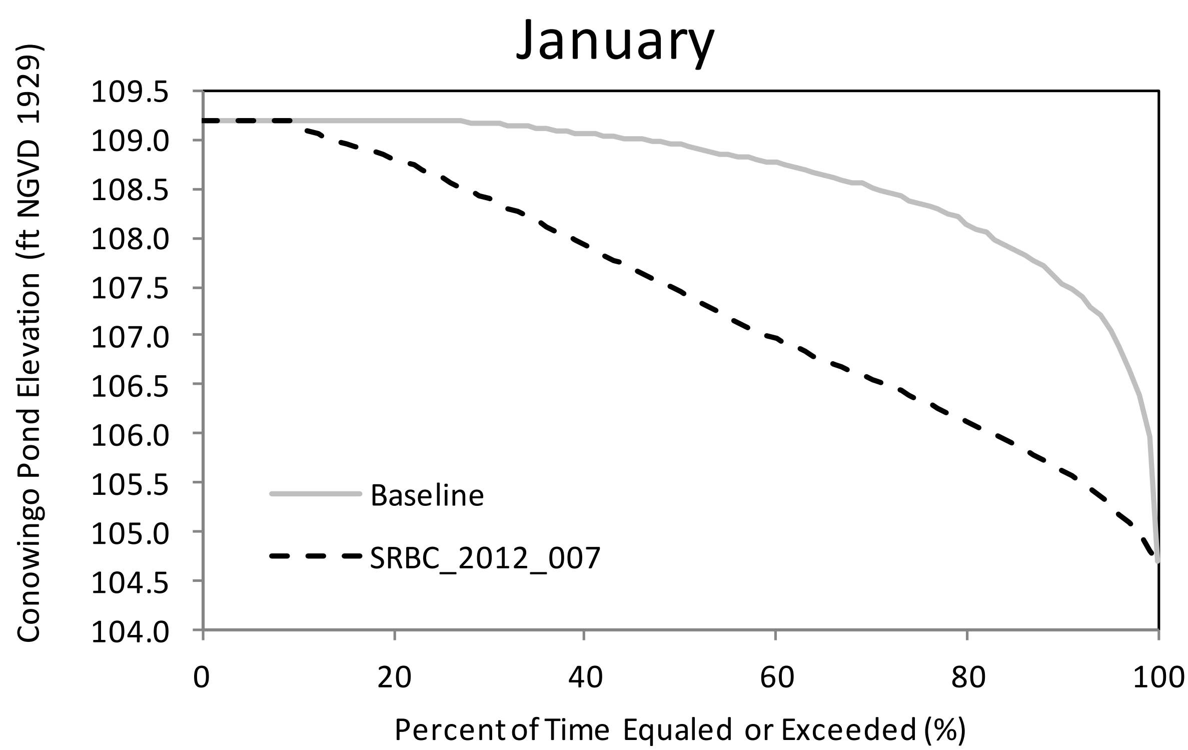

December
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_006

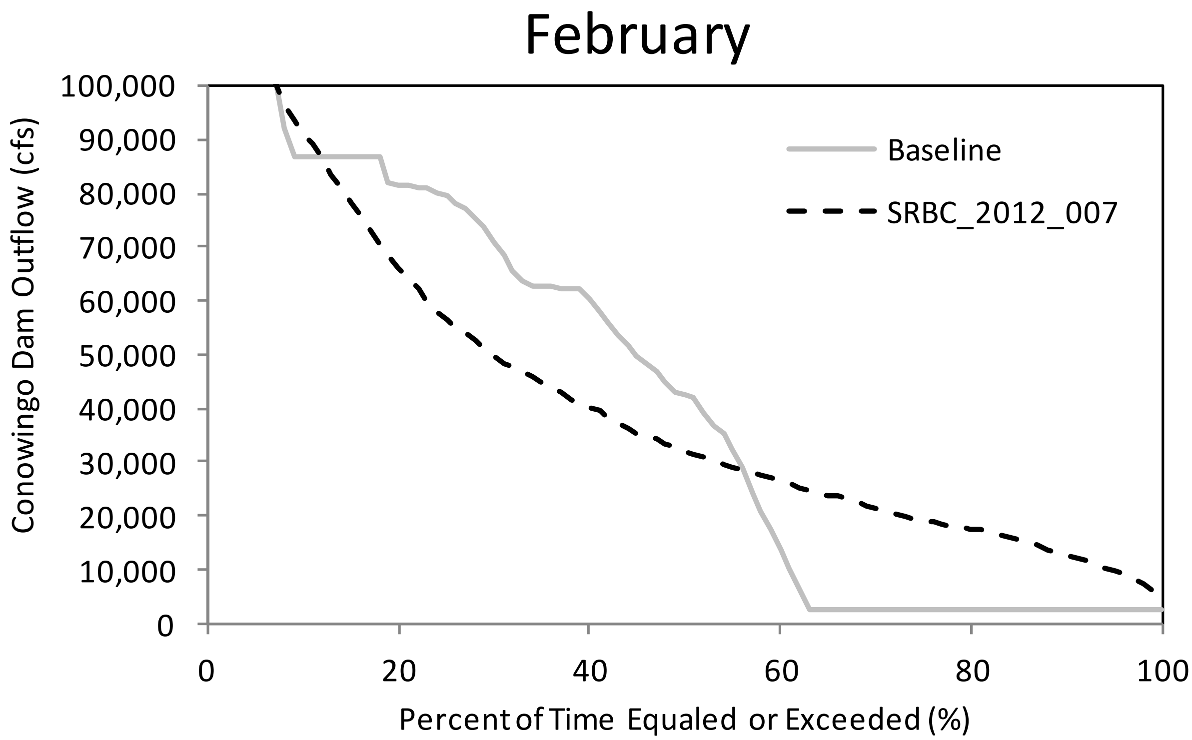
APPENDIX C: PRODUCTION RUN SRBC-007 ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW AND POND ELEVATION EXCEEDENCE CURVES

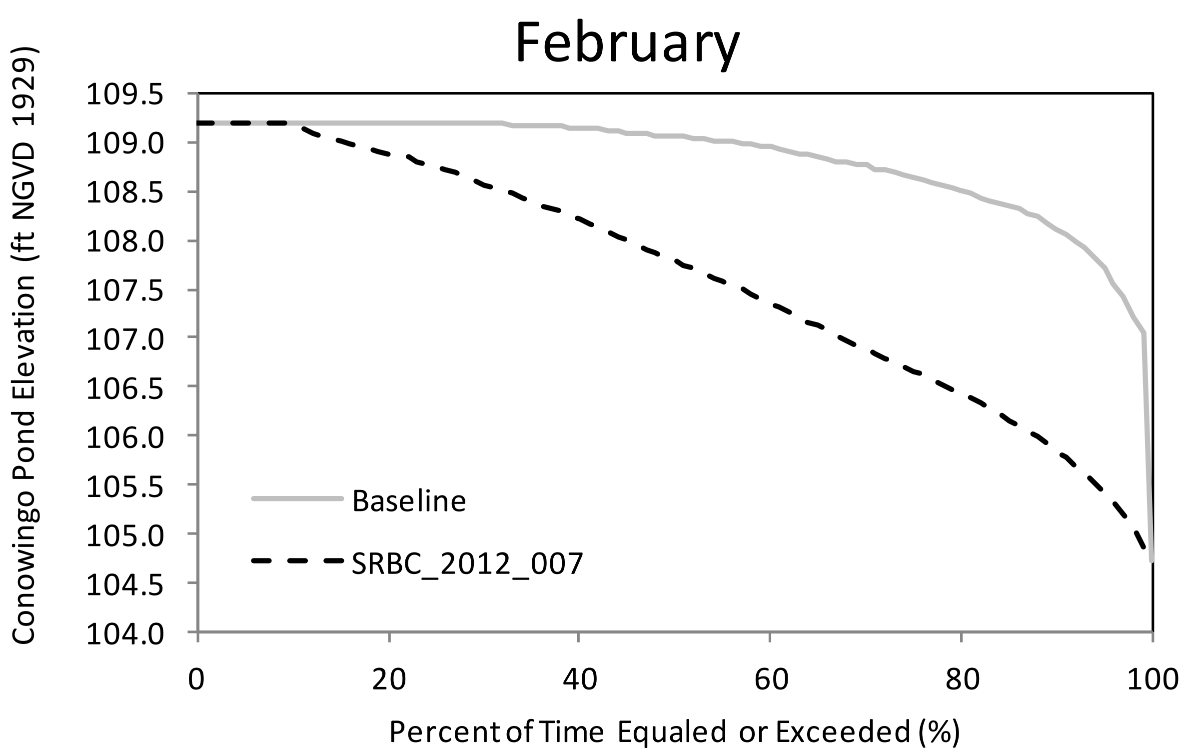

Annual
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

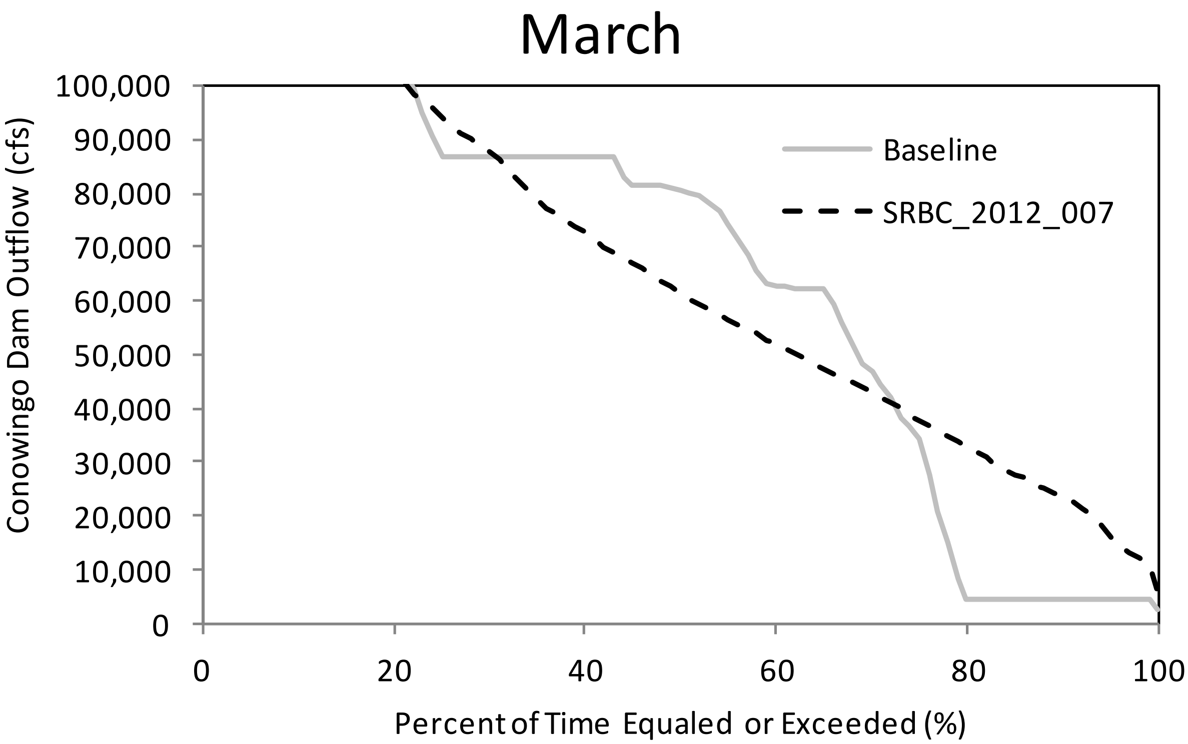

Annual
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

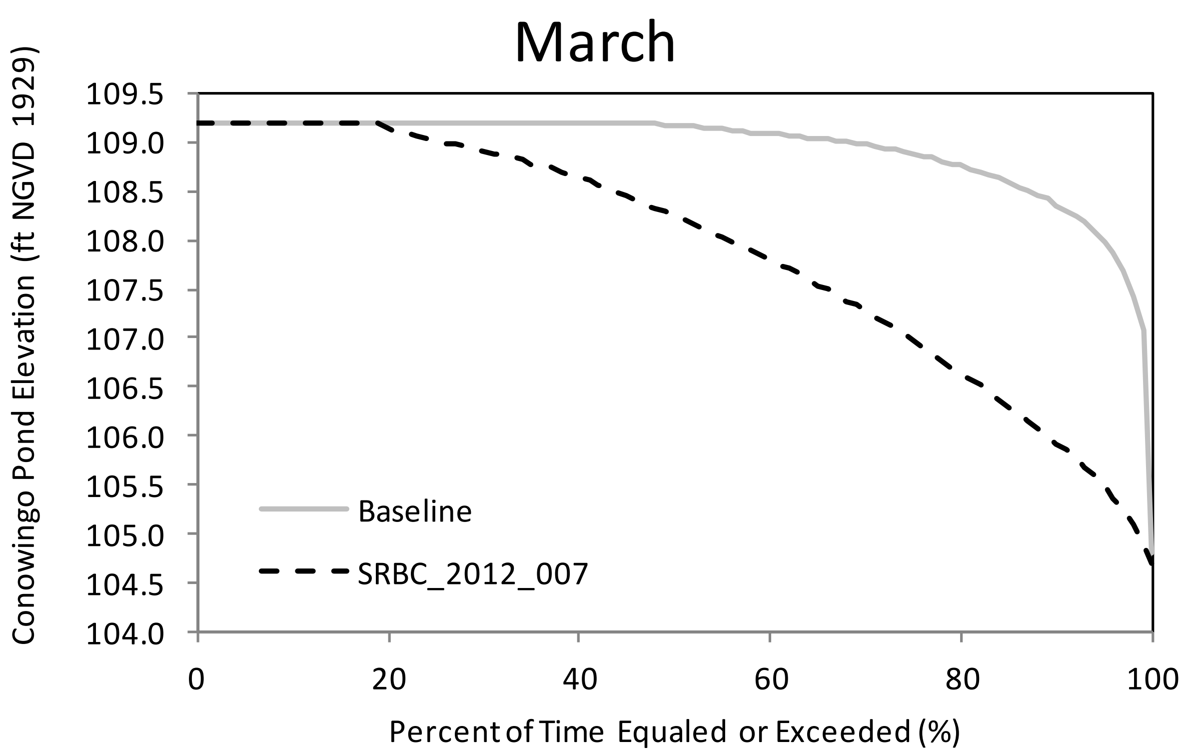

January
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

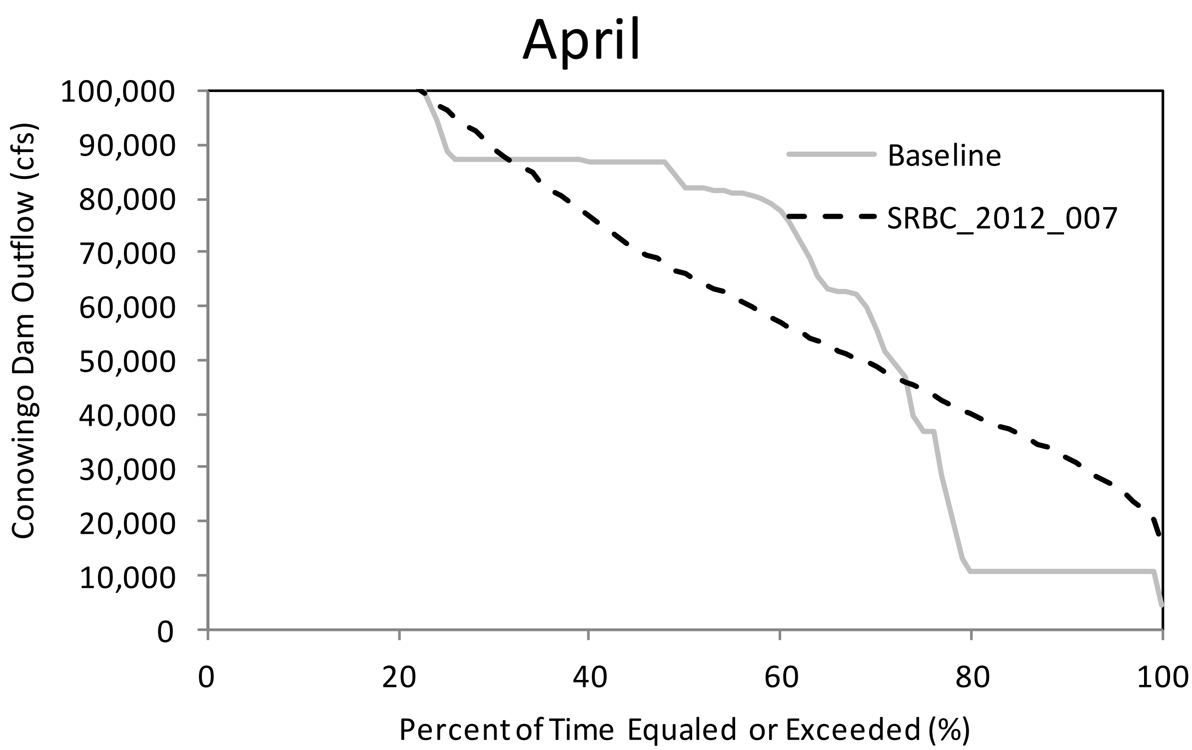

January
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

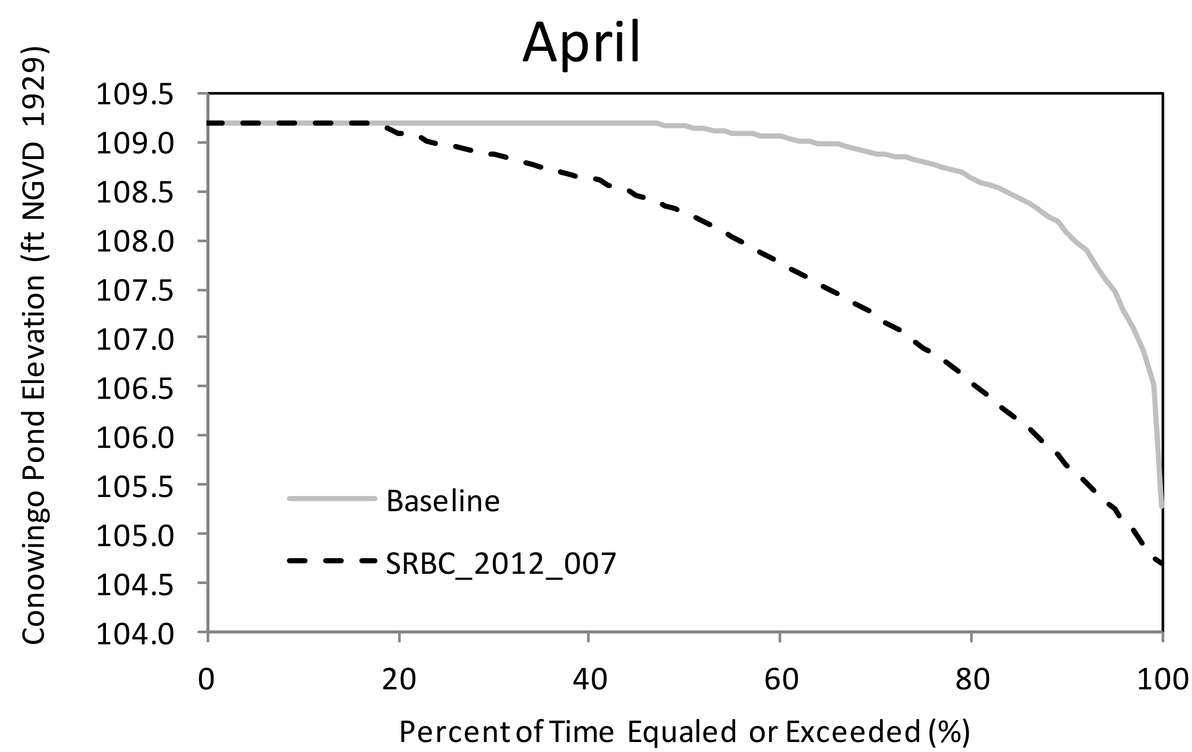

February
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
Baseline
SRBC_2012_007
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

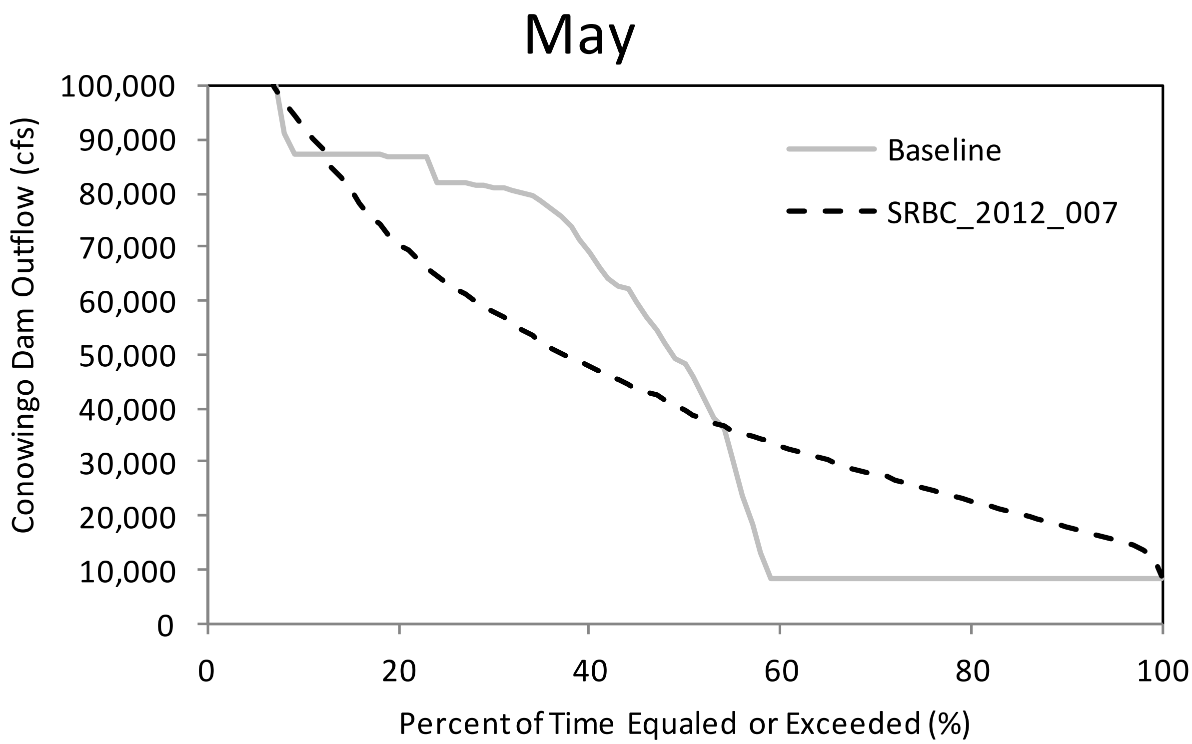

February
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
Baseline
SRBC_2012_007
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

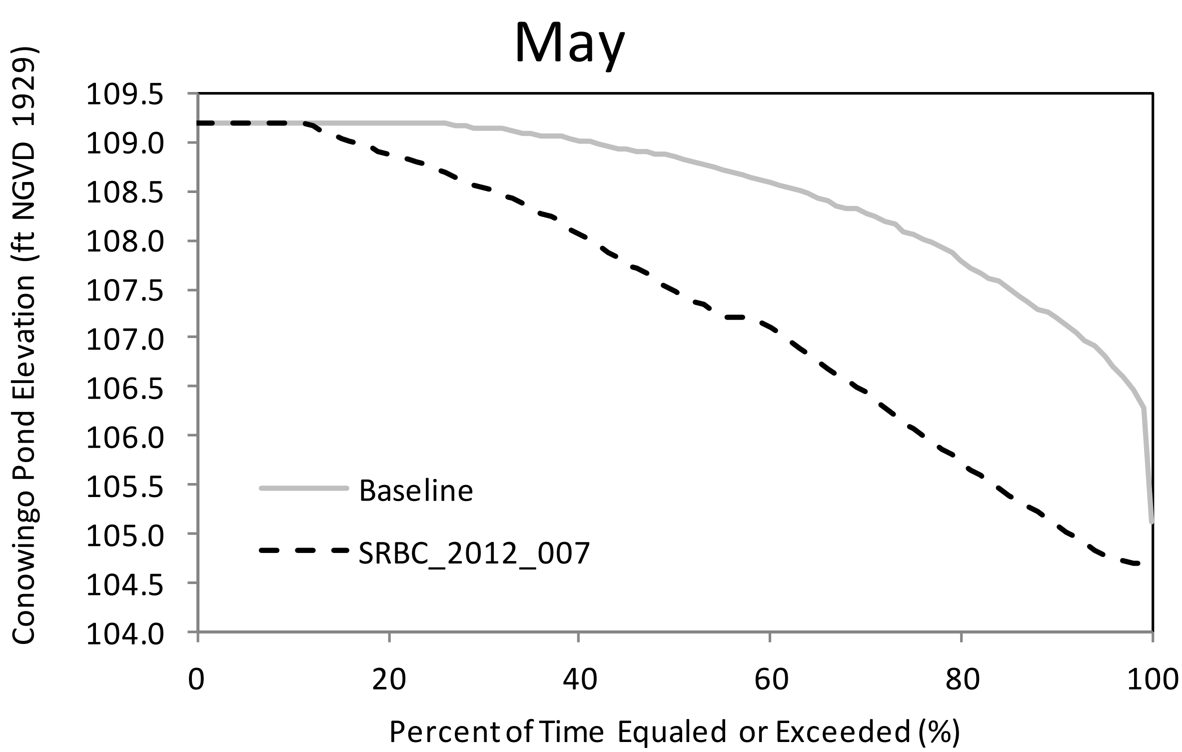

March
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

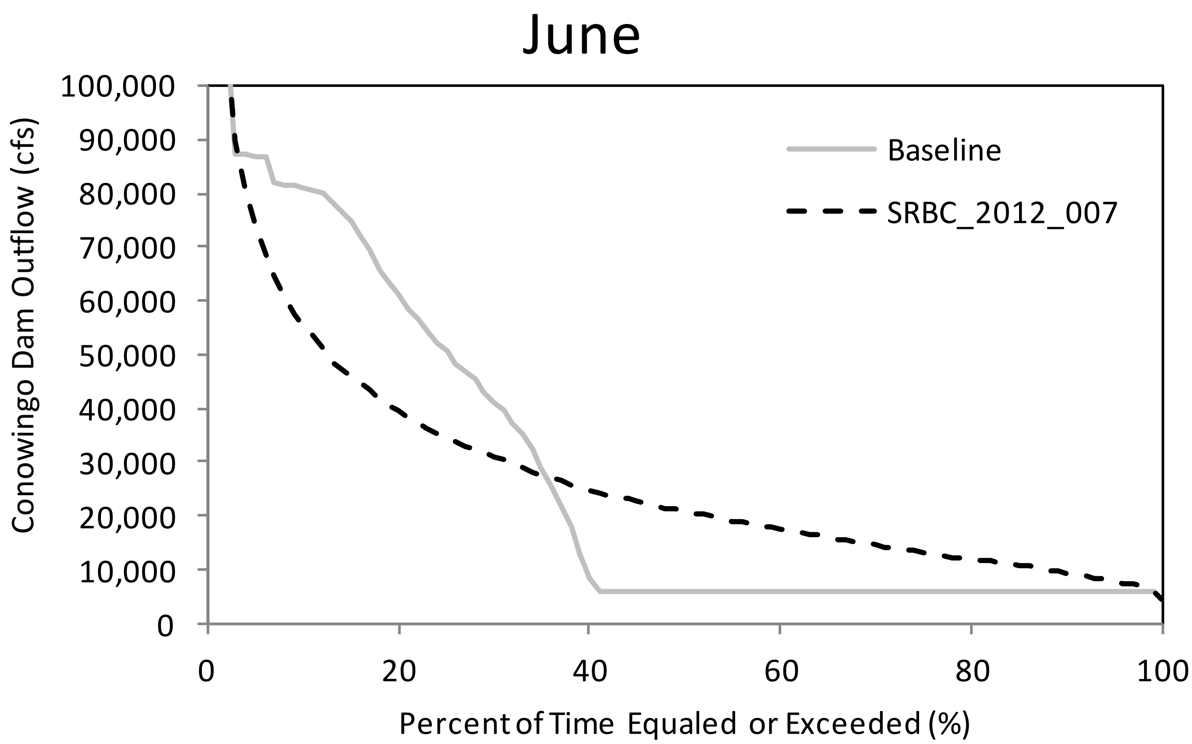

March
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

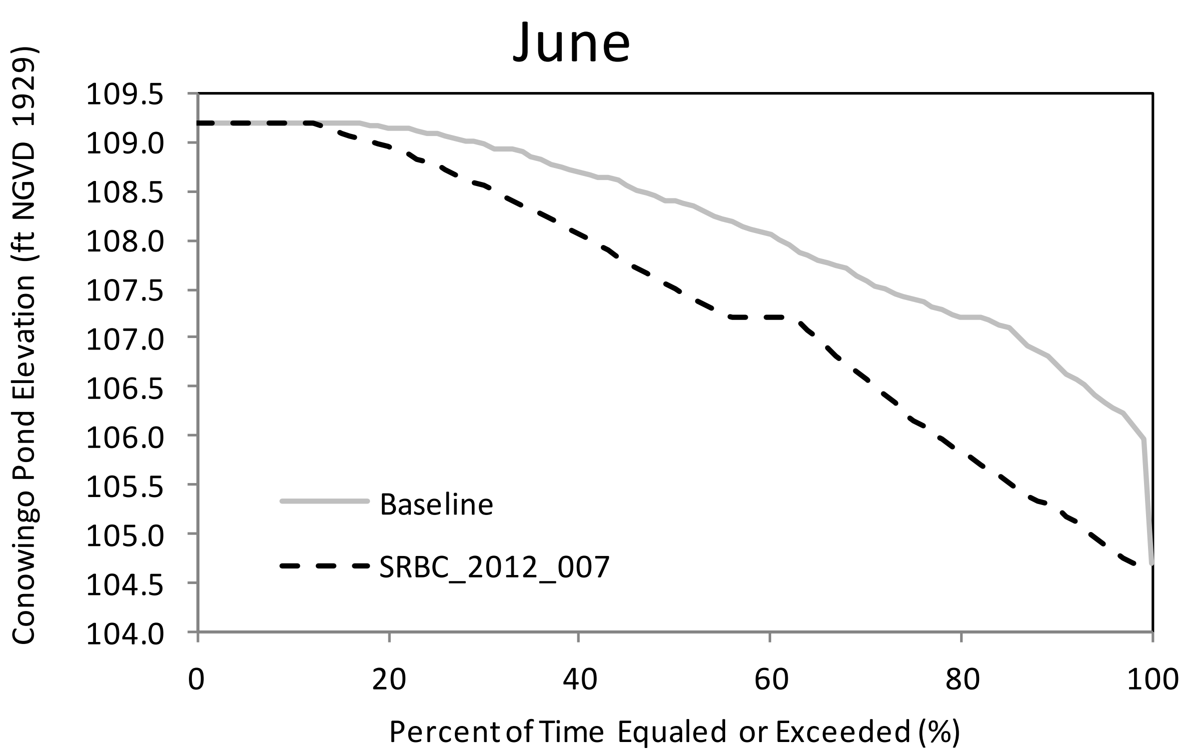

April
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

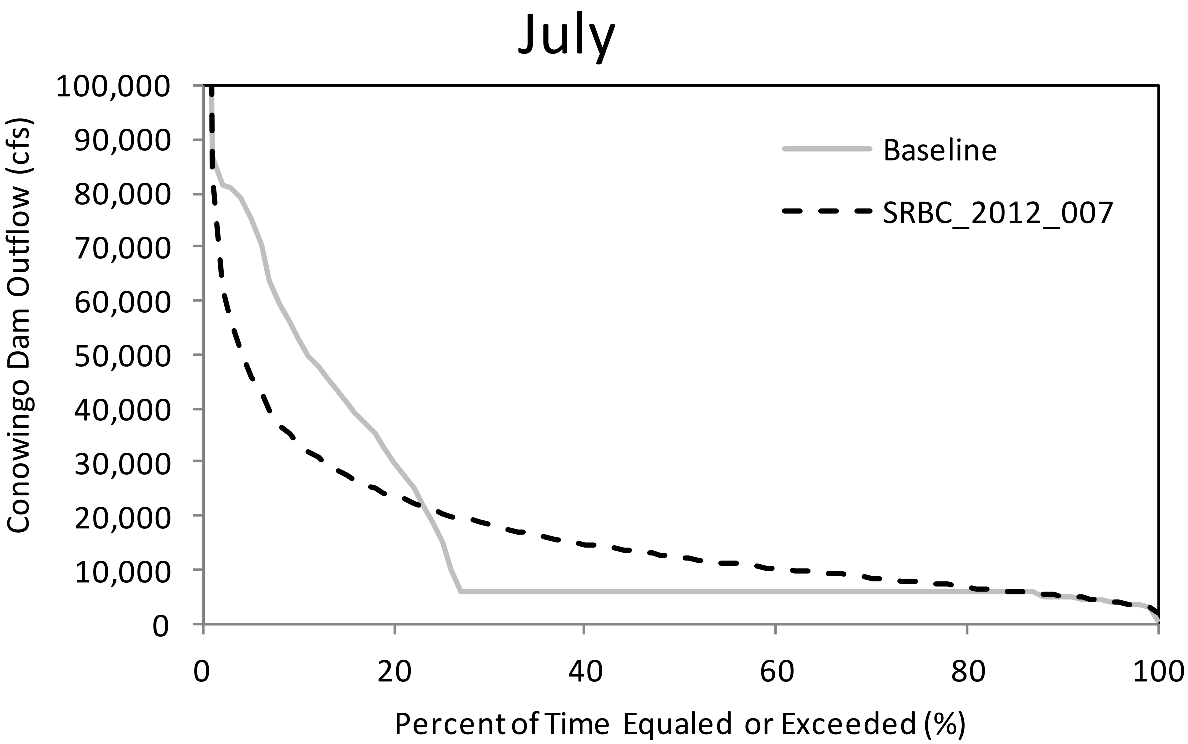

April
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

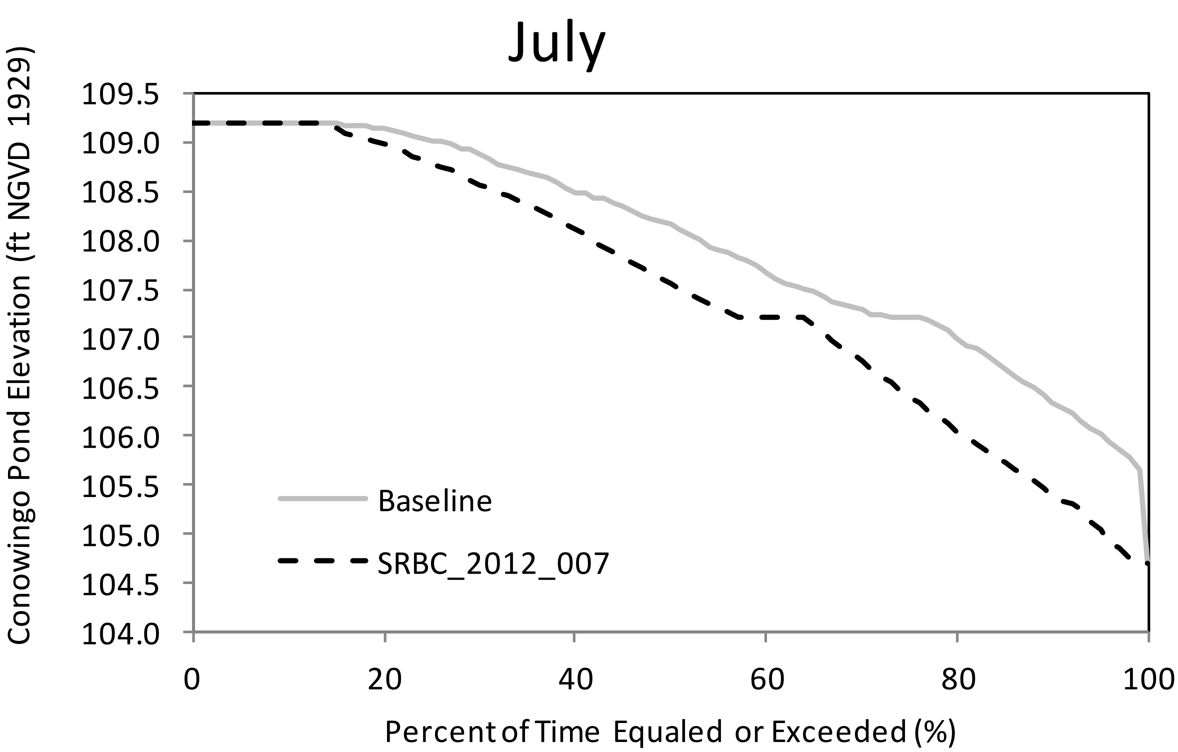

May
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

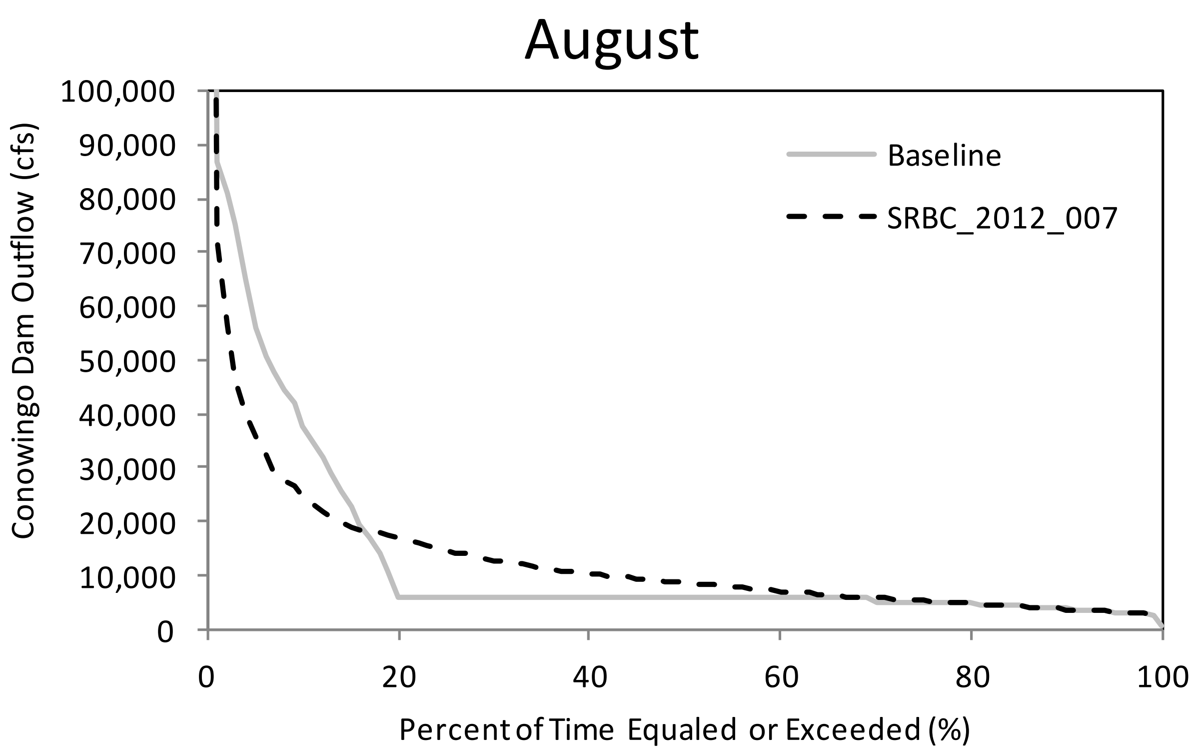

May
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

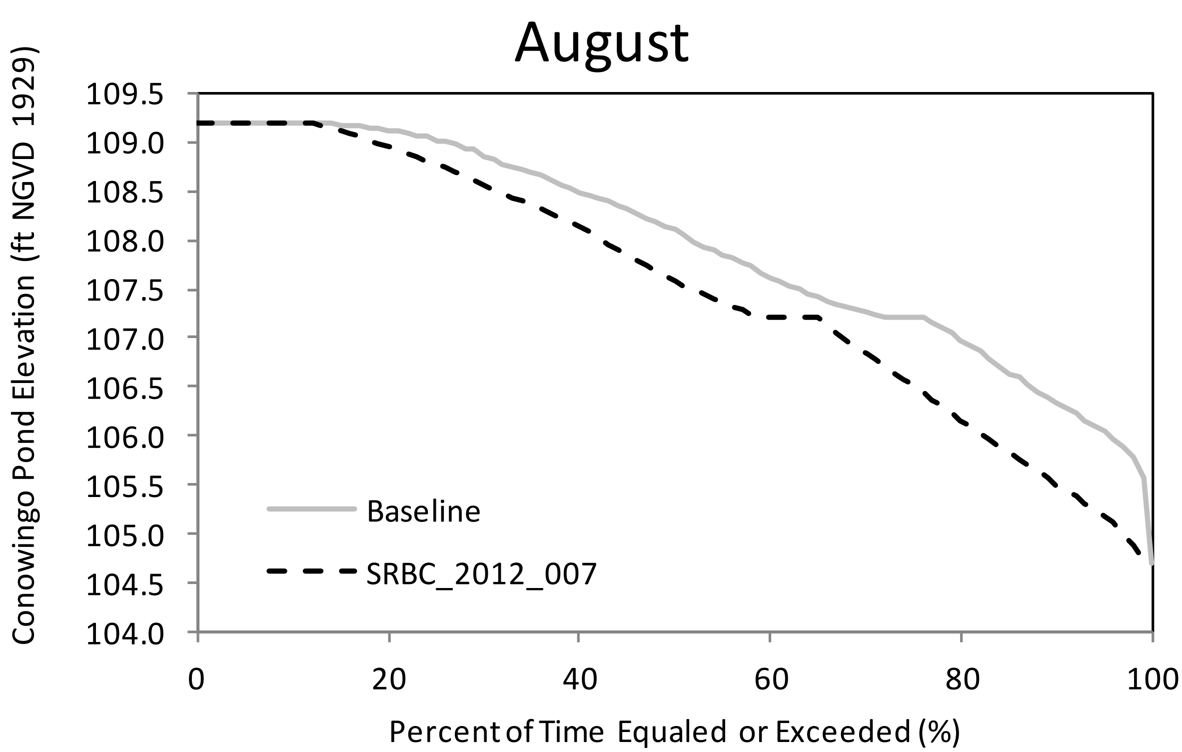

June
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

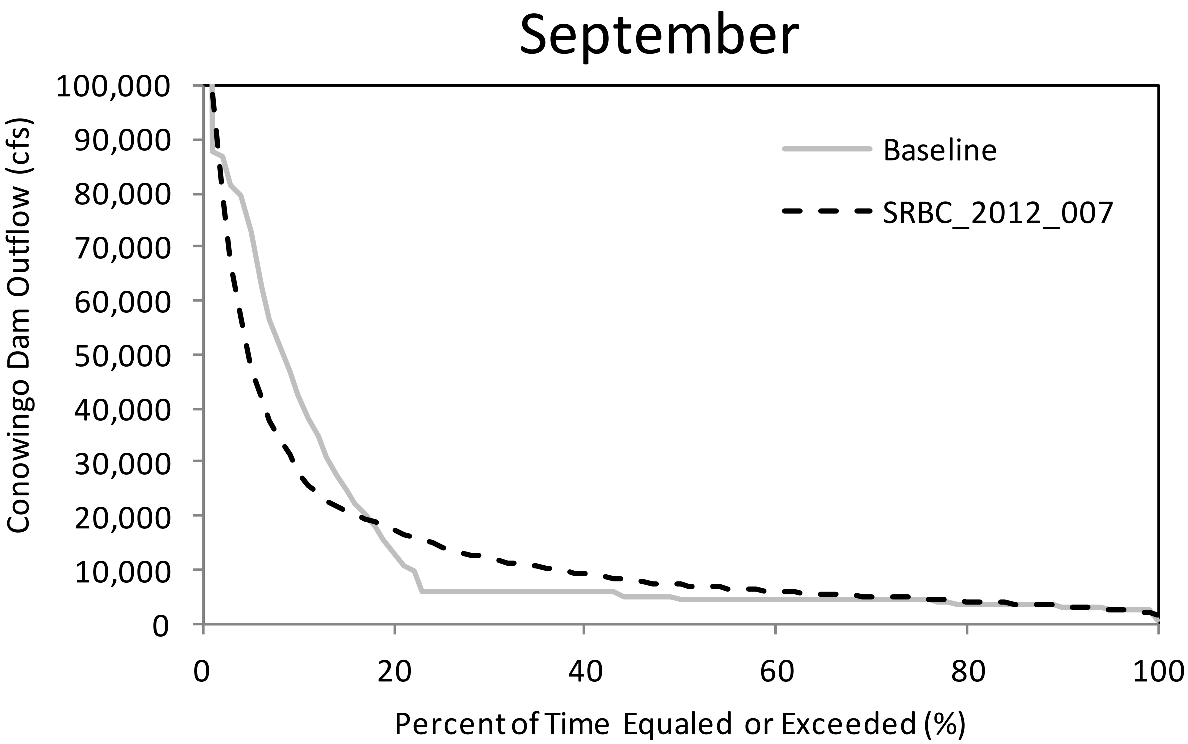

June
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

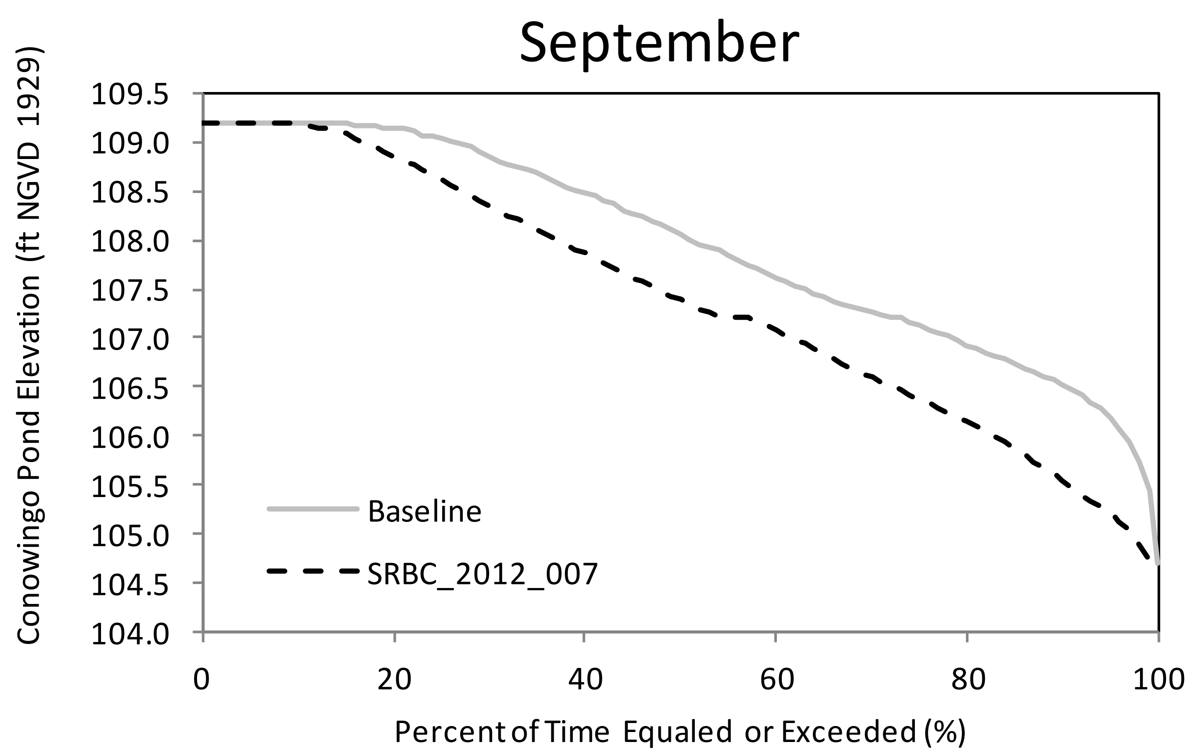

July
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

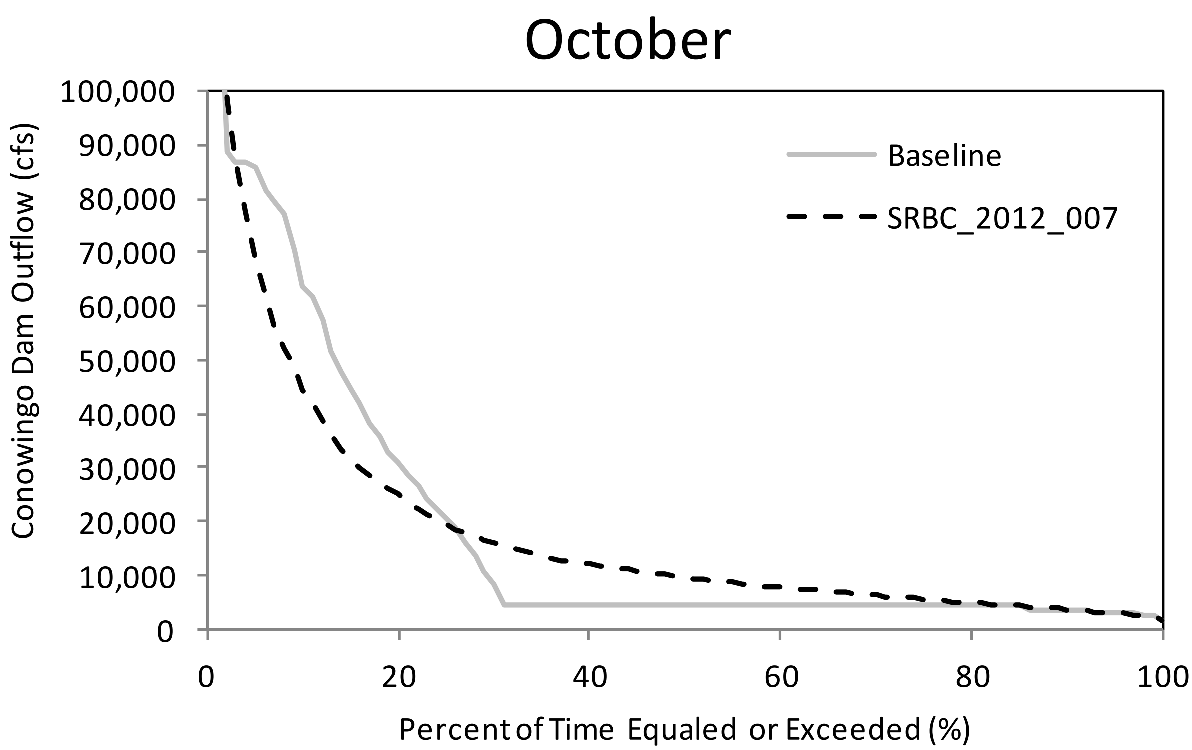

July
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007


August
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

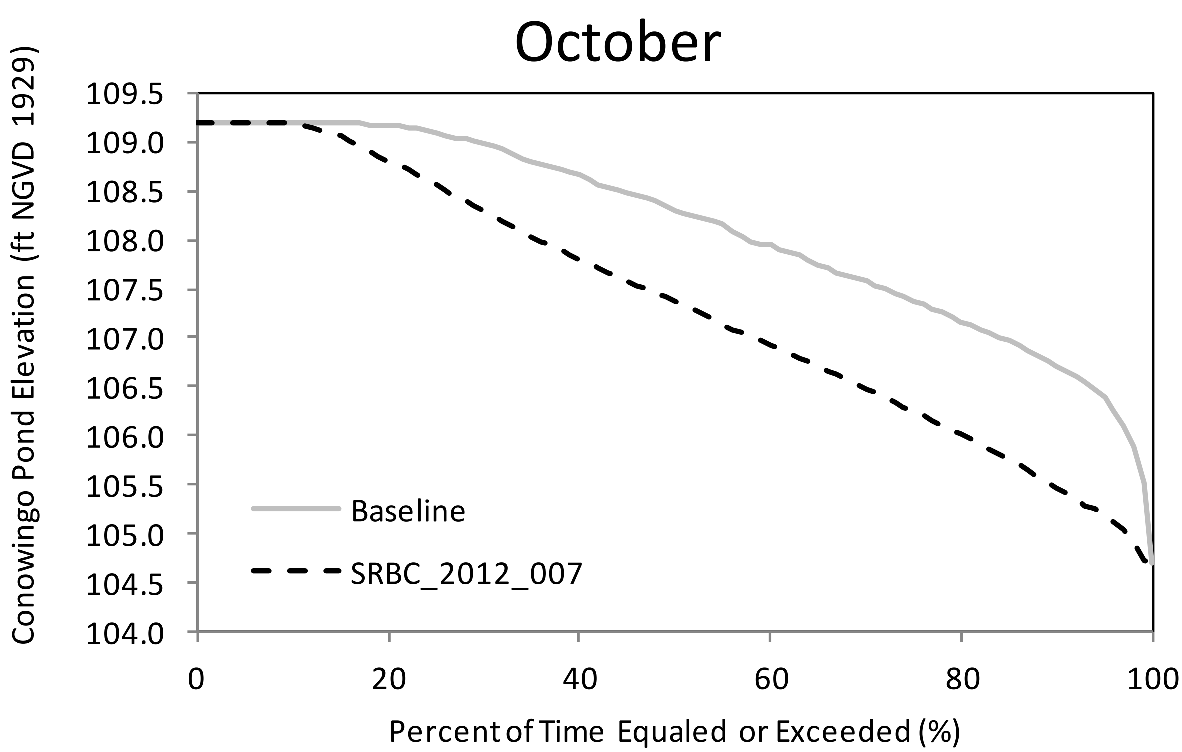

August
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007


September
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

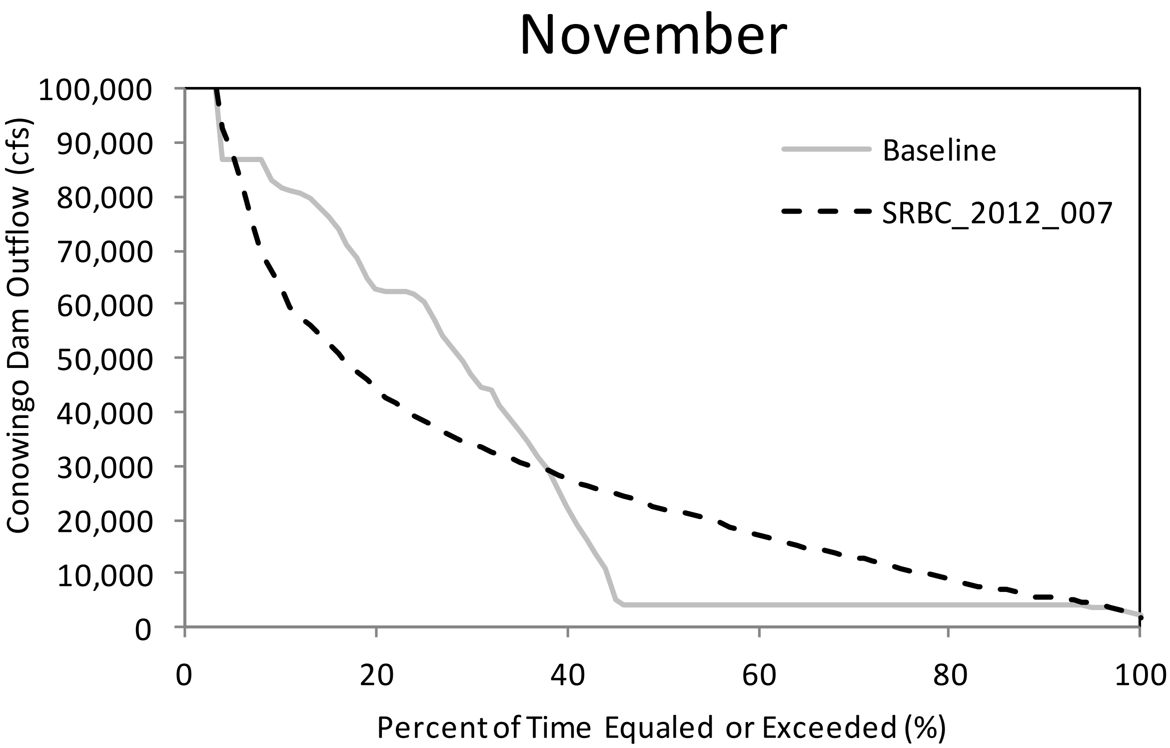

September
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

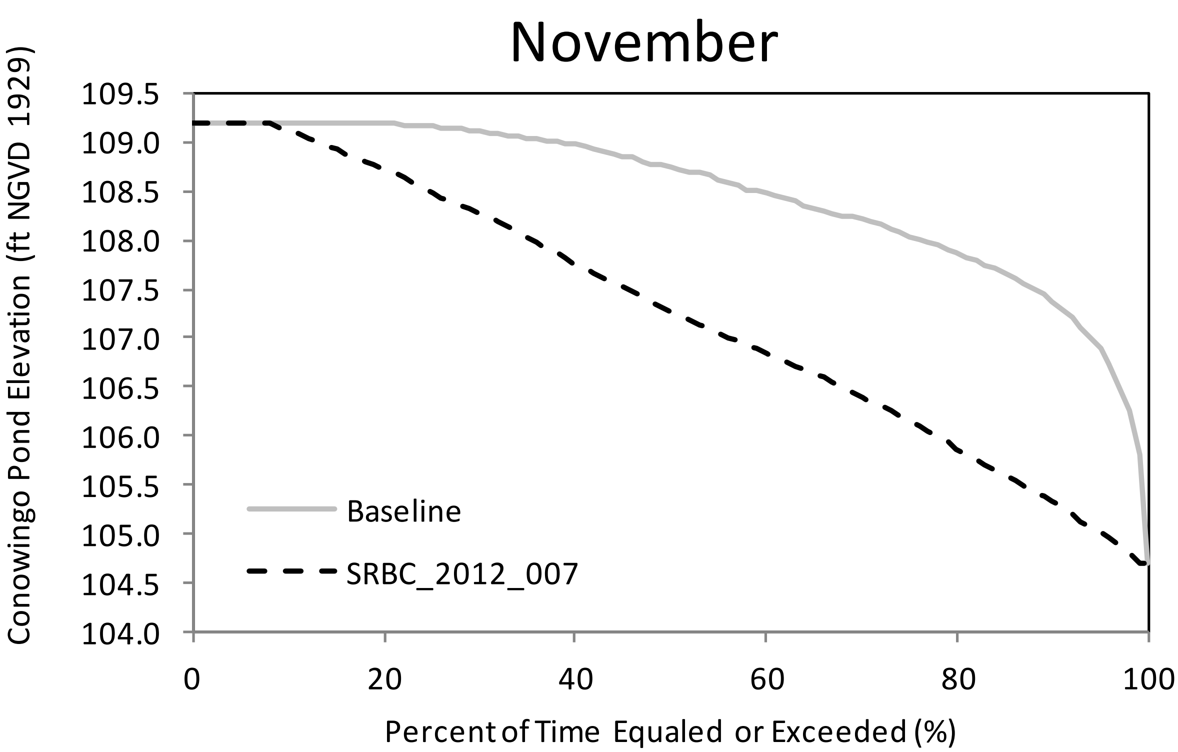


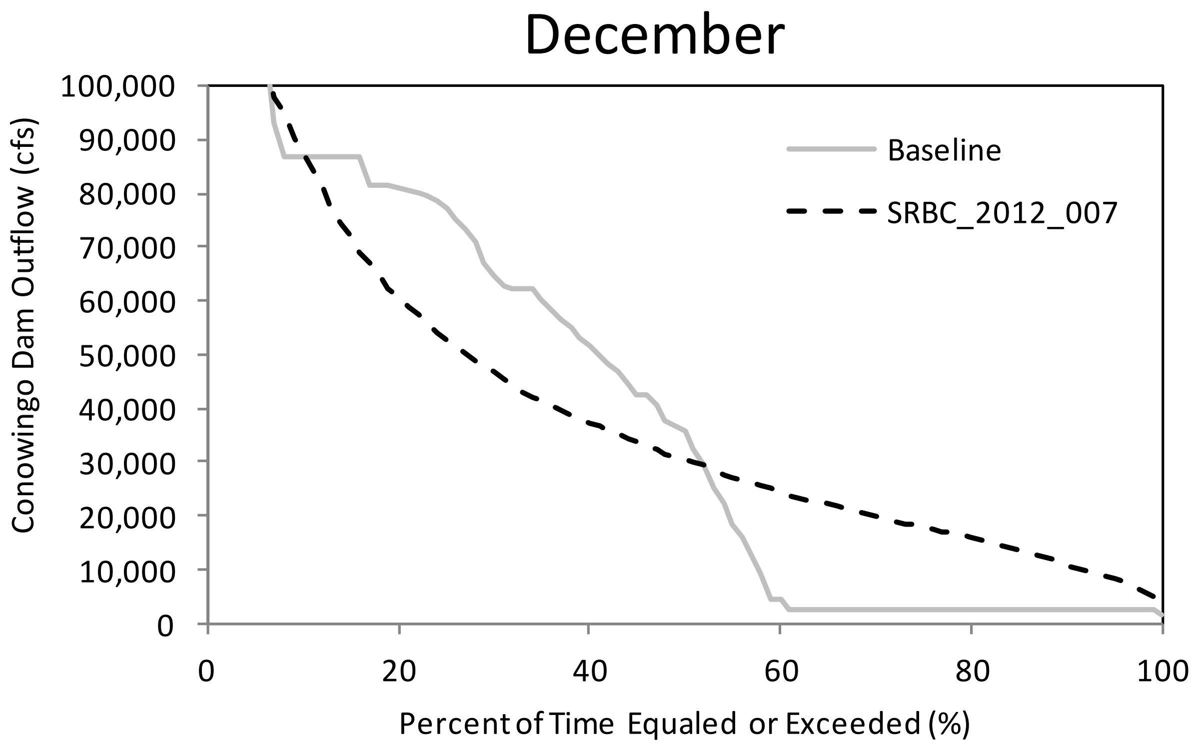
October
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

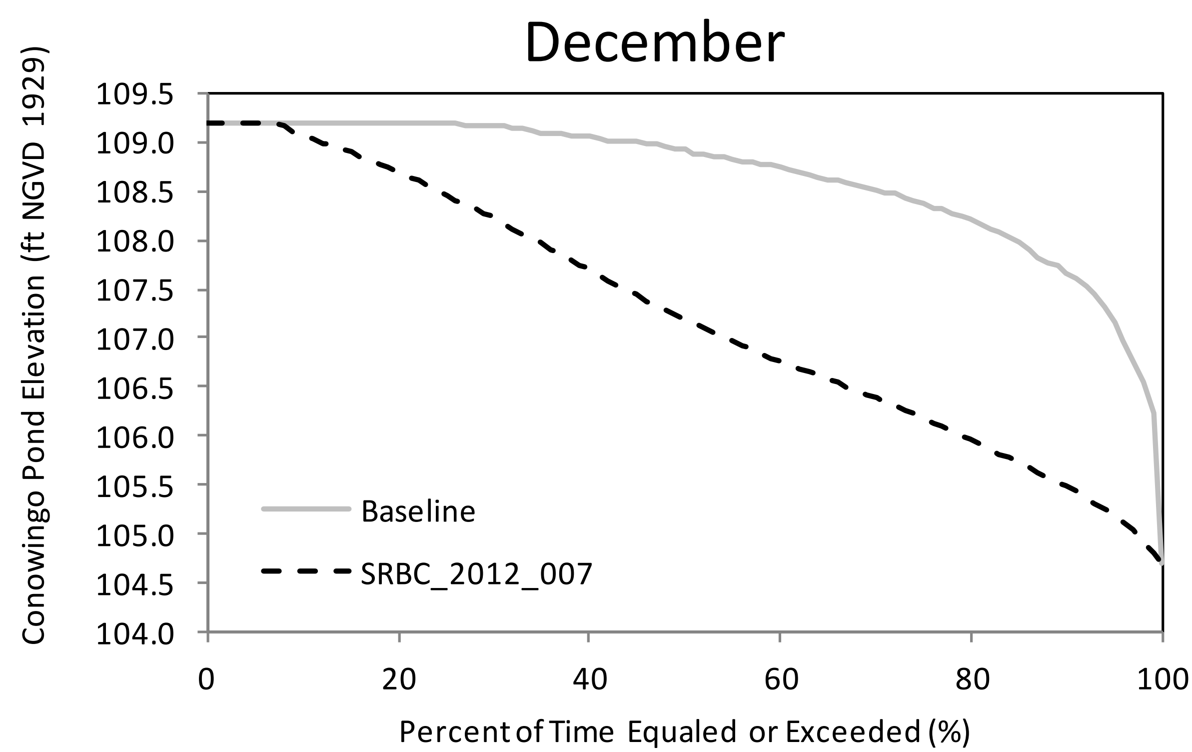


October
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

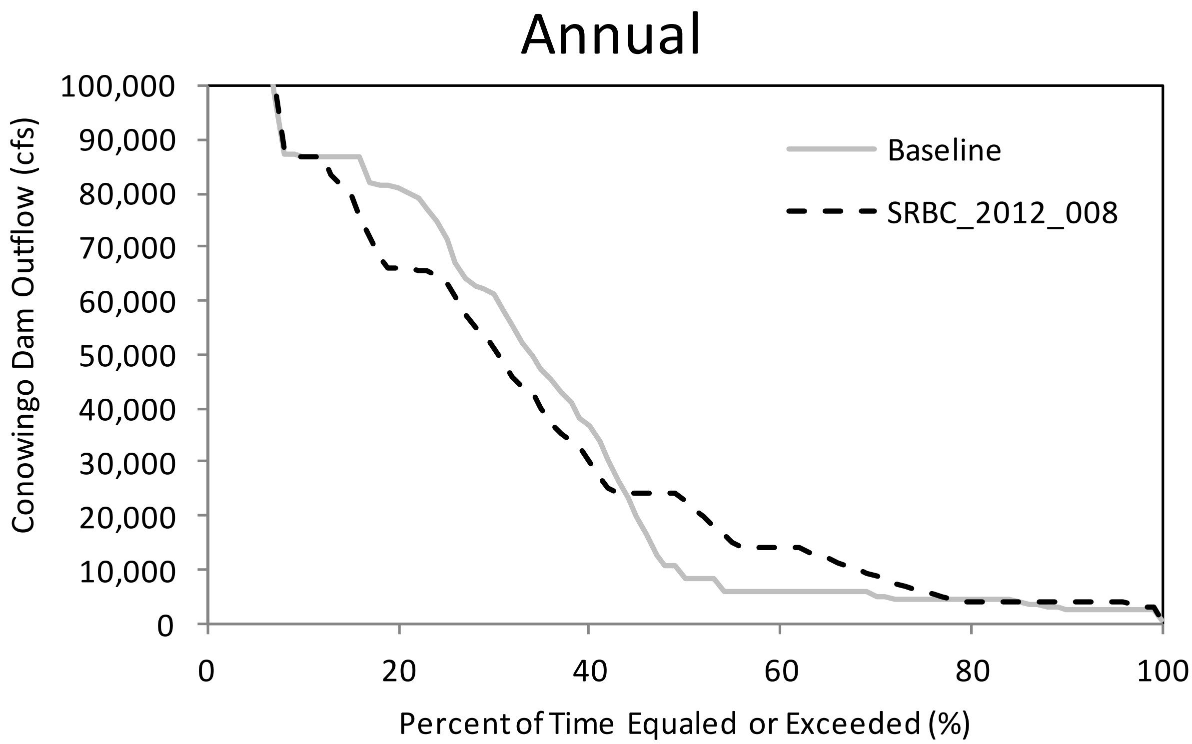

November
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

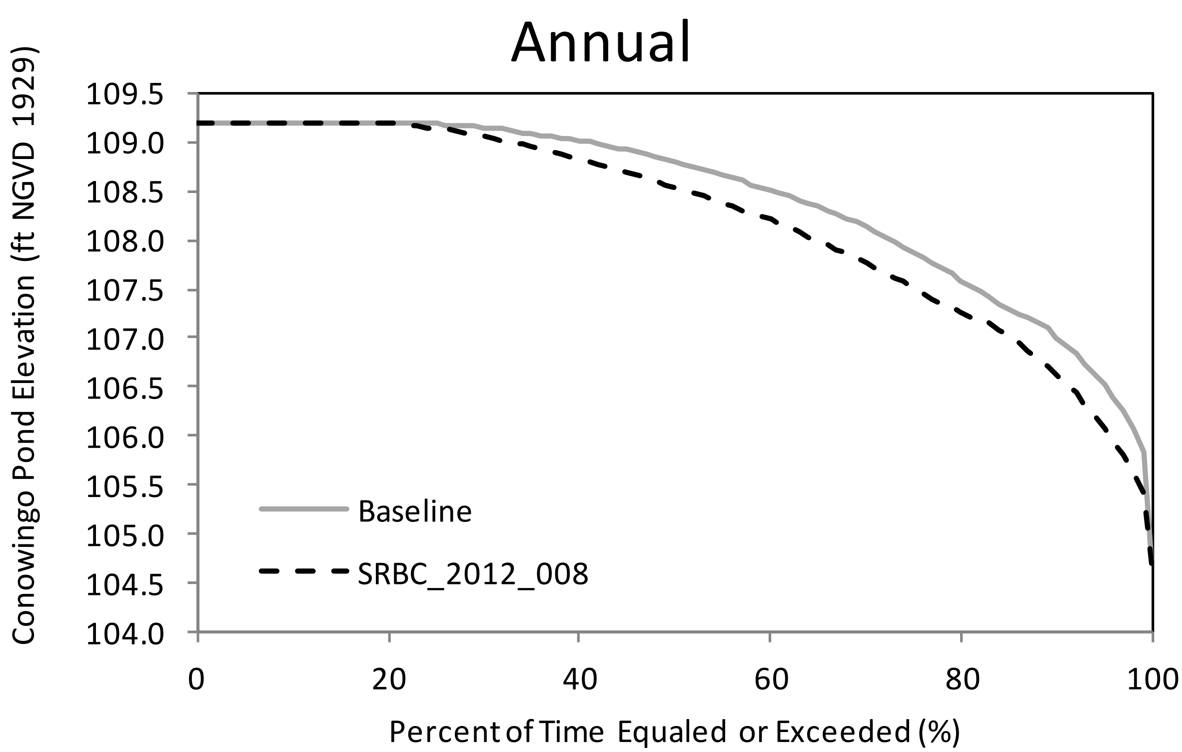

November
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

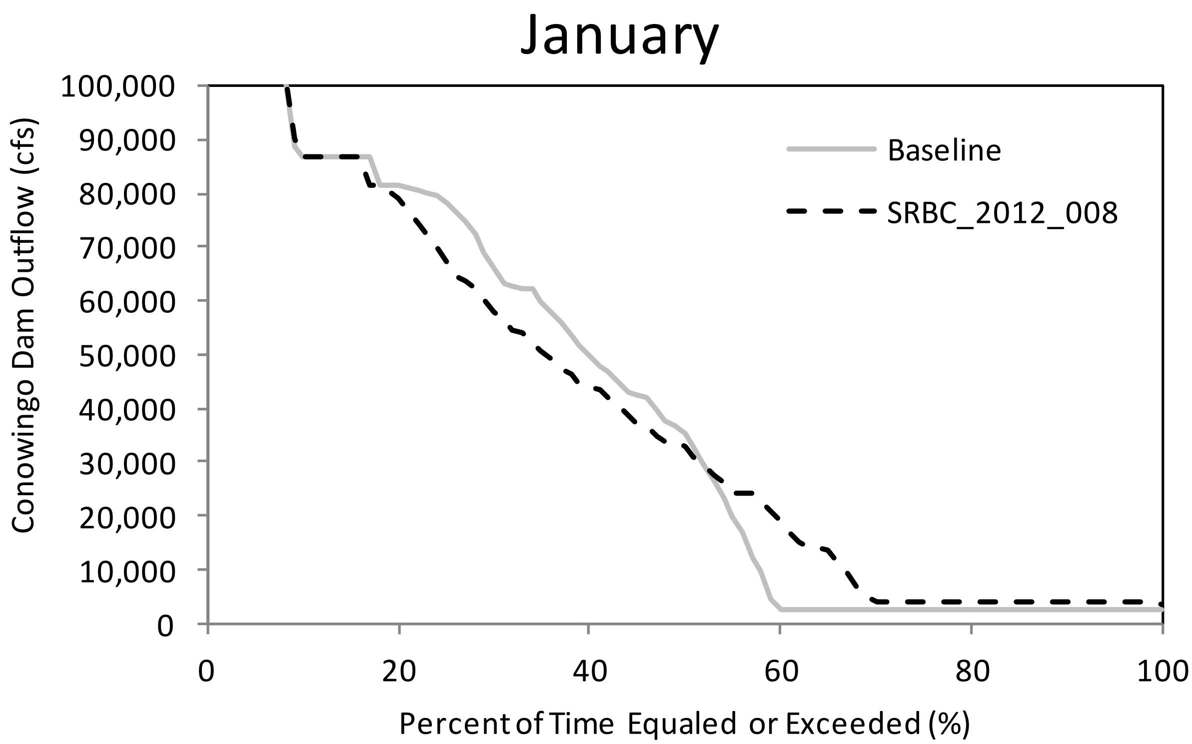

December
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

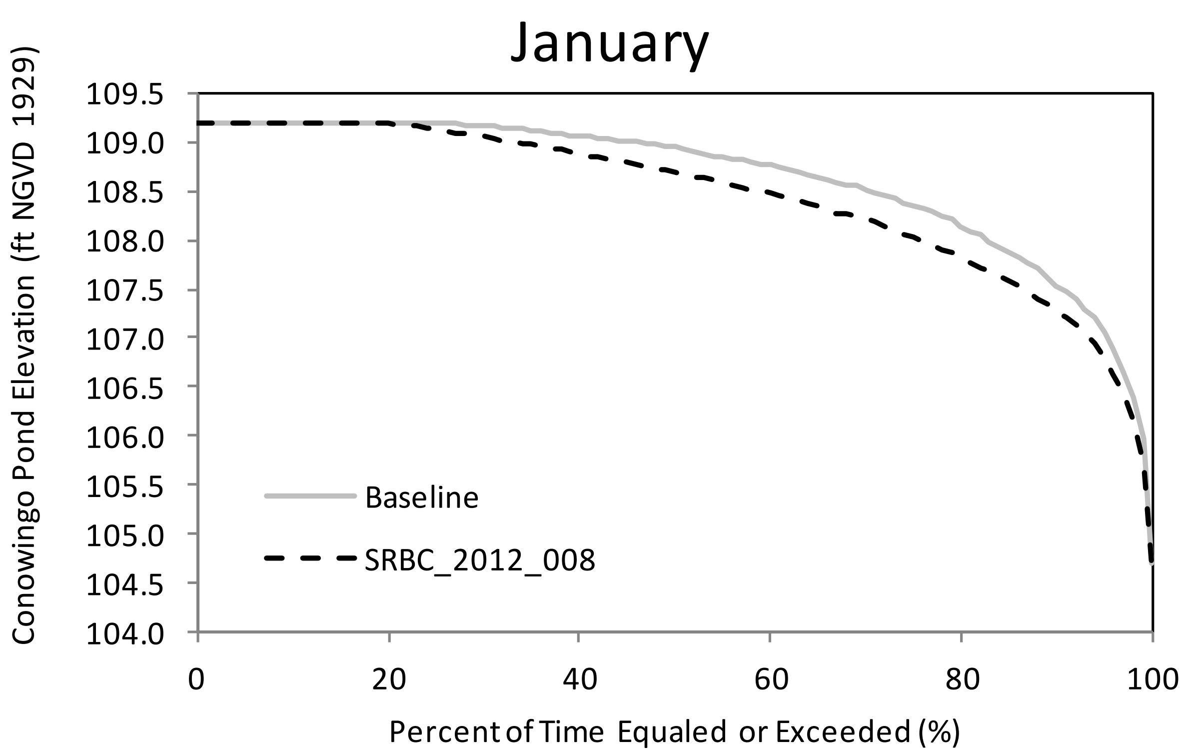

December
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_007

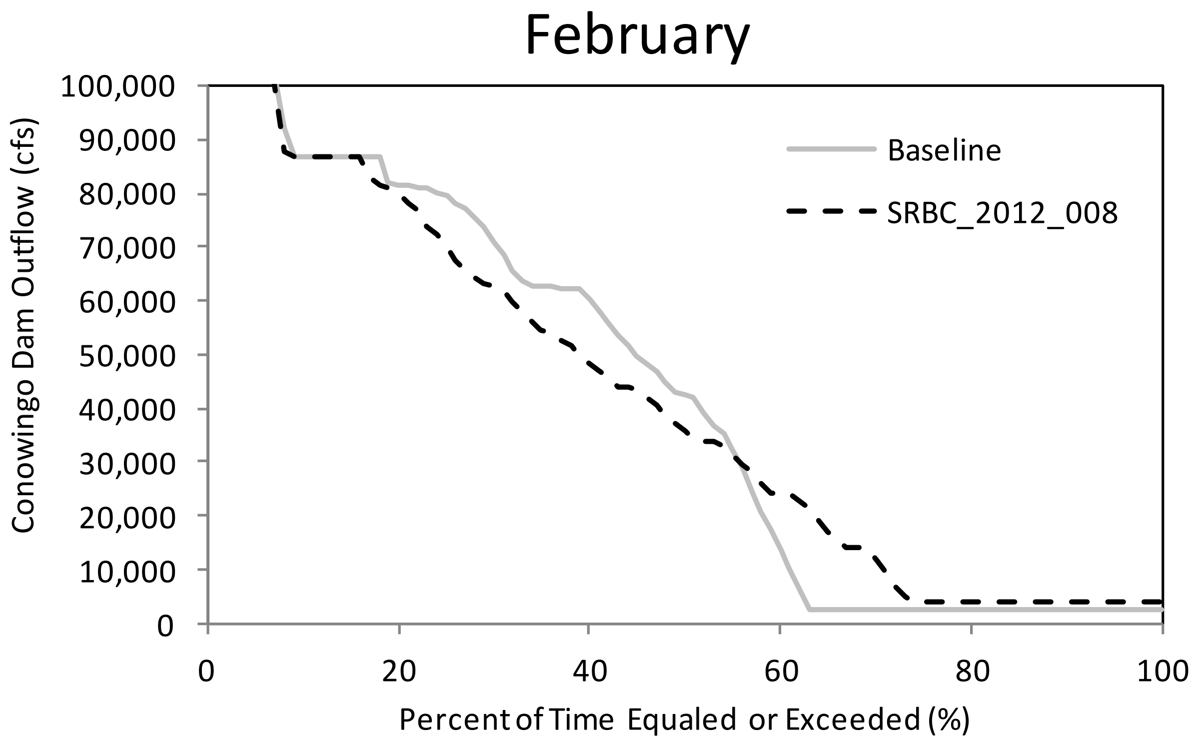
APPENDIX D: PRODUCTION RUN SRBC-008 ANNUAL AND MONTHLY CONOWINGO DAM OUTFLOW AND POND ELEVATION EXCEEDENCE CURVES

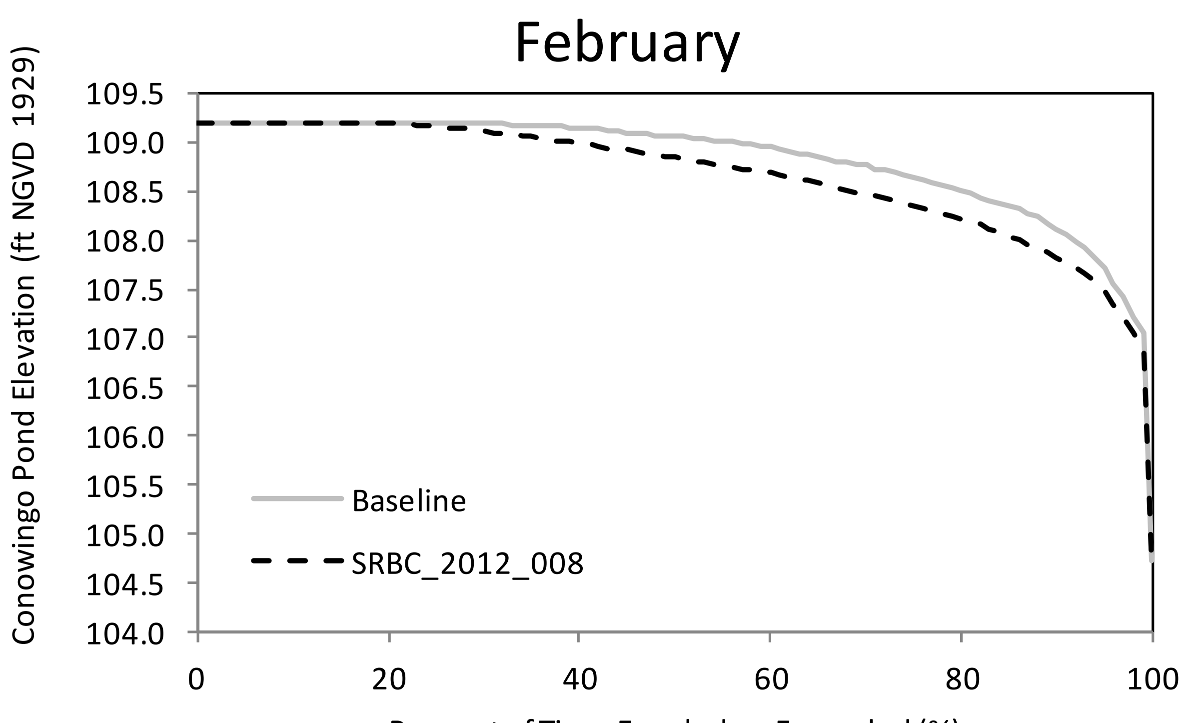

Annual
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

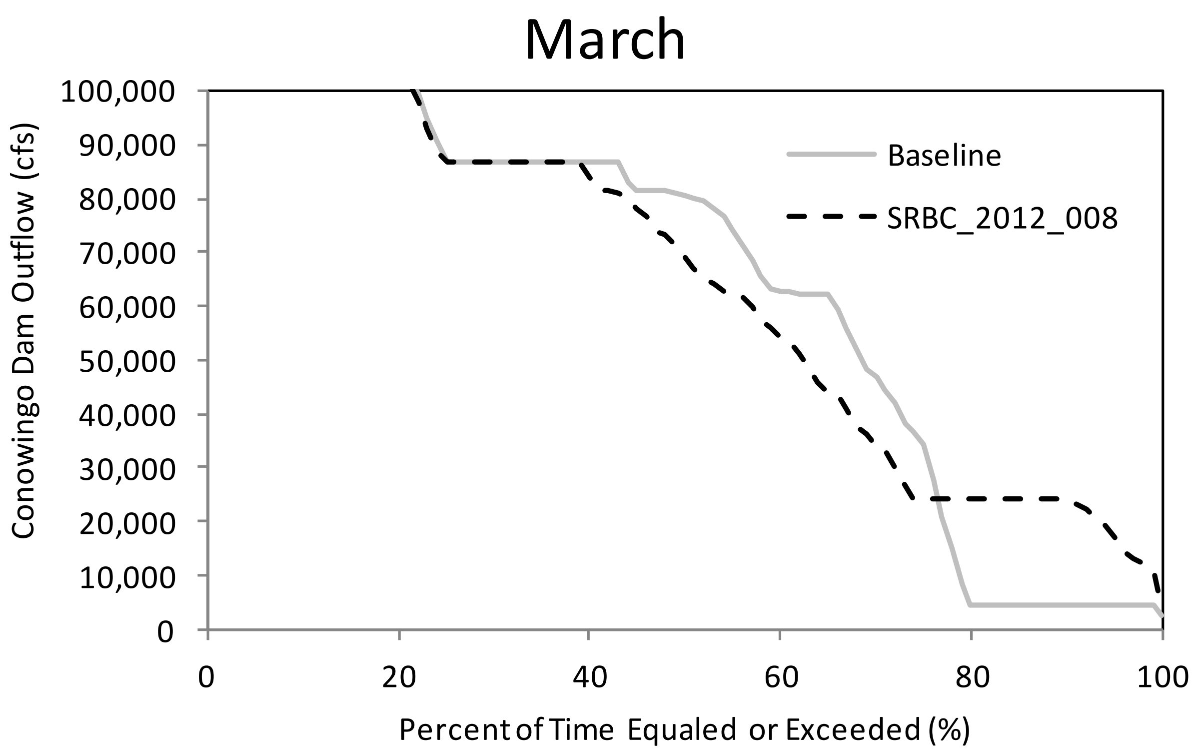

Annual
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

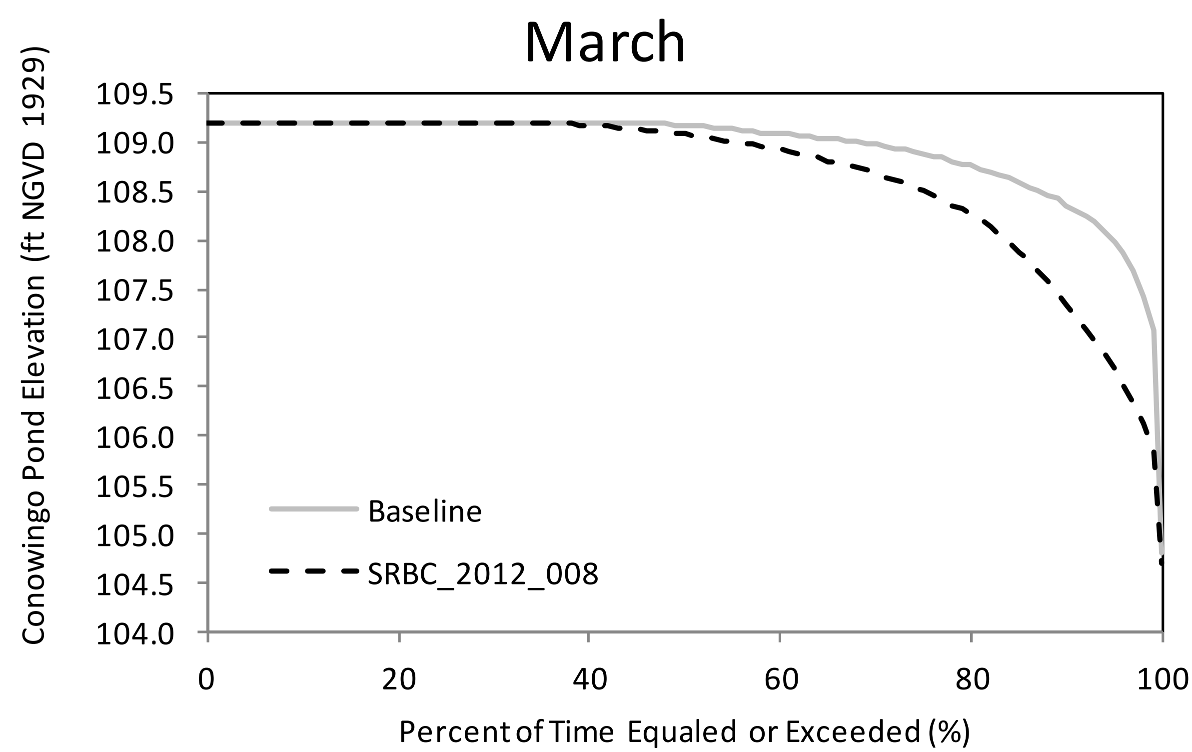

January
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

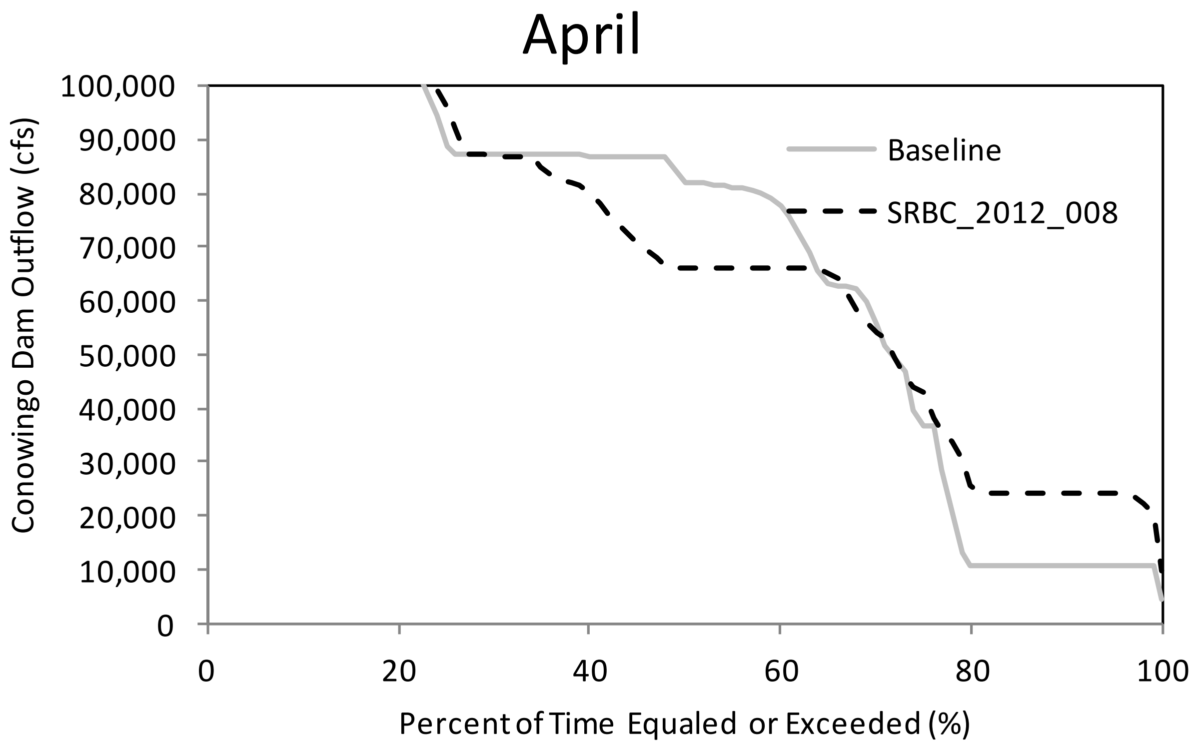

January
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008


February
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

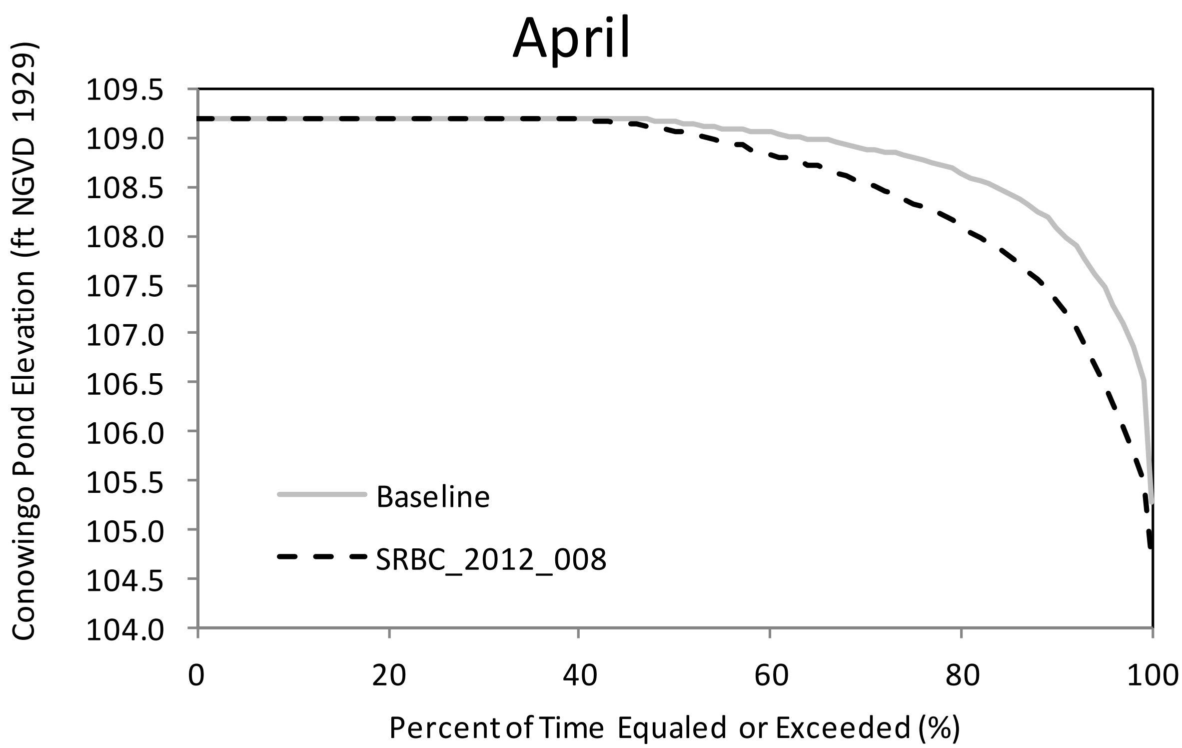

February
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008


March
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

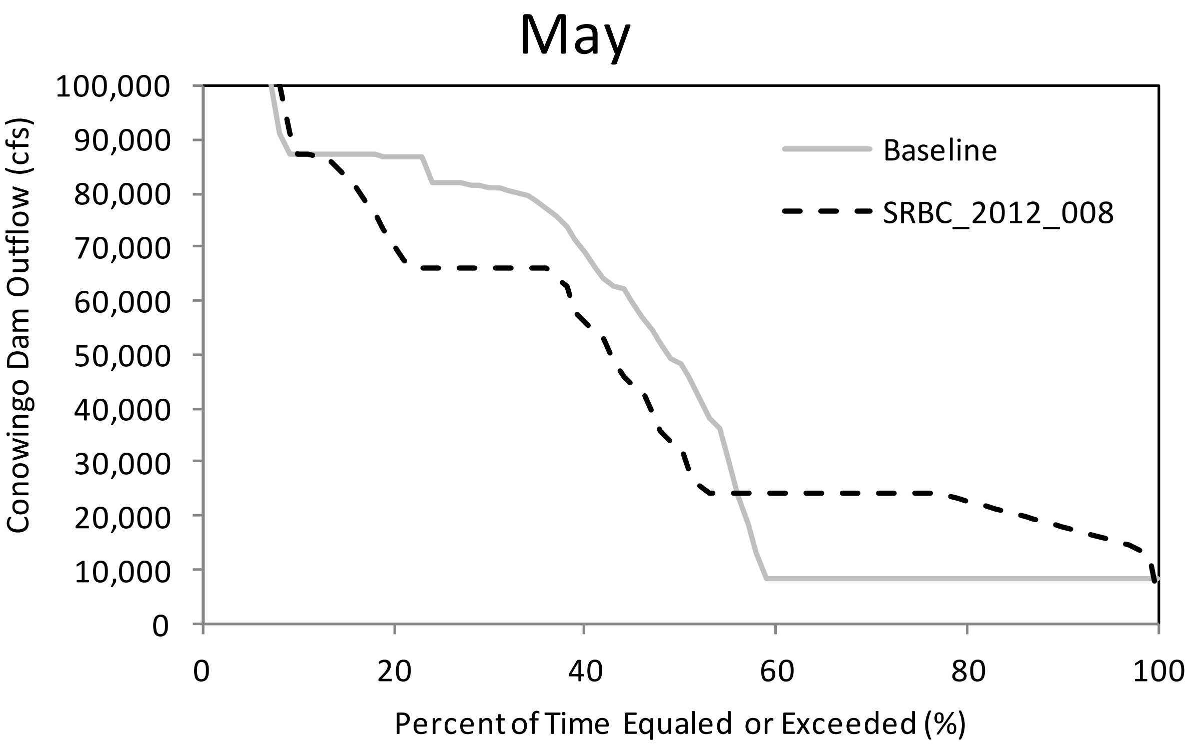

March
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

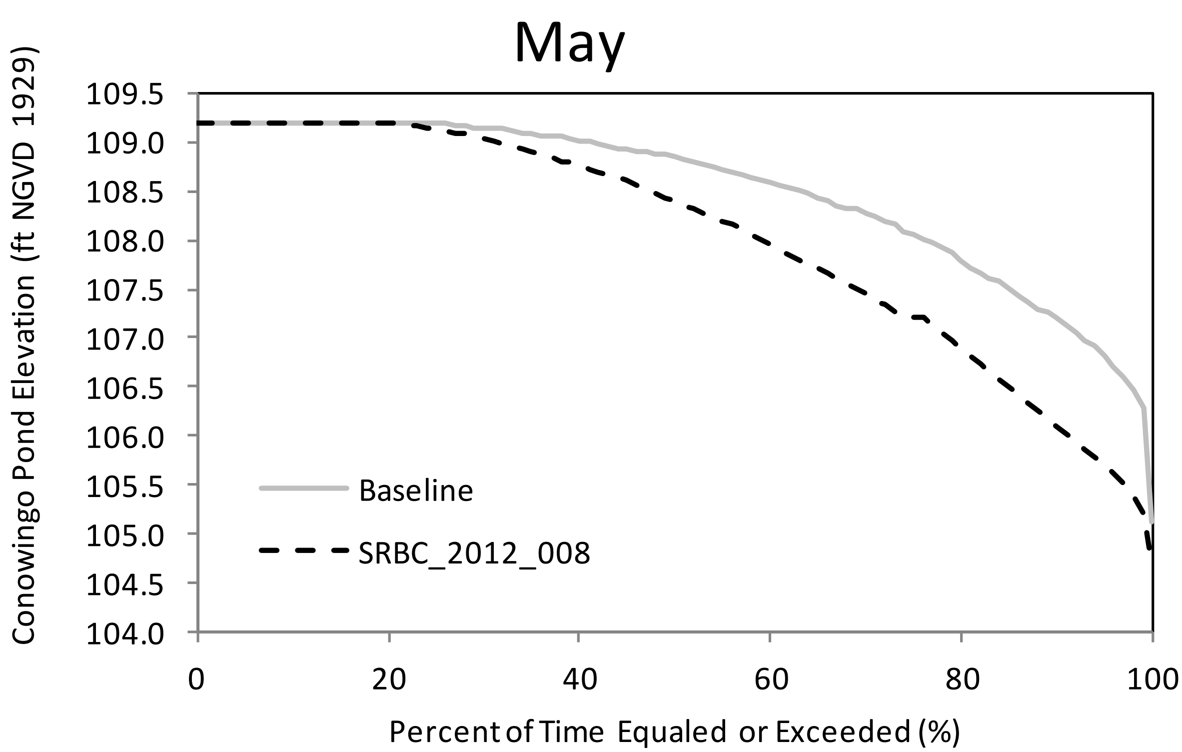


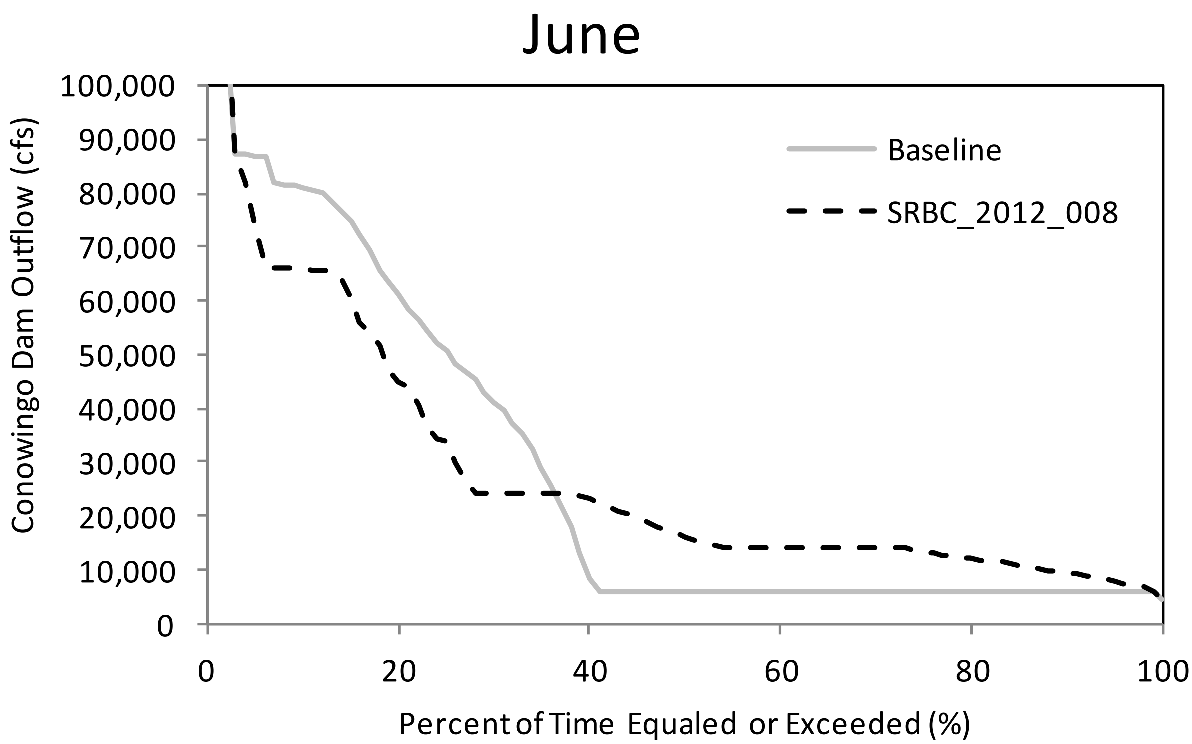
April
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
Baseline
SRBC_2012_008
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

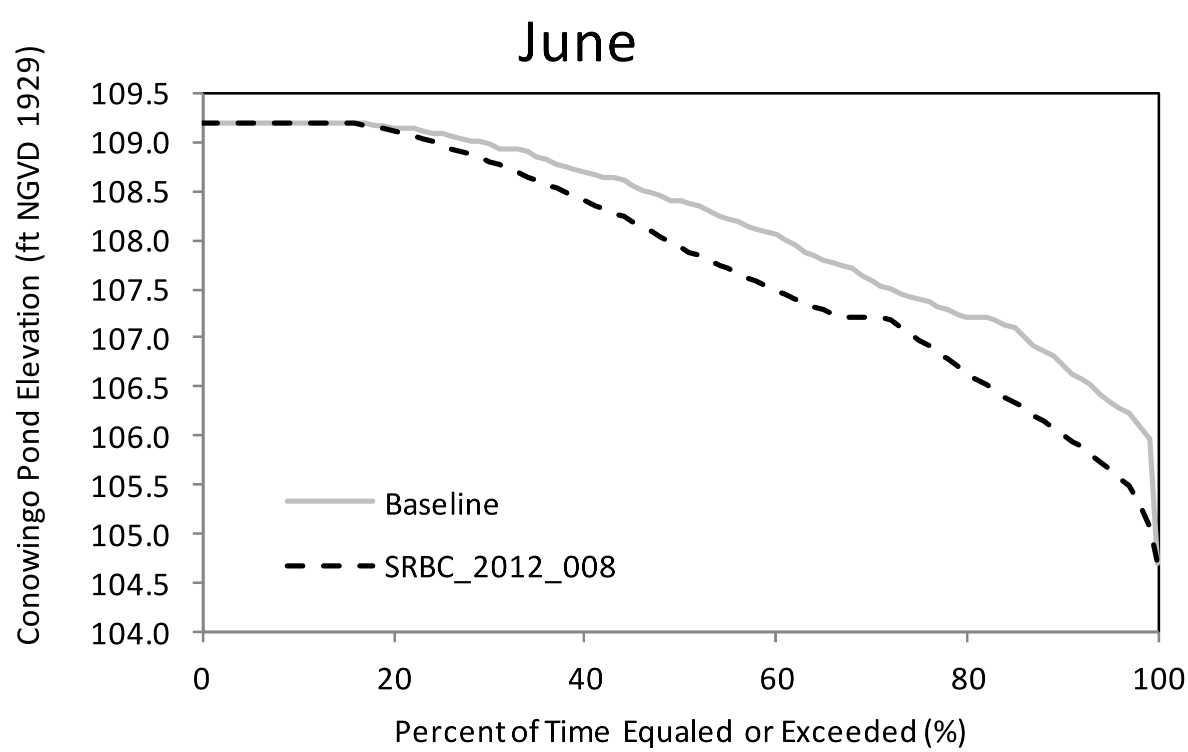


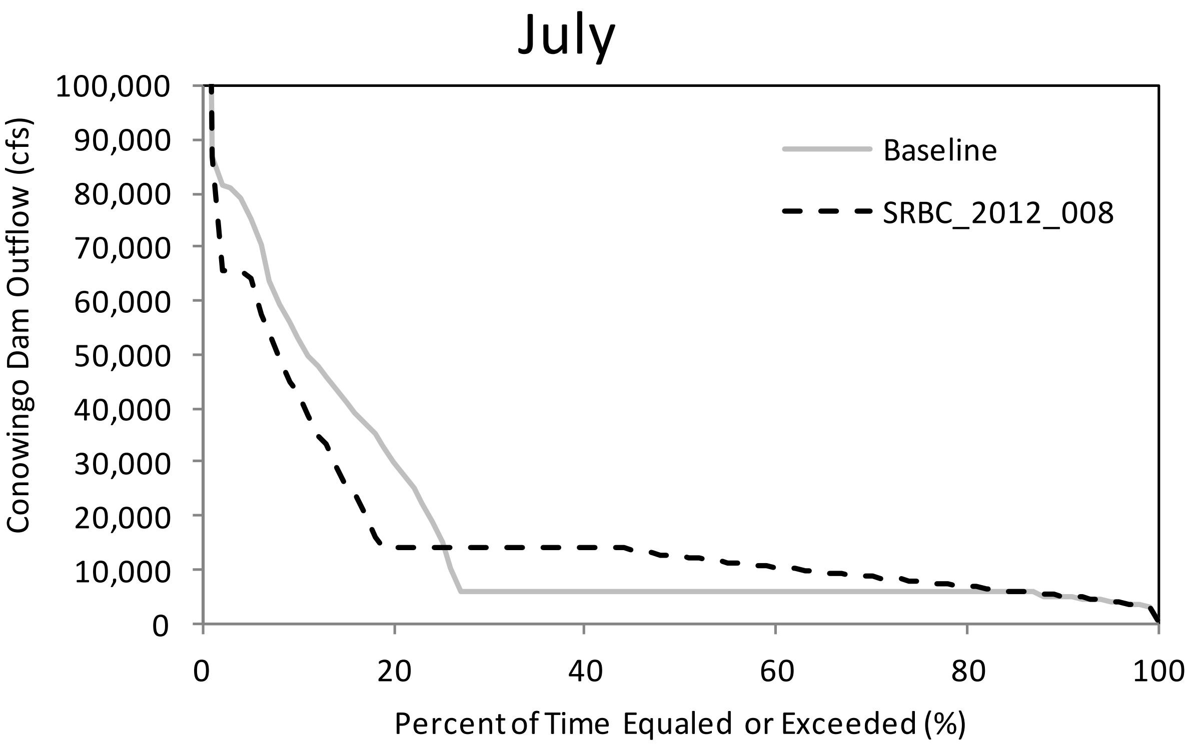
April
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
Baseline
SRBC_2012_008
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

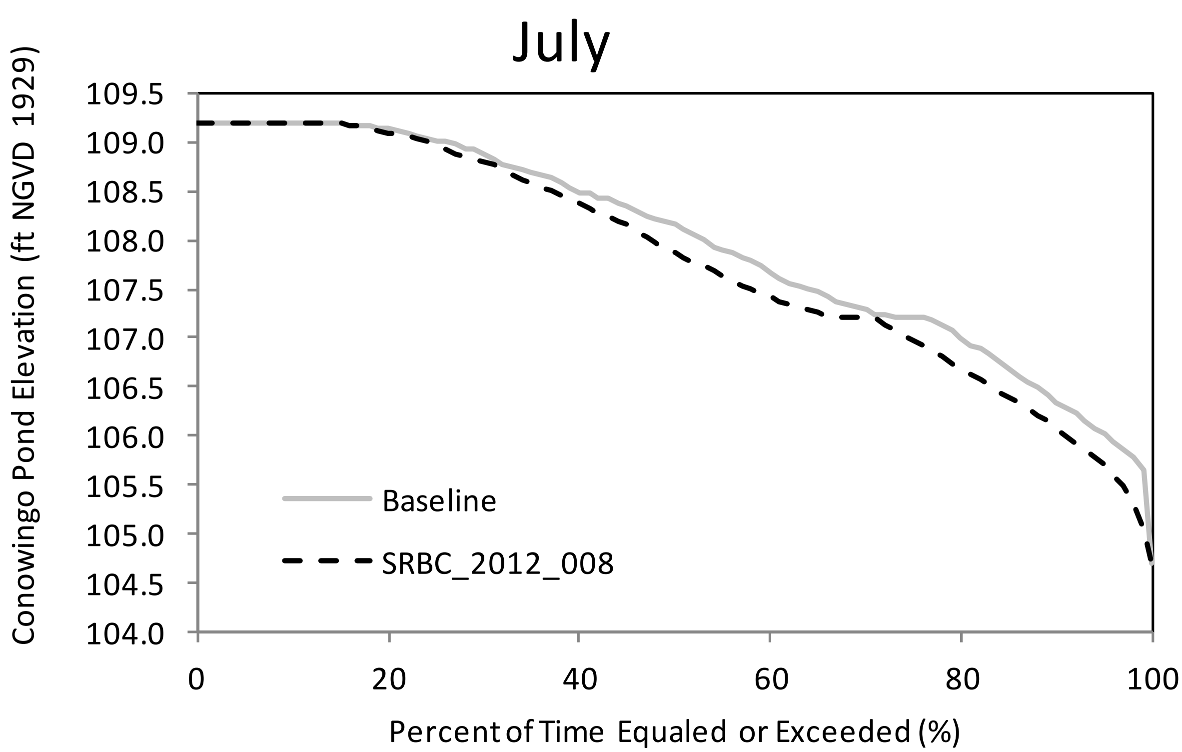

May
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

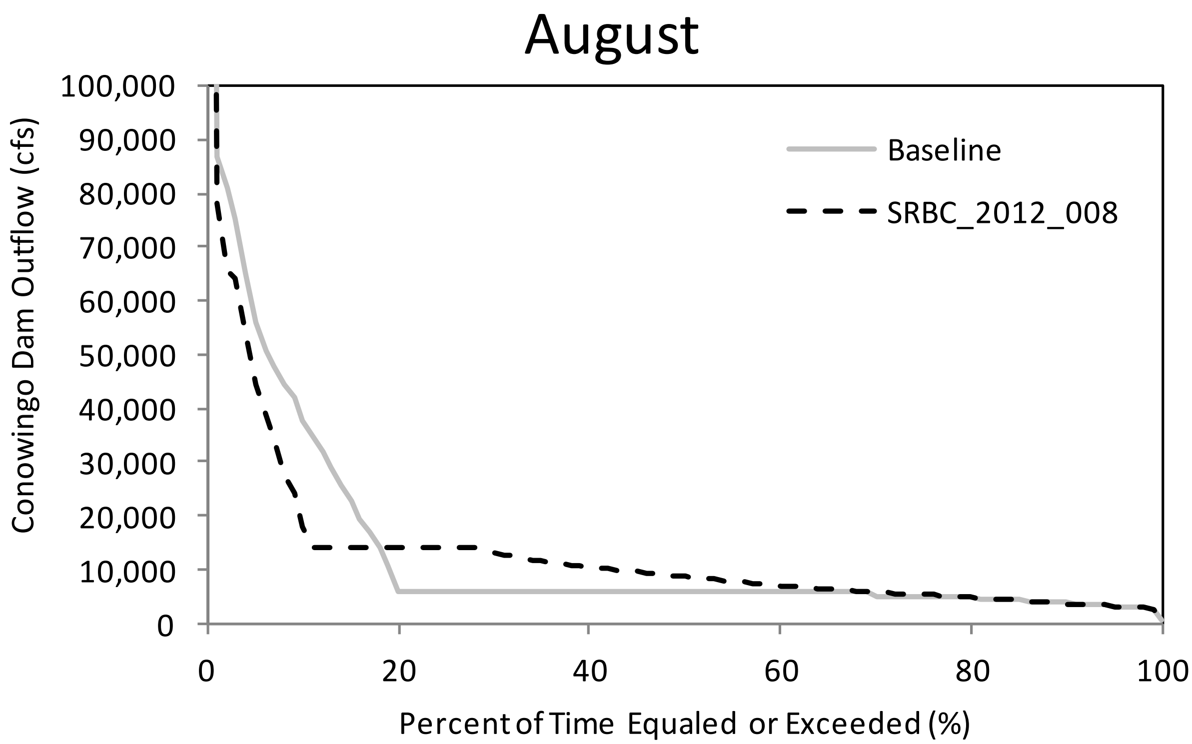

May
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

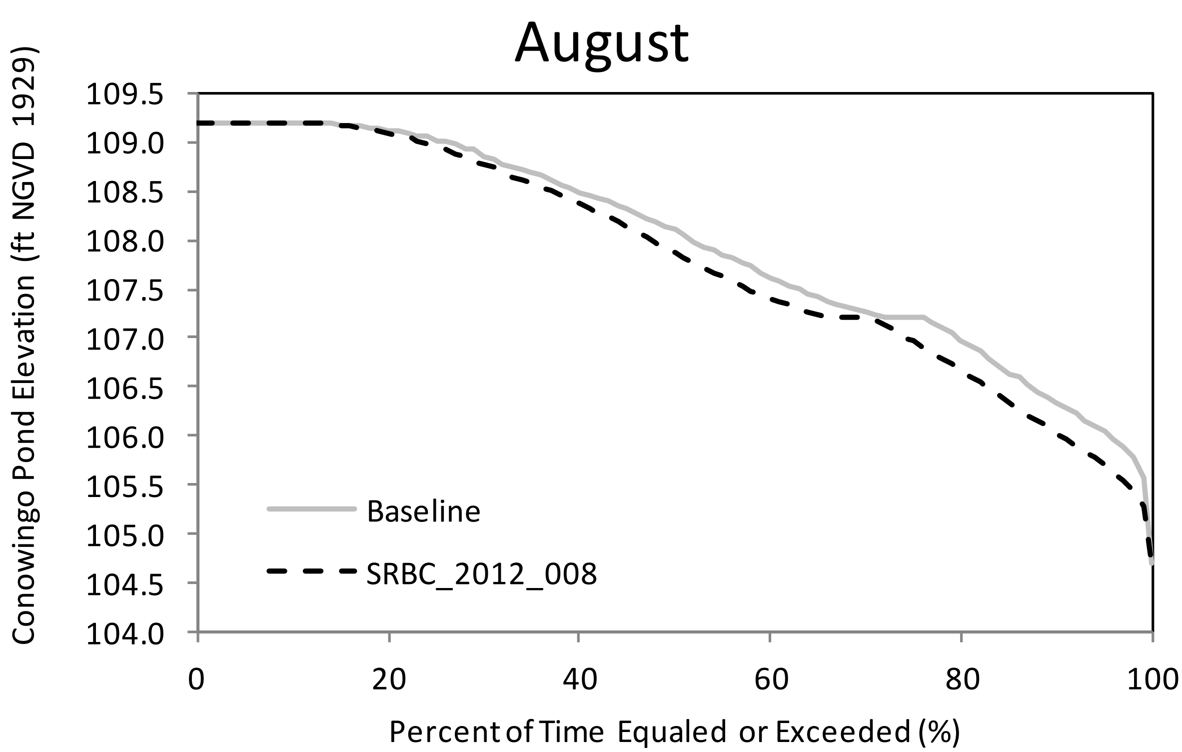

June
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
Baseline
SRBC_2012_008
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

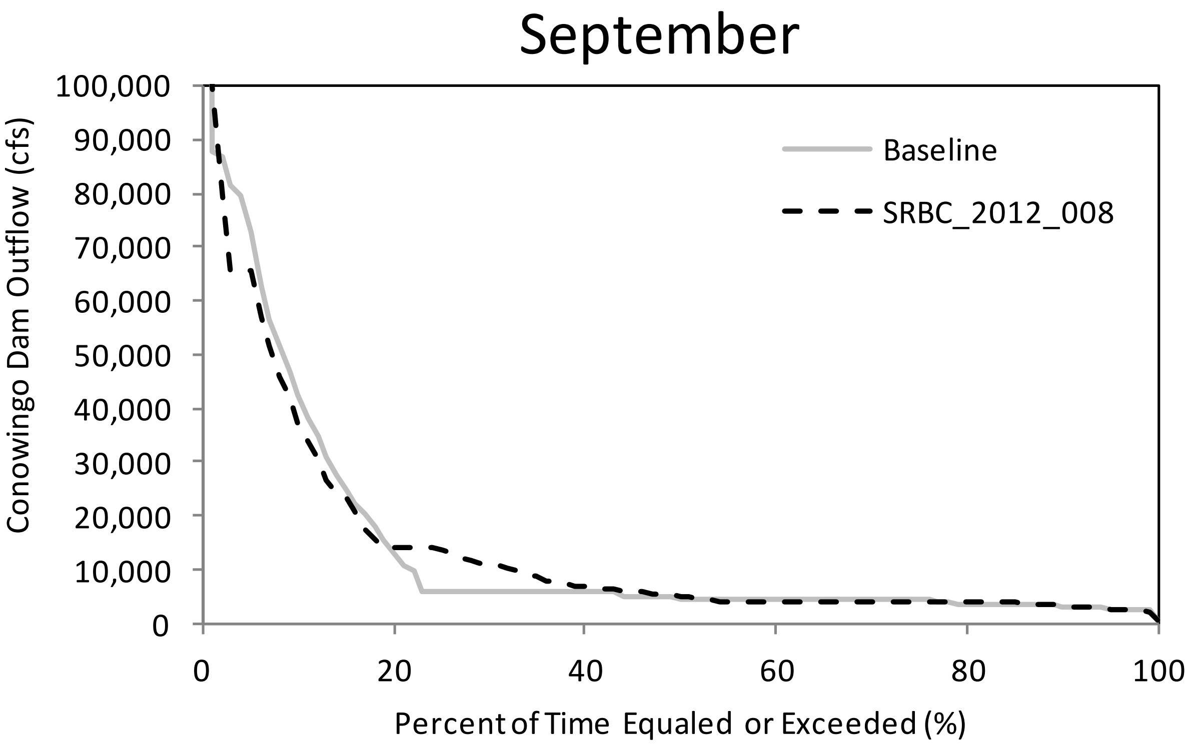

June
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
Baseline
SRBC_2012_008
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)

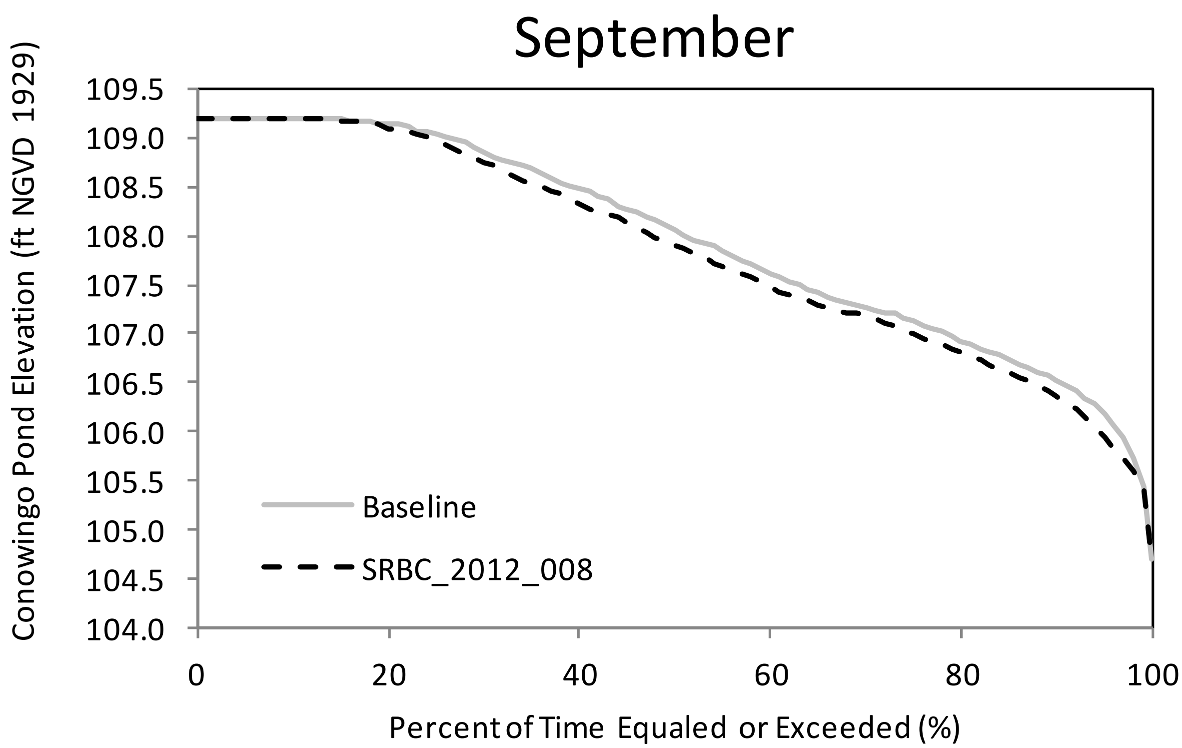

July
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

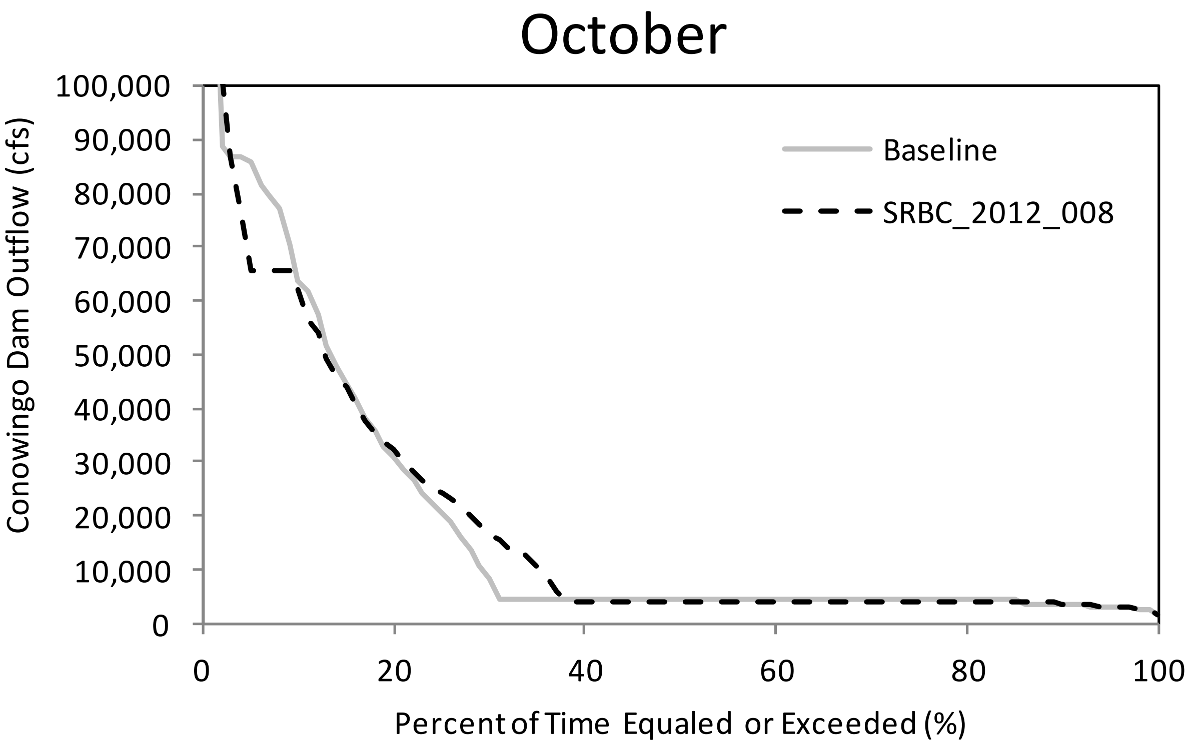

July
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

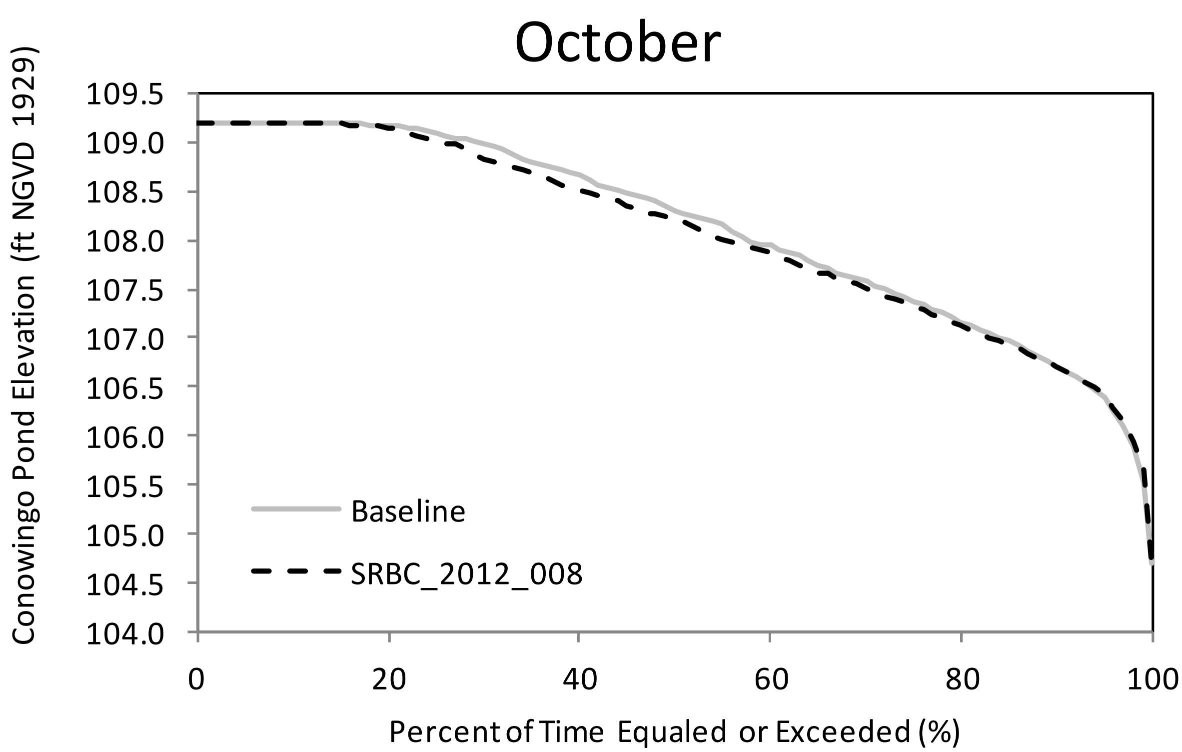

August
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

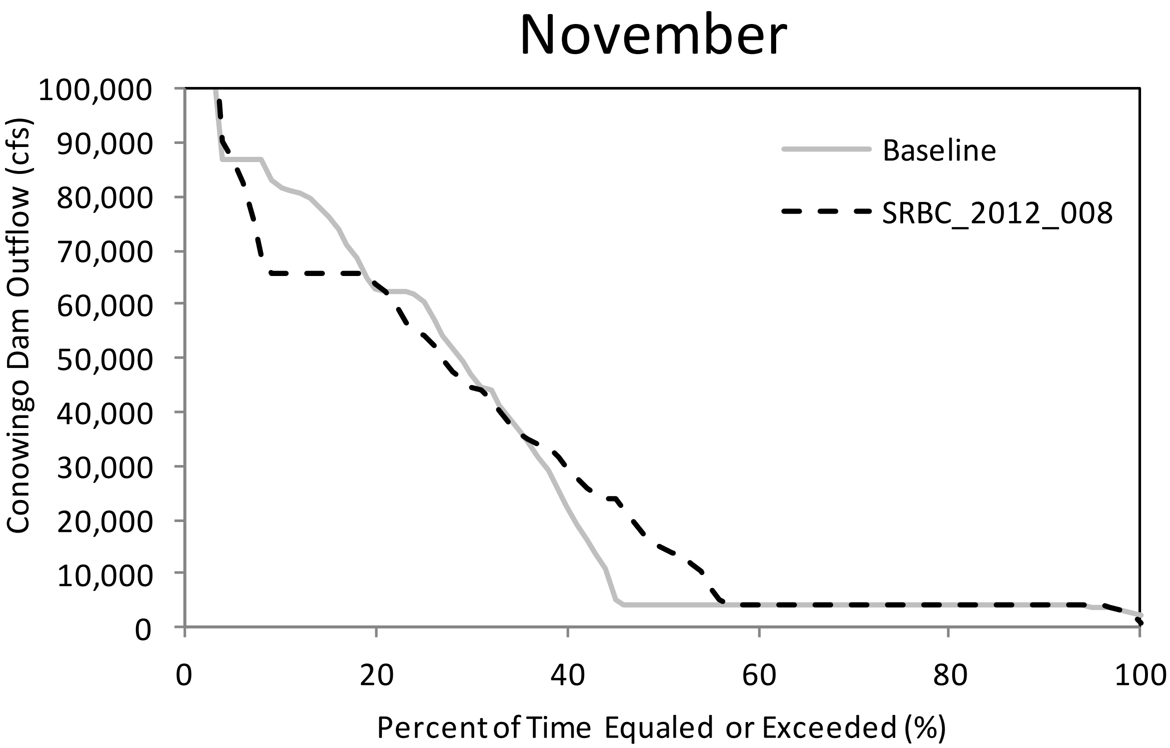

August
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008


September
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

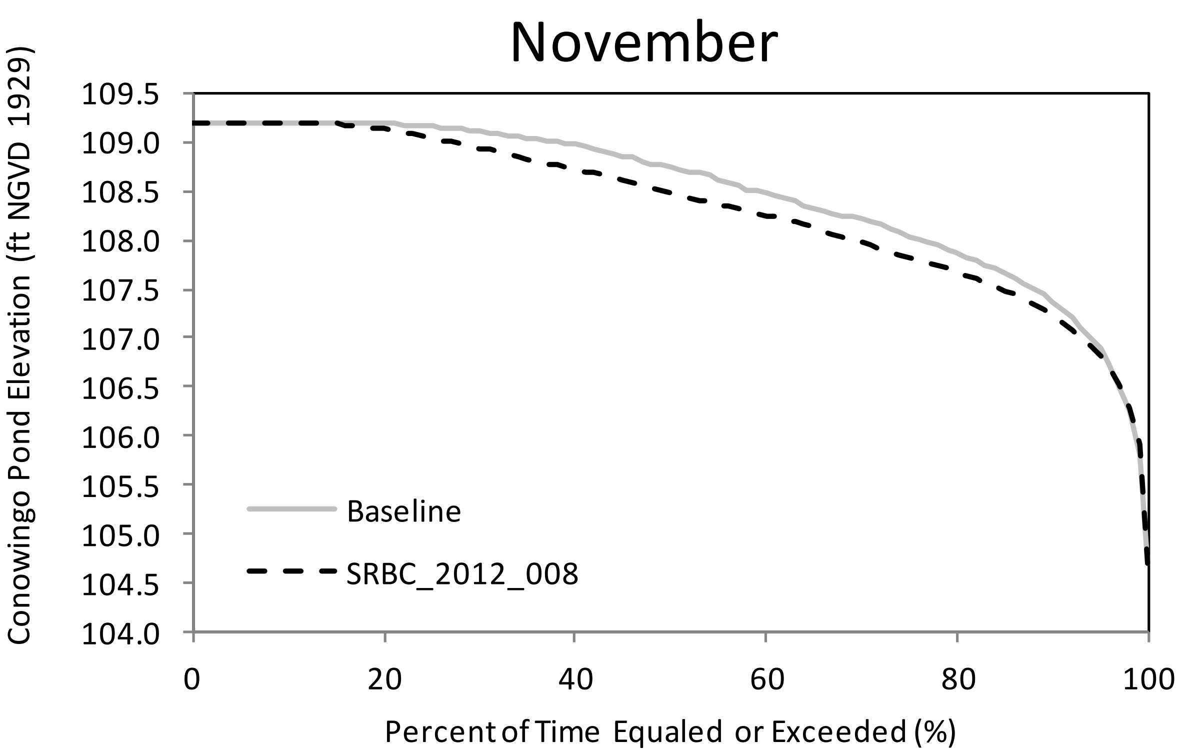

September
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008


October
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

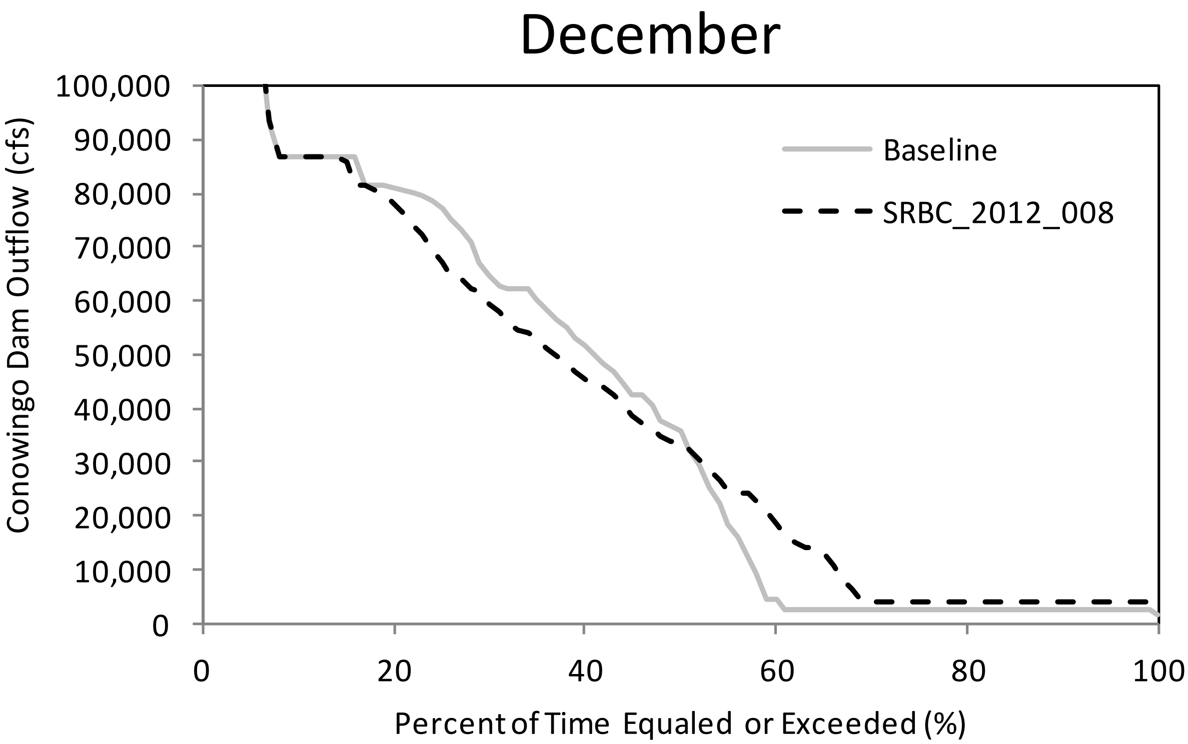

October
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

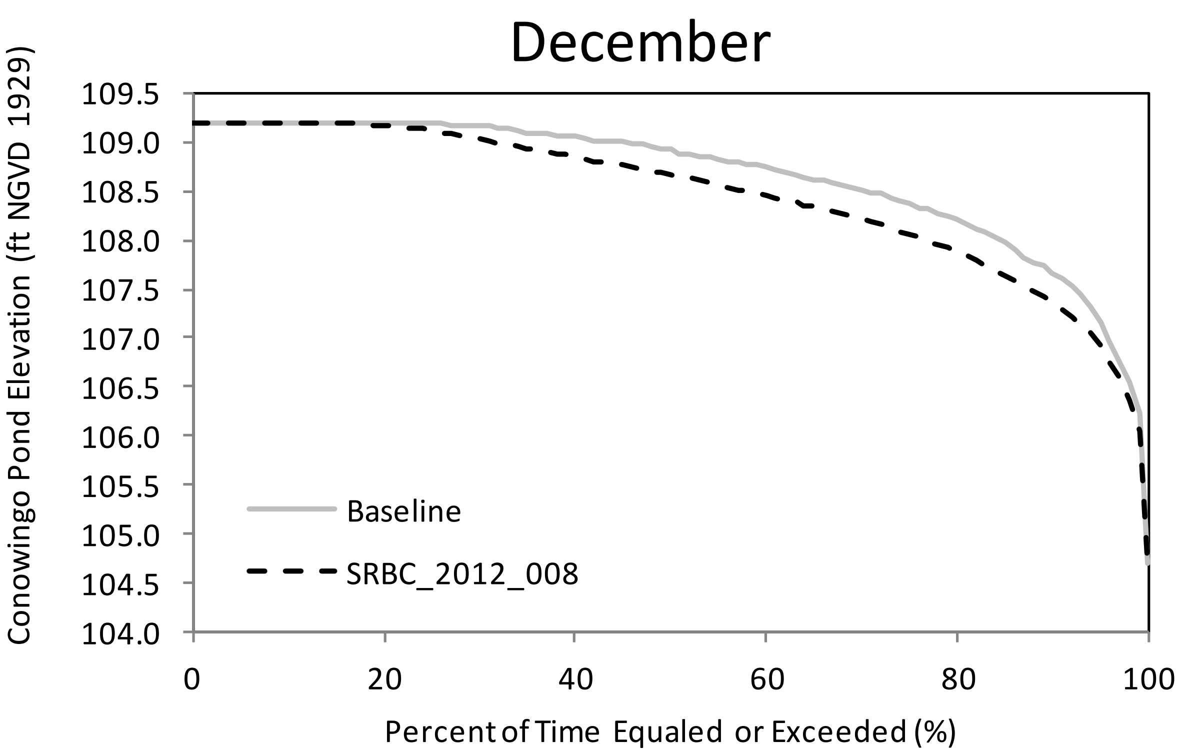


November
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Conowingo Dam Outflow (cfs)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008



November
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
Conowingo Pond Elevation (ft NGVD 1929)
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008


December
Conowingo Dam Outflow (cfs)
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008


December
Conowingo Pond Elevation (ft NGVD 1929)
109.5
109.0
108.5
108.0
107.5
107.0
106.5
106.0
105.5
105.0
104.5
104.0
0
20
40
60
80
100
Percent of Time Equaled or Exceeded (%)
Baseline
SRBC_2012_008

FINAL STUDY REPORT

OPERATIONS MODELING CALIBRATION REPORT

ADDENDUM TO

CONOWINGO HYDROELECTRIC PROJECT - RSP 3.11
FERC PROJECT NUMBER 405

AND

MUDDY RUN PUMPED STORAGE PROJECT – RSP 3.2
FERC PROJECT NUMBER 2355

Prepared for:

Exelon

Prepared by:

Gomez and Sullivan Engineers, P.C.

HydroLogics, Inc

August 2012

EXECUTIVE SUMMARY

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project), and the 800-megawatt Muddy Run Pumped Storage Project (Muddy Run Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. The current license for the Muddy Run Project was issued on September 21, 1964 and expires on August 31, 2014. FERC issued final study plan determinations for both Projects on February 4, 2010.

Conowingo's final study plan determination required Exelon to conduct a Hydrologic Study of the Lower Susquehanna River. The study's objectives were to: 1) Describe the history of flow management practices in the lower Susquehanna River basin; 2) Confirm the accuracy of the Conowingo USGS gage; 3) Perform a statistical analysis to describe the lower Susquehanna River flow regime; 4) Evaluate changes in Conowingo Project operations since energy deregulation laws came into effect in 1998; 5) Conduct operations modeling production runs to evaluate various operating scenarios to understand how operation changes may impact water use in the lower Susquehanna River; and 6) Develop a bathymetric map of the tailwater area below Conowingo Dam.

Muddy Run's final study plan determination required Exelon to conduct a Hydrologic Study of the Muddy Run Water Withdrawal and Return Characteristics. The study's objectives were to: 1) Describe the history of flow management practices in the lower Susquehanna River basin; 2) Examine the water withdrawal and return characteristics of the Muddy Run Project; 3) Describe the operations of the Muddy Run Project; 4) Develop bathymetric mapping of the Muddy Run Project reservoir and tailrace; and 5) Examine the impacts of alternative flow management regimes in the lower Susquehanna River on Muddy Run Project generation.

Conowingo Study Report 3.11 addressed Conowingo study 3.11 objectives 1 through 4 and objective 6. Muddy Run Study Report 3.2 addressed Muddy Run study 3.2 objectives 1 through 4. The purpose of this addendum is to address Conowingo Study 3.11 objective 5 and Muddy Run Study 3.2 objective 5, describing the operations model structure and calibration. No model production runs are described in this report, which focuses only on the model calibration. Future reporting will compare the results of several production runs, including a "baseline" model run. Alternative production runs will be designed in consultation with the resource agencies and other stakeholders.

An initial study report (ISR) was filed on June 2, 2011. A meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

The operations model calibration results show that historic operations at Conowingo and Muddy Run were matched well. Though individual peaking events were not always matched, the modeled flow distribution matched the observed flow distribution closely. Annually, modeled and observed Conowingo Pond elevation distributions matched within 0.75 ft, but the summertime (growing season) pond elevation distribution matched within +/- 0.25 ft. The close matches to historic data distributions indicate that the operations model is appropriate for use in long-term hydrologic applications in the lower Susquehanna River.

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LIST OF ACRONYMS

FERC	Federal Energy Regulatory Commission
GWh	Gigawatt-hours
ILP	Integrated Licensing Process
MW	Megawatt
MWh	Megawatt-hours
NGO	Non-Government Organization
NOI	Notice of Intent
OASIS	Operational Analysis and Simulation of Integrated Systems
PAD	Pre-Application Document
PPL	PPL Holtwood, LLC
PSP	Proposed Study Plan
RSP	Revised Study Plan
SRBC	Susquehanna River Basin Commission
USGS	United States Geological Survey
WSE	Water Surface Elevation
WY	Water Year

1. INTRODUCTION

Exelon Generation Company, LLC (Exelon) owns and operates the Conowingo Hydroelectric Project (Conowingo) and Muddy Run Pumped Storage Project (Muddy Run) on the lower Susquehanna River. Exelon has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt (MW) Conowingo project and the 800-MW Muddy Run project. Exelon is applying for a new license using the FERC's Integrated Licensing Process (ILP). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. The current license for the Muddy Run project was issued on September 21, 1964 and expires on August 31, 2014.

As required by the ILP, Exelon filed its Pre-Application Document (PAD) and Notice of Intent (NOI) with FERC on March 12, 2009. On June 10-12, 2009, site visits and scoping meetings were held at each project location for resource agencies and interested members of the public. Following these meetings, formal study requests were filed with FERC by several resource agencies. Many of these study requests were included in Exelon's Proposed Study Plan (PSP), which was filed on August 24, 2009. On September 22 and 23, 2009, Exelon held a meeting with resource agencies and interested members of the public to discuss the PSP.

Formal comments on the PSP were filed with FERC on November 22, 2009 by Commission staff, and several resource agencies. Exelon filed a Revised Study Plan (RSP) for the Project on December 22, 2009. FERC issued the final study plan determination for the Project on February 4, 2010, approving the RSP with certain modifications.

Conowingo's final study plan determination required Exelon to conduct a Hydrologic Study of the Lower Susquehanna River. The study's objectives were to:

1) Describe the history of flow management practices in the lower Susquehanna River basin
2) Confirm the accuracy of the Conowingo USGS gage
3) Perform a statistical analysis to describe the lower Susquehanna River flow regime
4) Evaluate changes in Conowingo Project operations since energy deregulation laws came into effect in 1998
5) Conduct operations modeling production runs to evaluate various operating scenarios to understand how operation changes may impact water use in the lower Susquehanna River
6) Develop a bathymetric map of the tailwater area below Conowingo Dam

Muddy Run's final study plan determination required Exelon to conduct a Hydrologic Study of the Muddy Run Water Withdrawal and Return Characteristics. The study's objectives were to:

1) Describe the history of flow management practices in the lower Susquehanna River basin
2) Examine the water withdrawal and return characteristics of the Muddy Run Project
3) Describe the operations of the Muddy Run Project
4) Develop bathymetric mapping of the Muddy Run Project reservoir and tailrace
5) Examine the impacts of alternative flow management regimes in the lower Susquehanna River on Muddy Run Project generation

Conowingo Study Report 3.11 addressed Conowingo study 3.11 objectives 1 through 4 and objective 6. Muddy Run Study Report 3.2 addressed Muddy Run study 3.2 objectives 1 through 4. The purpose of this addendum is to address Conowingo Study 3.11 objective 5 and Muddy Run Study 3.2 objective 5, describing the operations model structure and calibration. No model production runs are described in this report, which focuses only on the model calibration. Future reporting will compare the results of several production runs, including a "baseline" model run. Alternative production runs will be designed in consultation with the resource agencies and other stakeholders.

An initial study report (ISR) was filed on June 2, 2011. A meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

2. BACKGROUND

The Susquehanna River is one of the United States mid-Atlantic region's major freshwater sources. In addition to the abundant natural resources provided by the basin, the river is an important alternative energy source. The lower Susquehanna has several hydroelectric projects that collectively influence the river's flow characteristics. In the approximately 45 miles between the Marietta, PA United States Geological Survey (USGS) gage (No. 01576000) and the mouth of the Susquehanna at Chesapeake Bay, there are three main channel dams and one pumped storage facility, all constructed for the purpose of hydroelectric energy generation. These four hydroelectric projects have a combined 1,897 MW nameplate capacity, and in 2010 produced a reported combined 4,844,485 megawatt-hours (MWh) of energy. In addition to the hydroelectric energy generation, there are several other withdrawals for various uses, including power generation cooling water as well as drinking water withdrawals.

3. MODEL DESCRIPTION

3.1 Model Purpose and Overview

Exelon developed an operations model to better understand how operational changes at the lower Susquehanna River's four hydroelectric facilities affect the timing of river flows and energy generation. This involved adjusting the model parameters and constraints to match historic[1] data (flow, stage, generation) in several "calibration" runs, and then using the parameters and constraints from the calibration model to predict plant operations over a longer-term period (1930-2008) to establish a "baseline" model run.

3.2 Model Development

During the period 2002 – 2005, the Susquehanna River Basin Commission (SRBC) developed an operations model ("the SRBC model") of the Susquehanna River Basin to use in its "Conowingo Pond Management Alternatives Analysis" project (SRBC 2006). This model included the various hydrologic inputs, water withdrawals and returns within the entire Susquehanna River Basin, as well as engineering data (e.g. reservoir stage-storage tables). The model simulated water movement through various dams and hydropower facilities[2] on a daily time step. In 2007, Exelon began development of its own operations model for its FERC licensing proceeding. The Exelon model is based on the SRBC OASIS model. However, the Exelon model also includes hydroelectric operations at the Lower Susquehanna River dams, namely Safe Harbor, Holtwood, Muddy Run and Conowingo.

Both models utilize the Operational Analysis and Simulation of Integrated Systems (OASIS) software, which is a generalized program for modeling water resource system operations. OASIS simulates water movement through a river system represented by nodes (any point of interest in the system is a node such as reservoirs or junctions) and arcs (any hydraulic connection between two nodes such as river reaches, pumps, and turbines). OASIS simulates each model node using a linear program (LP) that describes the system for each time step. The LP is solved to determine the optimal way to route water through the system for each time step, operating within the specified rules and constraints. OASIS's LP categorizes two forms of operating rules: constraints and goals. A constraint is a rule that OASIS must obey at all times (e.g. Conowingo minimum flow release). A goal is a rule that OASIS attempts to best meet but is

[1] Historic data refers to the period 2004-2007

[2] Though hydroelectric reservoirs were included in the SRBC model, hydroelectric operations were not modeled. Water was simply routed through the reservoirs.

not required to obey at all times. Goals may have conflicting requests at times, thus OASIS allows users to weight goals to dictate the priority in which goals are pursued.

While OASIS can model a system's physical constraints, its primary purpose is to simulate the operating policies that result from human control of the system. For the most part, the operating policies and human control constitute a decision-making process about how much water to release or divert, and the timing associated with such decisions. In the context of the Susquehanna River model, this meant maintaining certain model constraints such as maintaining minimum required flows, and/or maintaining the reservoirs within prescribed minimum and maximum stages (elevations).

The development of each model is described in the following sections.

3.3 SRBC OASIS Model

3.3.1 Model Description

The Conowingo Pond Management Alternatives Analysis project spurred the Susquehanna River Basin OASIS model development. Because of the many conflicting pool uses, SRBC brought many stakeholders together to discuss and evaluate pool management. SRBC initiated a process to investigate other alternatives for managing the pool. The following two paragraphs, which were taken from the Conowingo Pond Management Report (SRBC 2006), describe the need.

> *"Effective management of the Conowingo pond is critical to economic, environmental and human welfare needs in the area. As demands on the resource increase, there is the potential during future droughts for inflow into the pond to decrease to the point where difficult economic and environmental decisions are necessary. There currently is no framework in place to facilitate the dialog and policy development necessary to support those decisions.*
>
> *The primary purpose of this planning effort was for the Conowingo Pond Workgroup to evaluate operational alternatives for the pond and identify a selected management plan that best meets the identified needs. In addition, the Workgroup was to identify actions beneficial to management of the Conowingo pond that the SRBC should consider for inclusion in its regulatory and water resources management program."*

The scope of the SRBC model included the entire Susquehanna Basin. This included numerous facilities, such as Corps of Engineers' reservoir storage facilities. The SRBC model includes approximately 80 river/stream segments, 40 demand (withdrawal) points, 30 reservoirs and several other flow bypasses and water transfers. Dams throughout the Susquehanna basin were incorporated into the SRBC model because upper basin dam operations can impact the flow magnitude and timing entering the Conowingo

Pool. The SRBC model, operated on a daily time step, extends from January 1, 1930 to April 30, 2008 (SRBC 2009).

The SRBC model includes facilities that were constructed after January 1, 1930, but assumes all facilities are present for the entire analysis period. For example, Muddy Run was constructed in the 1960's, but the model produces results assuming Muddy Run is present in 1930. This allows historic hydrologic conditions to be considered (e.g. 1930's drought) in the context of modern operations, even though the modern facilities were not always present when specific hydrologic events occurred.

3.3.2 SRBC Model Input Data

The SRBC model required several input datasets. These data included hydrologic inputs, water withdrawals/returns and engineering data. Local[3] inflows are needed at various nodes (such as reservoirs) to account for incremental drainage area increases or local runoff between reservoirs. The method for predicting local inflows in the SRBC model was based on the existing network of USGS gages located along the Susquehanna River and on intervening tributaries. The flow records at the USGS gages required some modification to account for anthropogenic influences. For example, the USGS gage located below Conowingo Dam reflects upstream regulation from seasonally operated reservoirs, water supply withdrawals, Muddy Run Pumped storage operations, Conowingo generation, and all other upstream influences. The sources of hydrologic data (streamflow records, precipitation, reservoir evaporation rates, water supply withdrawals, and precipitation) that were used to develop the flow record are shown in Table 3.3.2-1.

The flow record used in the SBRC model extends from January 1930 through April 2008, a 79-year analysis period.

Sixty-one Susquehanna Basin streamflow gages were used to develop model inflows. The gages are listed in Table 3.3.2-2 and shown in Figure 3.3.2-1. Thirty-one gages began flow data collection prior to 1930. Additional drainage area data are shown in Table 3.3.2-3. Most of the gages have incomplete records, having started after 1930 or ended prior to April 2008.

The following paragraphs describe the steps taken to develop inflows to the SRBC model.

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[3] Local flow represents the incremental (or local) inflow draining into the Susquehanna between two nodes (such as two dams) in the model.

STEP 1: The first step in developing the flow record was to estimate a monthly record of unregulated USGS gage flows by adjusting observed flows. Unregulated in this report refers to the flows that a gage would have experienced had the river experienced no anthropogenic influences.

To estimate unregulated USGS gage flows, human-induced changes (Table 3.3.2-4)—such as a water supply withdrawal—were quantified. For example, the USGS gage below the Cowanesque Reservoir (located upstream in the Susquehanna River Basin) reflects regulated flow conditions. Deregulating this gage required adjusting the observed flow to account for changes in the pool storage and the net evaporation from the reservoir. All observed gage flows were adjusted if they were subject to human disturbances. A human disturbance or impairment (change in storage, water withdrawal, etc.) carries all the way downstream. Thus, a flow change due to a storage adjustment (elevation change) at Cowanesque Reservoir carries all the way down to the mouth of the Susquehanna River. Therefore, a gage is influenced by the cumulative effect of all upstream influences.

STEP 2: The second step in developing the flow record involved assembling a monthly record of unregulated "gains." This was represented by the flow difference between two unregulated gages - where one gage is located upstream of the other. In instances when two gages did not have common periods of record, the USGS program *Fillin* (Alley and Burns 1983) was used to estimate missing flows. *Fillin* is a statistical program that is used to extend gage flow records by developing statistical comparisons using the common flow records for the two gages. For example, unregulated Gage A may have a 73-year period of record (1930-2002) and unregulated Gage B, located just upstream of Gage A, may have a 60-year period of record (1943-2002). To make Gage B reflect the same 73-year period of record similar to Gage A the USGS *Fillin* program was used to estimate the missing flows (1930-1942). Flow record estimations were conducted on a monthly basis.

STEP 3: The third step in developing the flow record was to apportion the estimated flows (from the *Fillin* program) to ensure that their volumes matched with downstream, unregulated flows. Essentially, adjustments were made to preserve correct water volumes at all USGS gages.

STEP 4: The last step in the process for developing SRBC model inflow was disaggregating monthly flow volumes into daily flow estimations at every gage. This was accomplished by first identifying an unregulated (no human disturbances) USGS gage (Gage A) in proximity to the gage of interest (Gage B). Then, the mean daily flow recorded at the unregulated gage was multiplied by the ratio of the monthly flow volume between the two gages (Gage B/Gage A), calculated as:

$$Q_{daily\text{-}B} = Q_{daily\text{-}A} * (Q_{monthly\text{-}B} / Q_{monthly\text{-}A})$$

where $Q_{daily-B}$ is the daily average flow at gage B, $Q_{daily-A}$ is the daily average flow at gage A, $Q_{monthly-B}$ is the monthly flow volume at gage B, and $Q_{monthly-A}$ is the monthly flow volume at gage A. This process was repeated for each month over the entire period of record. The goal of daily flow estimation was to build a flow sequence whose variation is historically representative (similar flow distribution), not to exactly match historic flows. The output from this step consists of a set of inflows at all the OASIS nodes for the full period of record on a daily basis.

3.3.3 Flow Routing

Flow transport from one node to the next downstream node was in most cases assumed to occur completely within one time step of the model (one day). However, there are twelve river reaches between model nodes where extensive travel distance or hydrologic complexity required a more accurate travel time estimate. Many flow routing methods exist for different purposes. The OASIS model utilized Muskingum routing to determine travel times between selected nodes, which is described in the following section.

The Muskingum routing method relies on two coefficients, K (a measure of travel time through a reach) and X (a measure of channel storage within a reach). Using the two coefficients and an inflow hydrograph, the method calculates an outflow hydrograph from a reach (Chow et al. 1988). The K and X values lead to the computation of three coefficients: c_1, c_2, and c_3, (referred to collectively as c_i), which are used in the following equation to compute an outflow hydrograph:

$$O_{t+1} = c_1*I_{t+1} + c_2*I_t + c_3*O_t$$

where O_{t+1} is outflow from the reach at time step t+1, O_t is outflow from the reach at time step t and I_t and I_{t+1} are inflow into the reach at time step t and t+1, respectively.

The Microsoft Excel optimizer function was used to calculate the c_i coefficients. Three hydrographs were entered into Excel: upstream gage flows, computed local inflow, and downstream gage flows. The local inflows were added to the upstream hydrograph to create the composite inflow hydrograph. The composite inflow hydrograph was then used with the downstream hydrograph to compute the c_i coefficients. The objective function was to minimize the sum of the residuals' absolute values, subject to $c_1+c_2+c_3 = 1$ and $c_i>0$ are non-negative. Table 3.3.3-1 lists the twelve explicitly routed model reaches' routing coefficients.

There was no flow routing in the lower Susquehanna River (downstream of Marietta) because the reach lengths between the stations were minimal given the model time step, and because they consisted mainly of backwater reaches which transmit flow relatively rapidly.

3.4 Exelon OASIS Model

3.4.1 Model Development

In 2007, Exelon began development of its own operations model to evaluate alternative flow management scenarios' generation and flow impacts. The Exelon model is based on the SRBC OASIS model, using the same inflow and flow routing procedures. However, the Exelon model also includes hydroelectric operations at the Lower Susquehanna River hydropower projects, namely Safe Harbor, Holtwood, Muddy Run and Conowingo. The Exelon model operates on an hourly time step downstream of Safe Harbor to simulate peaking hydropower generation. To adequately predict hydropower peaking operations, an hourly energy price time series was created.

The Exelon model is run as a weekly optimization model, operating each hydroelectric facility to maximize revenue within a set of constraints. The model combines flow availability and energy price information to create a generation schedule in one-week blocks (Monday through Sunday). Revenue at each facility is optimized by operating the facility with week-ahead flow and energy price foresight. That is, each facility operates knowing exactly how much water will be available for generation and what the energy price will be for the upcoming week. The model calculates generation/flow releases for upstream hydroelectric projects first, and then calculates downstream projects based on upstream operations. Conowingo and Muddy Run are run in parallel because of the inherent hydraulic connection between the two projects (Muddy Run draws from Conowingo Pond).

Both the SRBC and Exelon models include facilities that were constructed after the model start date of January 1, 1930. Model runs reflect modern day structures and demands, even though the simulation extends back to January 1, 1930. For example, the Muddy Run Pumped Storage project was licensed in 1964, but the model will operate Muddy Run in 1930. Similarly, water supply demands are different today than they were in 1930. The reason the model was run this way was so operational alternative comparisons would include the Susquehanna River's longer-term historic hydrologic conditions. Thus, energy and flow analysis comparisons were not limited to hydrologic conditions from only the most recent years.

3.4.2 Flow Routing

Flows were routed in the Exelon model in the same fashion as the SRBC model. Because there are no explicitly routed reaches in the Lower Susquehanna River, the hourly time step downstream of Safe Harbor had no impact on explicitly routed reaches. The travel time between the reservoirs on the Lower Susquehanna River was assumed to have no lag (e.g. if Safe Harbor outflow is 12,000 cfs at 1:00, Holtwood inflow is 12,000 cfs at 1:00).

3.4.3 Engineering Data

This section contains all the reservoir and powerplant engineering data used in the Exelon model. Engineering data for each project includes:

- reservoir elevation versus surface area
- reservoir elevation versus storage volume
- minimum and maximum reservoir elevations (either for recreation purposes, water supply withdrawal, intake cooling water, hydropower generation or combinations thereof)
- minimum and maximum total station turbine flows (cfs)
- minimum and maximum total station turbine generation (kW)
- turbine/generator efficiencies, including pump and turbine capacities
- powerplant tailwater data
- leakage flows

More detailed engineering data was available for Conowingo and Muddy Run compared to the other projects. Safe Harbor engineering data was obtained primarily from what was available in the public record. In a letter to PPL, Exelon requested Holtwood Dam engineering data for model use. Most of the engineering data for the Holtwood project was obtained in PPL's response to Exelon's request or in PPL's Draft License Application. While each project's engineering data is in different datums, this report provides all elevations relative to the National Geodetic Vertical Datum of 1929 (NGVD 1929)[4].

[4] Holtwood data was provided to Exelon in Holtwood datum, which is reported to be within +/- 0.1 ft of NGVD 1929, while no datum was specified with Safe Harbor data. Both were assumed to be in the NGVD 1929 datum.

3.4.3.1 Safe Harbor Hydroelectric Project

Safe Harbor Dam has a reported hydraulic capacity of 110,000 cfs and a generation capacity of 417 MW, as reported in the "River Flow Coordination Agreement Between Safe Harbor Water Power Corporation and PPL Holtwood, LLC" dated March 9,2011. Safe Harbor's elevation versus area and storage curves are shown in Figure 3.4.3.1-1. Table 3.4.3.1-1 specifies Safe Harbor's various engineering attributes, values and data sources. Tailwater elevations at Safe Harbor are influenced by Lake Aldred elevations, so no tailwater rating curve was used.

3.4.3.2 Holtwood Hydroelectric Project

The Holtwood expansion is expected to be completed in 2012. Thus, the calibration runs used pre-expansion data, while the future baseline and alternative operation production runs will use post-expansion data. Upon completion of the expansion project, Holtwood's reported pre-expansion hydraulic capacity of 31,500 cfs and 107 MW (as reported in the "River Flow Coordination Agreement Between Safe Harbor Water Power Corporation and PPL Holtwood, LLC" dated March 9, 2011) will have a hydraulic capacity of 61,460 cfs and a generation capacity of 196 MW (as reported in Holtwood's license amendment, issued October 30, 2009). Holtwood's pre-expansion conditions supply no minimum flow release. As part of the project expansion license agreement, Holtwood agreed to supply Conowingo with a continuous inflow of 800 cfs, and a daily volumetric flow equivalent to 98.7% of Conowingo's minimum continuous flow requirement aggregated over a 24 hour period, or net inflow, whichever is less. The agreement is contingent on Holtwood completing construction on the expansion, though the minimum flows must be supplied by no later than 2012. Holtwood's elevation versus area and storage curves are shown in Figure 3.4.3.2-1, while the minimum and maximum pool elevations are shown in Figure 3.4.3.2-2. Holtwood's pre-expansion and post-expansion tailwater rating curves are shown in Figure 3.4.3.2-3. The pre-expansion rating curve was used for calibration runs, while the post-expansion rating curve will be used for the future baseline and alternative operation production runs. Table 3.4.3.2-1 specifies Holtwood's various engineering attributes, values and data sources.

3.4.3.3 Muddy Run Pumped Storage Project

Muddy Run has generation and pumping hydraulic capacities of 32,000 cfs and 28,000 cfs, respectively, with a nameplate generation capacity of 800 MW. Muddy Run's elevation versus area and storage curves were recently updated using 2010 bathymetry data, and are shown in Figure 3.4.3.3-1. Table 3.4.3.3-1 specifies Muddy Run's various engineering attributes, values and data sources. Tailwater elevations at Muddy Run are influenced by Conowingo Pond elevations, so no tailwater rating curve was used.

3.4.3.4 Conowingo Hydroelectric Project

Conowingo has a hydraulic capacity of 86,000 cfs and a nameplate generation capacity of 573 MW. Conowingo's elevation versus area and storage curves are shown in Figure 3.4.3.4-1, while the minimum and maximum pool elevations are shown in Figure 3.4.3.4-2 and the tailwater rating curve is shown in Figure 3.4.3.4-3. Seasonal minimum flow requirements are shown in Figure 3.4.3.4-4. Table 3.4.3.4-1 specifies Conowingo's various engineering attributes, values and data sources.

3.4.4 Model Optimization

This section provides a description of the linear program that was used to compute energy generation at the hydropower projects.

The OASIS model is first run in an optimization mode, assuming a constant head and efficiency for each station. The constant head is based on the average head conditions at each project based on long-term data. Thus, the model is run using a constant head at each project for 72 years of record. Output from this optimization run is hourly energy and discharge. The energy produced in this model run is not what is reported; rather a post-processor is run to produce the reported energy values. Using the hourly discharge data and hourly storage volumes computed in the optimization model (for each project), a post-processor is then run to compute the energy.

The net head at each project is based on the following equation:

Net Head (ft) = Pond Elevation (feet) - Tailwater Elevation (feet) - Headlosses (ft)

The hourly pond elevation is computed in the post processor by using the hourly storage volumes produced by the optimization model, and determining the pond elevation via the stage versus storage curve.

The hourly tailwater elevation is computed in the post processor by using the hourly discharge produced by the optimization model, and determining the tailwater elevation via the tailwater rating curve. In the case of Safe Harbor and Muddy Run, the tailwater elevation was computed from the downstream reservoir elevation.

No headloss rating curve was available for any of the stations, and thus it was not included in the model. No turbine efficiency curve was available for any of the stations and thus a constant turbine/generator efficiency value was used for each project.

The post processor then uses the hourly pond elevation, and hourly tailwater elevation to compute the net head at each project. Using the hourly discharge data from the optimization model, the net head computed in the post-processor and the constant efficiency, the hourly varying energy is computed in the post-processor.

The equations and process used by OASIS to compute hourly discharges at each project follows. To maintain flow continuity for all nodes in the model (for non-reservoir nodes the storage terms are dropped) the following formula was applied:

Storage(end of hour)[acre-ft] = Storage(start of hour) [acre-ft] + Inflow(this hour) [acre-ft/hr] – Outflow(this hour)[acre-ft/hr]

Discharge through the turbines is converted to energy with this equation, assuming a constant head:

*Energy (gen)[MWh]=0.00102[MWh/acre-ft/ft]*Flow[acre-ft/hr]* Head[ft]*Efficiency*
*Energy (pumping) [MWh]=0.00102[MWh/acre-ft/ft]*Flow[acre-ft/hr]*Head[ft]/Efficiency*

The objective function is (note that pumping only applies to Muddy Run):

Maximize *Value[$] = Price[$/MHh] * Energy (generation)[MWh] – Price[$/MWh] * Energy (pumping)[MWh]*

In the OASIS model, the hydroelectric system is driven by the energy prices, and the water is "dispatched" by the optimization to maximize weekly revenue for the four powerplants during the week, within the existing environmental and recreation constraints of each station (e.g. minimum flow releases, recreational pond levels). In the OASIS model, no consideration is given to the rest of Exelon's generation system.

3.4.5 Energy Price Time Series

In order to execute the model optimization routine, the OASIS model required hourly energy prices to determine when and how much each station would generate. For the model calibration, historic hourly price data was input into the model. For future production runs, Exelon will provide an estimated hourly price forecast data for 2014 using the hourly time series data from the specified price year for all modeled years. For example, the price specified on 1/1 at 1:00 PM in the input energy price data would be repeated for all modeled years (1/1/1930 1:00 PM, 1/1/1931 1:00 PM, etc.). For the purposes of this model, the same hourly pricing was used to operate Safe Harbor, Holtwood, Muddy Run and Conowingo.

The OASIS model does not account for external power conditions when dispatching the hydroelectric projects. For example, within the model, Conowingo and Muddy Run are dispatched without any knowledge of external energy or transmission system needs.

4. CALIBRATION PROCEDURE

The calibration goal was to have the model output accurately represent the hydrologic conditions in the lower Susquehanna River. This was achieved by comparing model outputs to several historic datasets (stage, flow, generation) from 2004-2007. Several constraints and modifications were added to the model to better match historic data. The historic datasets used for model calibration included Conowingo outflow, pond elevation and generation, and Muddy Run upper pond elevation and generation. Though Safe Harbor and Holtwood substantially impact the Susquehanna River's hydrology, no operational or outflow data were available for these projects. While limited modifications were made to the upstream projects (Safe Harbor, Holtwood) to better predict Conowingo Pond inflow, the ability to model these projects' operations was limited and not considered a primary objective of the model calibration. The following sections describe how each hydroelectric project on the lower Susquehanna River was modeled, including constraints and modifications added for calibration purposes.

4.1 Energy Price Time Series

Initial model runs resulted in all hydroelectric stations peaking more frequently than they historically did, often times two to three times per day, sometimes more. In addition, the model initially switched Muddy Run operations on and off nearly hourly, reflecting even small hour-to-hour price variations. This was likely a result of the model's optimization routine. To reduce overall volatility, the energy price time series was recalculated to reflect a 7-hour moving average of actual energy prices for flow optimization. This greatly reduced station volatility, and resulted in model output matching more realistic generation patterns.

4.2 Safe Harbor Hydroelectric Project

Safe Harbor Hydroelectric Project has a maximum licensed hydraulic capacity of 110,000 cfs. Since no data were available to confirm typical operations, a "best gate" maximum turbine flow at the dam was assumed to be 80,000 cfs. Safe Harbor is operated to use 7-day flow and energy price foresight to maximize revenue. Safe Harbor has no minimum flow releases, and it was modeled as such. The model assumed there were no leakage flows leaving Safe Harbor.

4.3 Holtwood Hydroelectric Project

The model has two different versions of Holtwood. The pre-expansion conditions are used for the calibration run, while the post-expansion conditions will be used for future production runs. Holtwood is operated to use 7-day flow and energy price foresight to maximize revenue. No operations data were available to validate Holtwood generation or storage. However, Holtwood's limited storage and capacity relative to the other projects on the lower Susquehanna River resulted in the model predicting outflows highly reflective of Safe Harbor outflows. While Holtwood outflows do largely reflect Safe Harbor operations, anecdotal information and Conowingo Pond elevation data suggest the model appears to underpredict the buffering capacity of Lake Aldred and/or Holtwood outflow structures. This results in outflow hydrographs from Holtwood with unrealistically rapid flow changes. To reduce the volatility of Holtwood's outflow hydrographs, Holtwood input into Conowingo Pond is converted into a 9-hour moving average from the initially calculated outflow hydrograph.

4.4 Muddy Run Pumped Storage Project

Muddy Run was optimized in parallel with Conowingo within the OASIS model. Initial results showed that revenue optimization resulted in the model greatly overpredicting the use (pumping and generation) of Muddy Run. This included not only how frequently it was operated, but also the magnitude of flows being pumped and released. In particular, the model frequently drew Muddy Run below 475 ft, while historic records indicate that Muddy Run rarely drops below 475 ft. To fix this issue, a constraint was added to the model preventing Muddy Run elevations from dropping below 475 ft. Additionally, a flow variation constraint of 15,000 cfs per hour was applied to both pumping and generation. This prevented rapid hourly transitions between pumping and generation that do not occur in actual operations.

The model also initially did a poor job of estimating Muddy Run's operating times. There were several instances when price variations dictated either pumping or generation at times when Muddy Run has not been historically operated (e.g. pumping at 6 PM or generating at 3 AM). To better understand Muddy Run's typical operations[5], historic records were analyzed to show when Muddy Run typically pumped, generated or varied. The results showed that operations typically followed a predictable pattern where some hours of the day were solely associated with either pumping or generation (e.g. generation almost

[5] Muddy Run operations are described in detail in Muddy Run Study 3.2: Hydrologic Study of the Muddy Run Water Withdrawal and Return Characteristics.

never occurred at 2AM). Thus, program restrictions were introduced into the modeling parameters to prevent unrealistic pumping and generation at certain hours of the day, as outlined in Table 4.4-1.

4.5 Conowingo Hydroelectric Project

The Conowingo generation schedule and flow releases were optimized in parallel with Muddy Run to maximize total combined revenue using 7-day flow and energy price foresight. Initial model runs showed three main differences between historic and modeled operations. First, the model tended to overpredict peaking frequency. Historic records (2004-2007) showed most days had one or two peaking cycles, while initial model results would occasionally peak several (up to five) times per day. Second, initial model results often showed Conowingo releasing flow in concentrated one or two hour periods at maximum generation, while historic records showed the station released a lower flow for a longer time period. This resulted in a flow duration curve showing a much larger amount of time at maximum generation than was historically observed. Third, elevation duration curves showed that the model drew Conowingo Pool below 105 ft fairly frequently, while historical records indicate Conowingo Pond very rarely drops below that elevation.

Several model constraints were placed on Conowingo to address the described issues. To reduce peaking frequency, a flow variation constraint of 40,000 cfs per hour was applied to Conowingo. To reduce the frequency of Conowingo Pond elevations dropping below 105 ft, the model was prevented from using elevations below 105 ft as active storage except for minimum flow releases. To reduce the frequency of flows at maximum generation, two regression equations were used to limit Conowingo capacity when Marietta flows were less than 55,000 cfs. The equation used when Marietta flows are less than 25,000 cfs is:

$$Q_{C-peak} = -211.8 + 14.47 \bullet Q_M$$

where $Q_{C\text{-}peak}$ is the peak discharge allowed at Conowingo for that one-hour timestep [cfs], and Q_M is the discharge volume at Marietta during the same timestep [cfs]. The equation used when Marietta flows are between 25,000 cfs and 55,000 cfs is:

$$Q_{C-peak} = -107054 + 21.17 \bullet Q_M - 2436.3\sqrt{Q_M} + 55053.4 \bullet \log(Q_M) - 0.08136 \bullet (Q_M)^{1.5}$$

where $Q_{C\text{-}peak}$ is the peak discharge allowed at Conowingo for that one-hour timestep [cfs] and Q_M is the discharge volume at Marietta during the same timestep [cfs].

5. CALIBRATION RESULTS

The purpose of the model calibration was to compare model-generated discharge, stage, and generation outputs to historic (2004-2007) data. The calibration process, including constraints and justifications, was described in Section 4. The following sections compare the model outputs to historic data from the calibration period of 2004-2007.

5.1 Discharge

Flow duration curves showed that the model's overall flow distribution closely matched the observed flow distribution (Figure 5.1-1). The model still showed a greater tendency to release flows at 86,000 cfs, but the overall frequency of releases at 86,000 dropped dramatically from initial model runs.

5.2 Stage

Annually, modeled and observed Conowingo Pond elevation distributions matched within 0.75 ft, with the model generally overpredicting pond elevations (Figure 5.2-1). However, the model was more accurate during the summer months, with the modeled elevation distribution matching the observed elevation distribution within +/- 0.25 ft (Figure 5.2-2).

5.3 Generation

The operations model was close to historic (2004-2007) annual average generation. Table 5.3-1 compares each stations' average annual generation. Energy generation was overpredicted by 1.6% at Conowingo and net energy use was overpredicted by 4.1% at Muddy Run.

6. CONCLUSIONS

The operations model calibration results show that historic operations at Conowingo and Muddy Run were matched well. Historic flow duration curves were matched well. Modeled and observed Conowingo Pond elevation distributions were within +/- 0.75 ft, but the summertime (growing season) pond elevation distribution matched within +/- 0.25 ft. Overall, the matches to historic data distributions indicate that the operations model is appropriate for use in long-term hydrologic applications in the lower Susquehanna River.

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TABLE 3.3.2-1: SOURCES OF HYDROLOGIC DATA FOR THE SRBC OASIS MODEL

Type of Data	Source
Streamflows	USGS Gage Data
Susquehanna basin reservoir historical stages	SRBC 2006, US Army Corps of Engineers
Evaporation for northern basin and southern basin	SRBC 2006
Water supply demands	SRBC 2006
Baltimore system inflows and demands	Rummel et al. 2001

TABLE 3.3.2-2: LIST OF USGS STREAM GAGES USED TO DEVELOP SRBC AND EXELON HYDROLOGIC INPUT RECORDS

Stream	Location	St.	Gauge Number	Hydro Start Date	Gauge End Date	Drain. Area	Ref. Name	Ref. Num.	Comments
Susquehanna R	Colliersville	NY	01497500	10/1/1928	09/30/1968	349	Collie	G1	
Susquehanna R	Unadilla	NY	01500500	07/1/1938	Present	982	**Unadil**	G2	Missing 04/1995 - 09/2000 *
Unadilla R	Rockdale	NY	01502500	12/1/1929	Present	520	Rockda	G3	Missing 10/1933 – 01/1937 and 04/1995 - 09/2000
Susquehanna R	Conklin	NY	01503000	10/1/1928	Present	2232	**Conkli**	G4	
Tioughnioga R	Cortland	NY	01509000	06/1/1938	Present	292	Cortla	G5	
Tioughnioga R	Itaska	NY	01511500	10/1/1929	06/30/1967	730	**Itaska**	G6	
Chenango R	Chenango Forks	NY	01512500	10/1/1928	present	1483	**Chenan**	G7	
Susquehanna R	Vestal	NY	01513500	10/1/1937	06/30/1967	3941	**Vestal**	G8	
Susquehanna R	Waverly	NY	01515000	03/1/1937	present	4773	**Waverl**	G9	Missing 04/1995 – 09/2000 **
Cowanesque R	Lawrenceville	PA	01520000	10/1/1951	present	298	Lawren	G10	outlet of Cowanesque Lk
Tioga R	Lindley	NY	01520500	04/1/1930	03/31/1995	771	**Lindle**	G11	u/s node 210
Tioga R	Erwins	NY	01526500	10/1/1928	present	1377	**Erwins**	G12	d/s node 210
Chemung R	Corning	NY	01529950	10/1/1974	present	2005	**Cornin**	G13	
Chemung R	Chemung	NY	01531000	10/1/1928	present	2506	**Chemun**	G14	
Susquehanna R	Towanda	PA	01531500	10/1/1928	present	7797	**Towand**	G15	
Towanda Ck	Monroeton	PA	01532000	10/1/1928	present	215	Monroe	G16	
Susquehanna R	Meshoppen	PA	01533400	10/1/1976	present	8720	**Meshop**	G17	
TunkhannockCk	Tunkhannock	PA	01534000	10/1/1928	present	383	Tunkha	G18	enters d/s Meshoppen, 255
Lackawanna R	Old Forge	PA	01536000	10/1/1938	present	332	Oldfor	G19	
Susquehanna R	Wilkes Barre	PA	01536500	10/1/1928	present	9960	**Wilkes**	G20	
Susquehanna R	Danville	PA	01540500	10/1/1928	present	11,220	**Danvil**	G21	
WBr Susquehanna R	Bower	PA	01541000	10/1/1928	present	315	Bowerp	G22	Curwensville Lk inflow, 290
Clearfield Ck	Dimeling	PA	01541500	10/1/1928	present	371	Dimeli	G23	
WBr Susquehanna R	Karthaus	PA	01542500	03/1/1940	09/30/2007	1462	**Kartha**	G24	Missing 04/1991 - 09/2004, don't use after 1991
Driftwood Br	Sterling Run	PA	01543000	10/1/1928	present	272	Sterli	G25	
Sinnemahoning Ck	Sinnemahoning	PA	01543500	10/1/1938	present	685	**Sinnem**	G26	
First Fk	Stevenson	PA	01544000	10/1/1953	present	245	Fifork	G27	inflow to Stevenson, 305
Kettle Ck	Cross Fork	PA	01544500	10/1/1940	present	136	Crossf	G28	inflow to Bush Dam, 320
WBr Susquehanna R	Renovo	PA	01545500	10/1/1928	present	2975	**Renovo**	G29	
Spring Ck	Axeman	PA	01546500	10/1/1940	present	87.2	Axeman	G30	
Bald Eagle Ck	Milesburg	PA	01547200	10/1/1955	present	265	**Milesb**	G31	
Bald Eagle Ck	Blanchard	PA	01547500	05/1/1954	present	339	**Blanch**	G32	outlet of Sayers, 345
Blockhouse Ck	English Center	PA	01549500	10/1/1940	present	37.7	Englis	G33	

Stream	Location	St.	Gauge Number	Hydro Start Date	Gauge End Date	Drain. Area	Ref. Name	Ref. Num.	Comments
Pine Ck	Waterville	PA	01549700	10/1/1957	present	944	Waterv	G34	
Lycoming Ck	Trout Run	PA	01550000	10/1/1928	present	173	Troutr	G35	
WBr Susquehanna R	Williamsport	PA	01551500	10/1/1928	present	5682	**Wiport**	G36	assume d/s of Williamsport, 370
Chillisquaque Ck	Washingtonville	PA	01553700	05/1/1979	present	51.3	Washin	G37	d/s dam, 385
Susquehanna R	Sunbury	PA	01554000	10/1/1937	present	18,300	**Sunbur**	G38	d/s confluence w/ W. Br. Susq.
Penns Ck	Penns Creek	PA	01555000	10/1/1929	present	301	Pennsc	G39	
E Mahantango Ck	Dalmatia	PA	01555500	10/1/1929	present	162	Dalmat	G40	
Frankstown Br	Williamsburg	PA	01556000	10/1/1928	present	291	Wiburg	G41	
Juniata R	Huntingdon	PA	01559000	10/1/1941	present	816	Junhun	G42	does not include Raystown, inflow 405
Raystown Br	Saxton	PA	01562000	10/1/1928	present	756	Saxton	G43	unregulated inflow to Raystown
Raystown Br	Huntingdon	PA	01563200	10/1/1946	present	960	Rayhun	G44	Raystown outflow
Juniata R	Mapleton Depot	PA	01563500	10/1/1937	present	2030	**Maplet**	G45	includes Raystown
Aughwick Ck	Three Springs	PA	01564500	06/1/1938	present	205	3Sprin	G46	
Juniata R	Newport	PA	01567000	10/1/1928	present	3354	**Newpor**	G47	assumed d/s of Newport
Sherman Ck	Shermans Dale	PA	01568000	10/1/1929	present	200	Sherma	G48	
Clarks Ck	Carsonville	PA	01568500	10/1/1937	12/31/1996	22.5	Carson	G49	
Letort Spring Run	Carlisle	PA	01569800	07/1/1976	present	21.6	Carlis	G50	
Conodoguinet Ck	Hogestown	PA	01570000	10/1/1929	present	470	Hogest	G51	Missing 10/1958 - 06/1967
Susquehanna R	Harrisburg	PA	01570500	10/1/1928	present	24,100	**Harris**	G52	assumed d/s of Harrisburg
Yellow Breeches Ck	Camp Hill	PA	01571500	07/1/1954	present	216	Camphi	G53	div to local water supplier, inflow to 460
Swatara Ck	Harper Tavern	PA	01573000	10/1/1928	present	337	Harper	G54	
W Conewago Ck	Manchester	PA	01574000	10/1/1928	present	510	Manche	G55	
Codorus Ck	Spring Grove	PA	01574500	05/1/1929	present	75.5	Spring	G56	Missing 10/1964 - 10/1965
Codorus Ck	York	PA	01575500	08/1/1940	09/30/1996	222	Yorkpa	G57	
Susquehanna R	Marietta	PA	01576000	10/1/1931	present	25,990	**Mariet**	G58	
Conestoga R	Lancaster	PA	01576500	10/1/1928	present	324	Lancas	G59	Missing 04/1932 - 03/1933
Susquehanna R	Conowingo	MD	01578310	10/1/1967	present	27,100	Conowi	G60	
Deer Ck	Rocks	MD	01580000	10/1/1928	present	94.4	Rocksm	G61	

TABLE 3.3.2-3: DRAINAGE AREA (DA) [MI²] AT SRBC MODEL NODES

Stream Nodes	Drainage Area (mi²)	OASIS Node
Susq R @ Colliersville	349	110
Susq R @ Oneonta	679	115
Susq R @ Unadilla	982	130
Ouleout Ck. @ mouth	110	
Unadilla R. @ Rockdale	520	135
Unadilla R. @ mouth	562	
Susq. R @ Bainbridge	1,610	140
Susq. R @ Conklin	2,232	145
Susq. R. @ Binghamton	2,286	165
Otselic R @ mouth	258	150
Tioughnioga R @ Whit. Pt.	457	155
Tiough. R. @ Itaska	730	160
Tiough. R. @ mouth	761	
Chenango R. @ mouth	1,605	
Susq. R. @ Vestal	3,941	175
Susq. R. @ Waverly	4,773	180
Susq. R @ Athens	4,933	245
Tioga R. @ Tioga	282	185
Crooked Ck @ mouth	132	195
Cowanesque R @ mouth	300	
Tioga R @ Lawrenceville	461	
Tioga R @ Lindley	771	205
Tioga R. @ Erwins	1,377	210
Tioga R. @ mouth	1,388	
Cohocton R @ Campbell	470	215
Cohocton R @ mouth	604	
Chemung R @ Corning	2,006	220
Chemung R @ Elmira	2,162	230
Chemung R @ Chemung	2,506	240
Chemung R @ mouth	2,595	
Susq. R @ Towanda	7,797	250
Susq R @ Meshoppen	8,720	255
Lackawanna R @ Old	332	270
Lackawanna R @ mouth	348	
Susq R above Wilkes Barre	9,539	275
Susq R @ Danville	11,220	280
Clearfield Ck @ Dimeling	371	295
Clearfield Ck @ mouth	393	
W. Br. Susq @ Karthaus	1.462	300
W. Br. Susq @ Keating	1.594	315
First Fk Sinn. @ mouth	267	
Sinnemahoning Ck@ Sinn	685	310
Sinnemahoning Ck@	686	
W. Br. Susq @ Renovo	2,975	325

Stream Nodes	Drainage Area (mi²)	OASIS Node
Kettle Ck @ mouth	246	
W. Br. Susq @ Lock Haven	3.350	350
Spring Ck @ Axemann	87.2	
Spring Ck @ mouth	143	
Bald Eagle Ck @ Milesburg	265	340
Bald Eagle Ck @ mouth	770	
W. Br. Susq @ Jersey Sh	5.167	365
Little Pine Ck @ mouth	185	
Pine Ckeek @ mouth	986	
W. Br. Susq @ Williamsport	5.682	370
W. Br. Susq @ Lewisburg	6.847	380
Chillisquaque Ck @ mouth	112	
W. Br. Susq @ mouth	6.981	
Susq R @ Sunbury	11.298	385
Susq R @ Dalmatia	19.254	
Raystown Br. Juniata R @	963	
Juniata R. @ Huntingdon	960	405
Juniata R. @ Mapleton Depot	2.030	410
Juniata R. @ Newport	3.354	415
Juniata R. @ mouth	3.404	
Susq. R @ Duncannon	19,727	420
Clarks Ck @ mouth	44.9	
Susq R @ Dauphin	23,489	435
Conodoguinet @ Hogestown	470	445
Conodoguinet @ mouth	506	
Susq. R @ Harrisburg	24,100	450
Yellow Breeches @ Camp	216	460
Yellow Breeches @ mouth	219	
Swatara Ck @ Lebanon	337	465
Swatara Ck @ mouth	571	
W. Conewago Ck @ mouth	515	
Susq R @ Marietta	25,990	495
Codorus Ck @ Glatfelter Div	75.5	510
E. Br. Codorus @ mouth	44.5	
S. Br. Codorus @ mouth	117	
Codorus @ York	222	535
Codorus @ mouth	278	
Conestoga R @ Lancaster	324	545
Conestoga R @ mouth	477	
Muddy Run @ mouth	9.4	565
Deer Ck @ Rocks	94.4	600
Deer Ck @ Darlington	168	610
Deer Ck @ mouth	169	
Octoraro Ck @ mouth	223	

Dams	Drainage Area (mi²)	Stream
Whitney	257	Otselic R
Otsego	75.3	Susq R
East Sidney	103	Ouleout Ck
Tioga	280	Tioga R
Hammond	122	Crooked Ck
Cowanesque	298	Cowanesque R
Curwensville	365	WBrSusqR
Stevenson	243	First Fork Sinn
Bush	226	Kettle Ck
Sayers	339	Bald Eagle Ck
Glendale	41.9	
Shawnee	37.5	
Raystown	959	Raystown Br
Little PineCr	165.4	Little Pine Ck
Pinchot	17.5	
York Haven	24,973	Susq R
Marburg	24.3	Codorus Ck
Indian Rock	94	Codorus Ck
Williams	41.6	E. Br. Codorus Ck
Redman	40	E. Br. Codorus Ck
Safe Harbor	26,090	Susq R
Holtwood	26,786	Susq R
Muddy Run	9.2	Muddy Run
Octoraro	139.6	Octoraro Ck
Conowingo	27,100	Susq R
Chillisquaque		Chill. Ck
Letterkenny	33.8	Conodoguinet Ck
Dehart	21.6	Clarks Ck

u/s =
d/s = downstream
conf. = confluence
DA = drainage area in square miles

TABLE 3.3.2-4: DEMAND AND STORAGE RESERVOIR NODES IN THE SRBC MODEL

Demand Nodes				Reservoir Nodes	
Number	Name	Number	Name	Number	Name
170	Binghamton	182	Waverly	175	Whitney Point
225	Corning	235	Chemung	190	Tioga/Hammond
265	Wilkes Barre	285	Berwick PP	200	Cowanesque
316	Keating	366	Jersey Shore	290	Curwensville
382	Montour PP	386	Sunbury	345	Sayers
406	Huntingdon	416	Newport	400	Raystown
421	Duncannon	451	Harrisburg	570	Conowingo
476	York Haven Local	480	Three Mile Island PP		
485	Brunner Island PP	496	Marietta Local		
550	Lancaster	575	Peach Bottom PP		

TABLE 3.3.3-1: EXPLICITLY ROUTED RIVER REACHES' MUSKINGUM ROUTING COEFFICIENTS

Reach	Nodes	C1	C2	C3	Calibration Period
Oneonta to Unadilla	110 – 115	1.000	0.000	0.000	1940 – 1944
Bainbridge to Conklin	140 – 145	0.108	0.838	0.054	1940 – 1944
Itaska to Chenango Fork	155 – 160	0.925	0.000	0.075	1930 – 1934
Vestal to Waverly	175 – 180	0.888	0.112	0.000	1960 – 1964
Corning to Chemung	220 – 240	0.836	0.164	0.000	1980 – 1984
Towanda to Meshoppen	250 – 255	1.000	0.000	0.000	1980 – 1984
Meshoppen to Wilkes Barre	255 – 275	0.299	0.701	0.000	1980 – 1984
Wilkes Barre to Danville	275 – 280	0.576	0.424	0.000	1980 – 1984
Dimeling to Karthaus	297 – 300	0.559	0.154	0.287	1950 – 1954
Williamsport to Lewisburg	370 – 380	0.537	0.413	0.050	1980 – 1984
Sunbury to Duncannon	385 – 420	0.575	0.425	0.000	1980 – 1984
Mapleton Depot to Newport	412 – 415	0.431	0.439	0.130	1980 – 1984

TABLE 3.4.3.1-1: SAFE HARBOR'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Turbine Capacity – hydraulic	110,000 cfs	Kleinschmidt 2006a
Turbine Capacity – reported maximum generation	417 MW	Kleinschmidt 2006a
Turbine Efficiency	Unavailable- Assumed an efficiency of 80%	None
Recreational Stage	Unknown- not modeled.	---
Normal Elevation Range	224.2 – 227.2 feet, the model will not drop the pool elevation below 224.2 feet throughout the year	SRBC 2006
Fish Passage Flows	4/15 – 6/15, daytime (7 am-7 pm) – 300 cfs, nighttime – 0 cfs, unavailable for power	Normandeau
Dam Leakage	Unavailable- assumed 0 cfs.	---
Discharge Rating Curve	Unavailable	---
Headloss Curve	Unavailable- none used.	---

TABLE 3.4.3.2-1: HOLTWOOD'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Turbine Capacity – hydraulic	31,500 cfs (existing), 61,460 cfs (proposed)	Kleinschmidt 2006a
Turbine Capacity – reported maximum generation	107 MW (existing), 195 MW (proposed)	Kleinschmidt 2006a Kleinschmidt 2006b
Turbine Efficiency	85%- a constant was used over the range of head and flow conditions.	Kleinschmidt 2006a
Recreational Stage	167.5 feet May 15 to Sep 15, the model will not drop the pool elevation below 167.5 ft during May 15-Sep 15.	Kleinschmidt 2006a
Normal Elevation Range	163.5 – 169.75 feet, the model will not drop the pool elevation below 163.5 feet throughout the year.	Kleinschmidt 2006a
Fish Passage Flows	4/15 – 6/15, daytime (7 am-7 pm) – 450 cfs, nighttime – 0 cfs, unavailable for power.	Kleinschmidt 2006b
Dam Leakage	Unavailable - Assumed 0 cfs	
Headloss Rating Curve	Unavailable - none used	---

TABLE 3.4.3.3-1: MUDDY RUN'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Pump and Turbine Capacities – hydraulic	32,000 cfs – generation 28,000 cfs – pumping 25,600 cfs – pumping (alternative value)[6]	Exelon
Turbine Capacity – nameplate generation	800 MW	Exelon
Turbine Efficiency	A constant turbine efficiency of 87% was used. This accounts for generator energy losses and other headlosses.	Exelon, based on calibration
Pump Efficiency	A constant pump efficiency of 90% was used.	Exelon
Normal Elevation Range	470 ft – 520 ft	Exelon
Headloss Curve	Headlosses losses are incorporated in turbine efficiency	None

TABLE 3.4.3.4-1: CONOWINGO'S ENGINEERING ATTRIBUTES AND DATA SOURCES

Attribute	Values	Source
Turbine Capacity	Hydraulic - 86,000 cfs; Nameplate Generation – 573 MW	Exelon
Turbine Efficiency	Constant of 0.79 over the range of flow and head conditions.	Based on calibration process
Recreational Stage	107.2 ft, weekends May 22 – Sep 7, the model will not drop the pool elevation below 107.2 ft on weekends from May 22-Sep 7[7].	Exelon
Normal Elevation Range	104.7 ft – 109.2 ft, the model should not drop the pool elevation below 104.7 ft throughout the year.	SRBC-2002
Fish Passage Flows	4/1 – 6/15: daytime (7 am-7 pm) – 310 cfs, nighttime – 45 cfs, fish passage flows are unavailable for power.	Exelon
Dam Leakage	800 cfs, unavailable for power and not included in the fish passage flows	SRBC-2002
Headloss Curve	Unavailable- not incorporated in the model	----

[6] The published pump capacity is 28,000 cfs, but operations data show that 25,600 cfs should be used in the model.

[7] The weekend recreation limit was incorrectly reported as extending until September 30 in SRBC (2002)

TABLE 4.4-1: MUDDY RUN MODELING PROGRAM PARAMETERS, BY HOUR.

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
12:00 AM							
1:00 AM							
2:00 AM							
3:00 AM							
4:00 AM							
5:00 AM							
6:00 AM							
7:00 AM							
8:00 AM							
9:00 AM							
10:00 AM							
11:00 AM							
12:00 PM							
1:00 PM							
2:00 PM							
3:00 PM							
4:00 PM							
5:00 PM							
6:00 PM							
7:00 PM							
8:00 PM							
9:00 PM							
10:00 PM							
11:00 PM							
Yellow Means No Generation, Blue Means No Pumping, and Green Means Both Pumping and Generating Can Occur.							

TABLE 5.3-1: HISTORIC (2004-2007) AND MODELED AVERAGE ANNUAL ENERGY GENERATION COMPARISON FOR MUDDY RUN AND CONOWINGO

	Conowingo		Muddy Run	
	Historic	Modeled	Historic	Modeled
Average Annual Net Energy Production (GWh/yr)	1,955	1,986	-467	-489
Difference from Historic (2004-2007) Average (%)	-	1.57	-	4.60

FIGURE 3.3.2-1: LOCATIONS OF USGS FLOW GAGES IN THE SUSQUEHANNA RIVER BASIN[8].

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[8] Source: SRBC 2006

FIGURE 3.4.3.1-1: SAFE HARBOR ELEVATION VERSUS AREA AND STORAGE CURVES

Elevation (ft)	Storage (acre-ft)	Surface Area (acres)
218.0	43,500	4,200
224.0	72,800	5,200
227.2	91,000	7,200
228.0	97,300	7,200

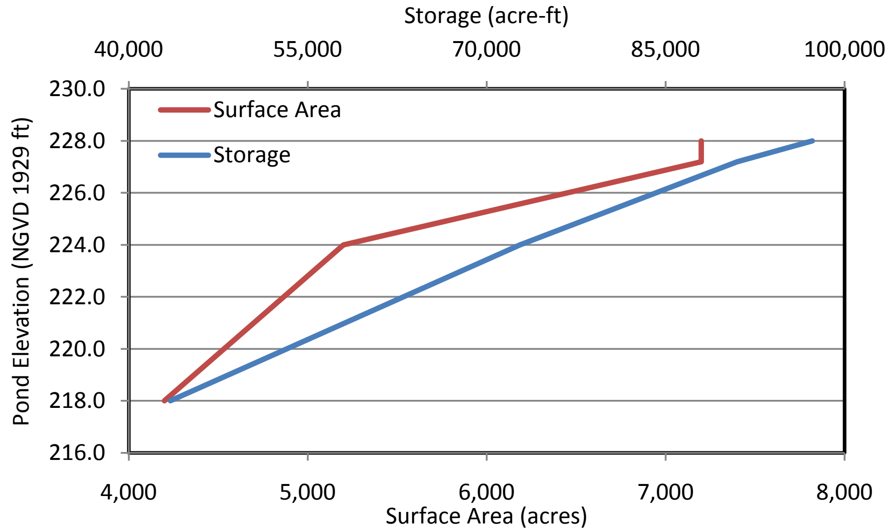


FIGURE 3.4.3.2-1: HOLTWOOD ELEVATION VERSUS AREA AND STORAGE CURVES

Elevation (ft)	Storage (acre-ft)	Surface Area (acres)
160.0	33,480	1,354
163.5	39,600	2,050
165.0	42,850	2,317
166.0	45,220	2,398
167.5	48,940	2,525
169.8	54,770	2,648
171.0	58,120	2,702

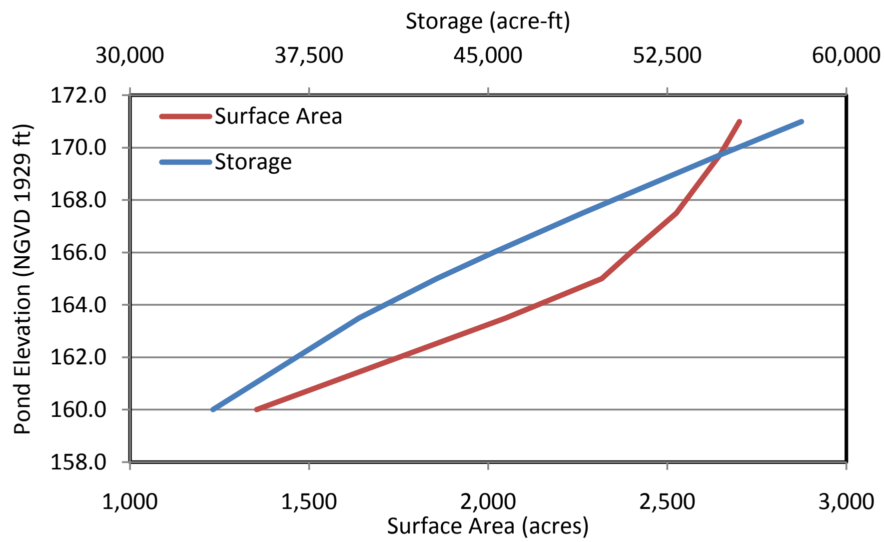


FIGURE 3.4.3.2-2: HOLTWOOD MINIMUM AND MAXIMUM POOL ANNUAL SCHEDULE

Date	Minimum Elevation (ft)	Maximum Elevation (ft)
1-Jan	163.5	169.75
14-May	163.5	169.75
15-May	167.5	169.75
15-Sep	167.5	169.75
16-Sep	163.5	169.75
31-Dec	163.5	169.75

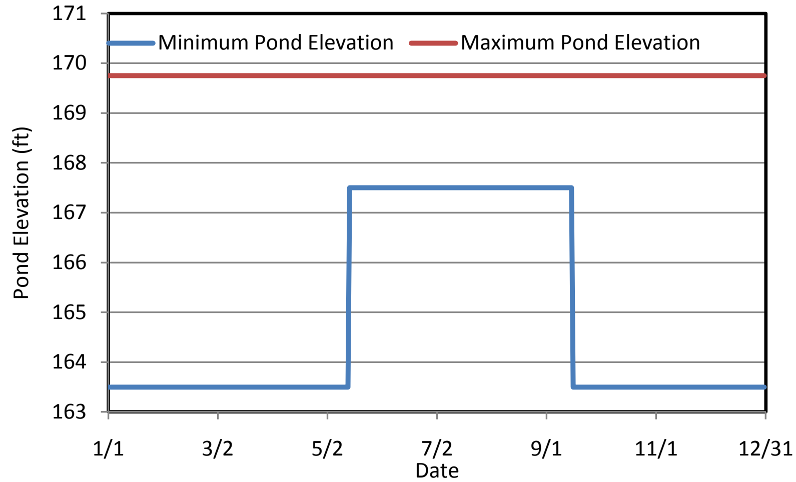
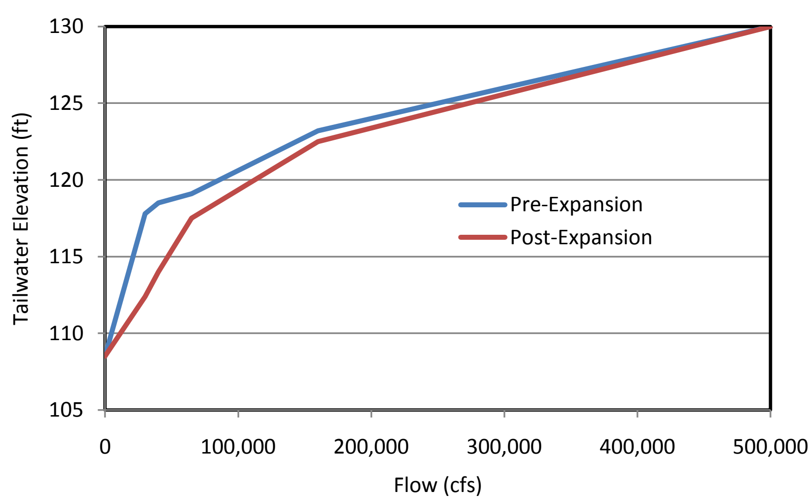


FIGURE 3.4.3.2-3: HOLTWOOD PRE AND POST-EXPANSION TAILWATER RATING CURVES[9].

Flow (cfs)	Pre-Expansion Elevation (ft)	Post-Expansion Elevation (ft)
0	108.5	108.5
30,000	117.8	112.4
40,000	118.5	114.0
65,000	119.1	117.5
160,000	123.2	122.5
500,000	130.0	130.0



[9] Holtwood tailwater can be influenced by Conowingo Pond fluctuations.

FIGURE 3.4.3.3-1: MUDDY RUN ELEVATION VERSUS AREA AND STORAGE CURVES

Elevation (ft)	Storage (acre-ft)	Surface Area (acres)
350.0	1,000	45
375.0	2,500	80
400.0	5,000	145
425.0	10,000	225
450.0	17,000	355
470.0	26,000	500
475.0	29,000	540
500.0	44,000	760
520.0	60,500	1,040

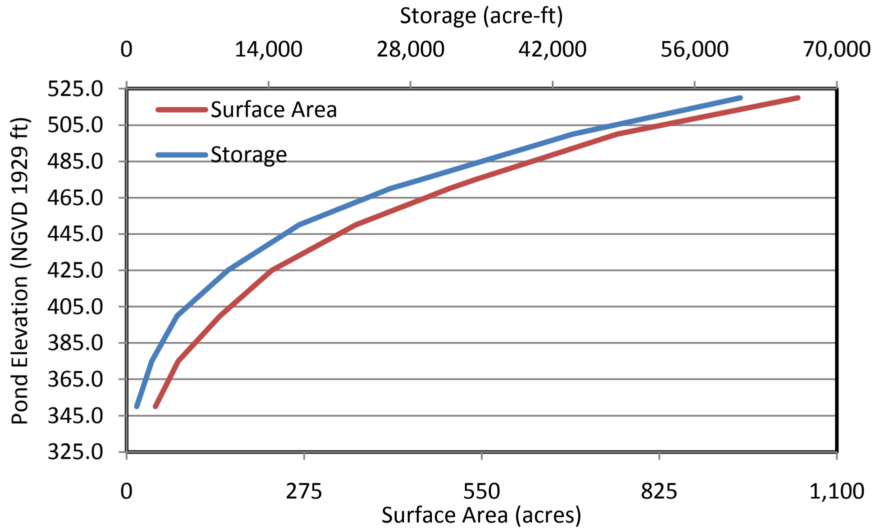


FIGURE 3.4.3.4-1: CONOWINGO ELEVATION VERSUS AREA AND STORAGE CURVES

Elevation (ft)	Storage (acre-ft)	Surface Area (acres)
94.5	189,000	7,502
95.2	194,000	7,603
95.9	199,000	7,683
96.5	204,000	7,762
97.2	209,000	7,837
97.8	214,000	7,901
98.5	219,000	7,969
99.1	224,000	8,038
99.7	229,000	8,094
100.0	230,600	8,114
100.5	234,600	8,151
101.5	242,800	8,202
102.5	251,000	8,254
103.5	259,200	8,325
104.5	267,600	8,365
105.5	275,900	8,430
106.5	284,400	8,470
107.5	292,200	8,530
108.5	301,400	8,575
109.5	310,000	8,625

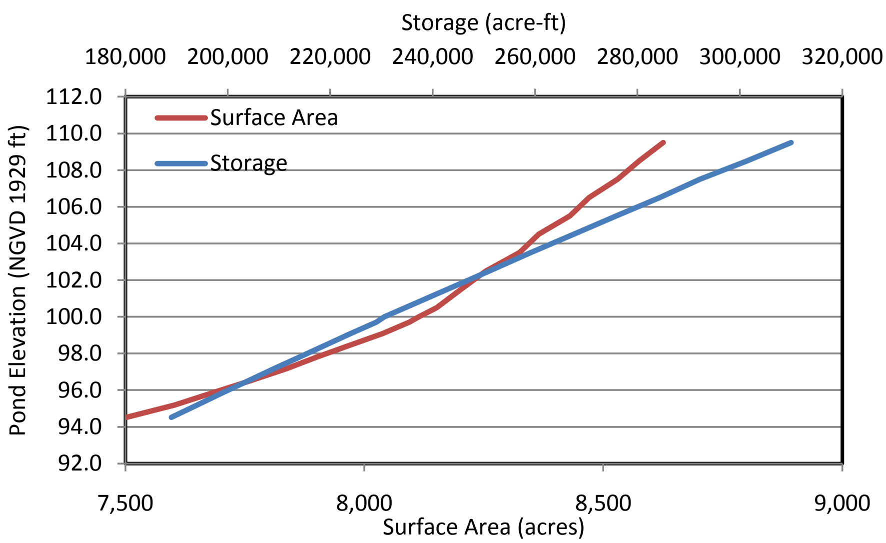


FIGURE 3.4.3.4-2: CONOWINGO POND MINIMUM AND MAXIMUM ELEVATION[10] ANNUAL SCHEDULE.

Date	Minimum Elevation (ft)	Maximum Elevation (ft)	Peach Bottom
1-Jan	104.7	109.2	104.2
21-May	104.7	109.2	104.2
22-May	107.2	109.2	104.2
7-Sep	107.2	109.2	104.2
8-Sep	104.7	109.2	104.2
31-Dec	104.7	109.2	104.2

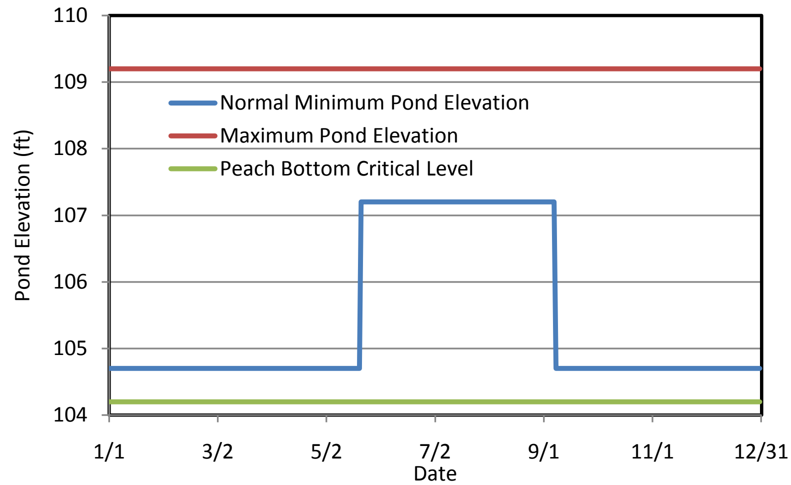
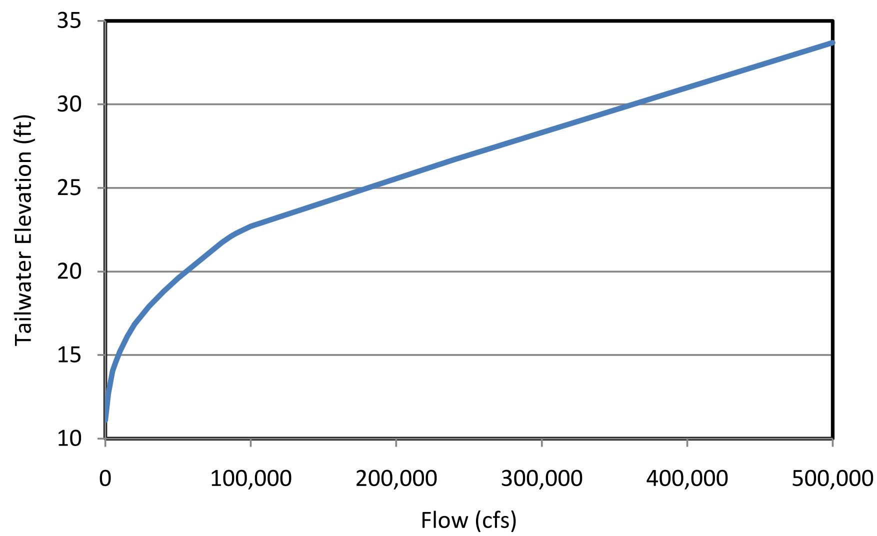


FIGURE 3.4.3.4-3: CONOWINGO DAM TAILWATER RATING CURVE.

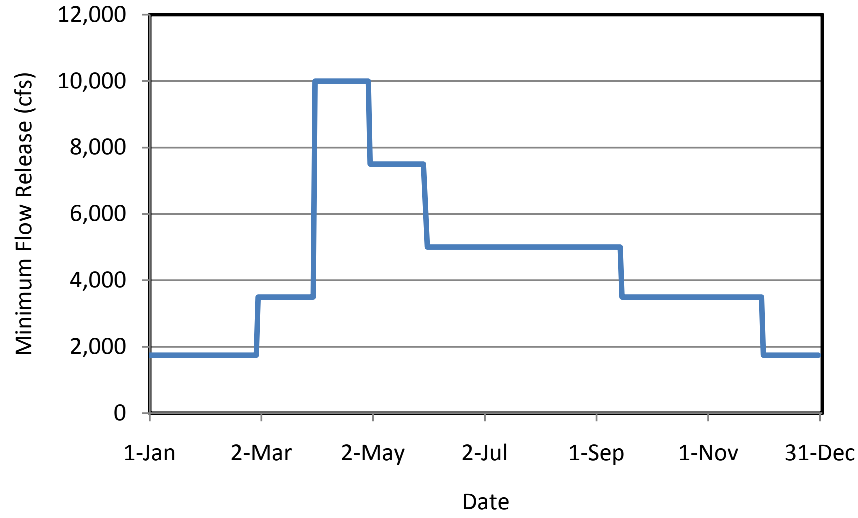
Discharge	Tailwater Elevation (ft)
0	11.10
2,000	12.70
5,000	14.05
7,000	14.55
10,000	15.20
15,000	16.12
20,000	16.85
30,000	17.92
40,000	18.80
50,000	19.60
60,000	20.32
70,000	21.02
80,000	21.73
86,000	22.10
90,000	22.30
100,000	22.70
240,000	26.70
500,000	33.70



[10] Normal minimum pond refers to the elevation at which pond levels are maintained except to meet minimum flow releases. The Peach Bottom critical level refers to the elevation below which Peach Bottom begins to experience cooling issues. Pond levels are not allowed to drop below the Peach Bottom critical level under any circumstances.

FIGURE 3.4.3.4-4: CONOWINGO DAM SEASONALLY-VARYING MINIMUM FLOW RELEASES[11].

Date	Minimum Flow (cfs)
1-Jan	1,750
28-Feb	1,750
1-Mar	3,500
31-Mar	3,500
1-Apr	10,000
30-Apr	10,000
1-May	7,500
30-May	7,500
1-Jun	5,000
14-Sep	5,000
15-Sep	3,500
30-Nov	3,500
1-Dec	1,750
31-Dec	1,750



[11] The 1,750 cfs minimum flow for the period December 1-February 28 reflects an average of the 6 hours on, 6 hours off at 3,500 cfs, as stipulated in the minimum flow agreement.

FIGURE 5.1-1: HOURLY FLOW DURATION CURVE COMPARING ANNUAL MODELED AND OBSERVED CONOWINGO FLOW DISTRIBUTIONS

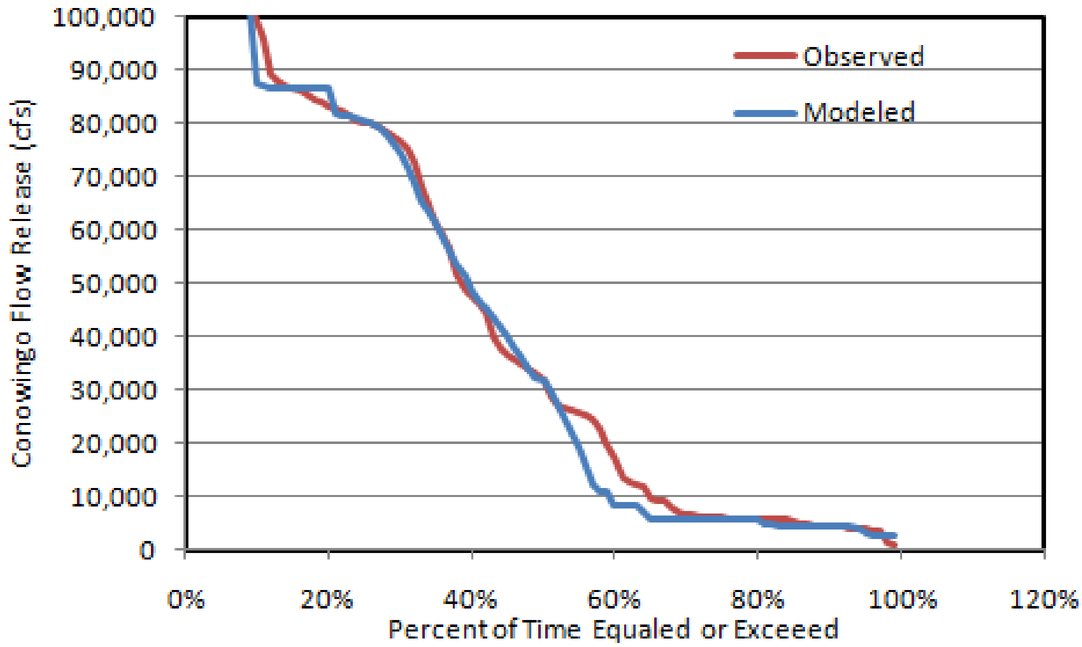


FIGURE 5.2-1: HOURLY ELEVATION DURATION CURVE COMPARING ANNUAL MODELED AND OBSERVED CONOWINGO POND ELEVATION DISTRIBUTIONS

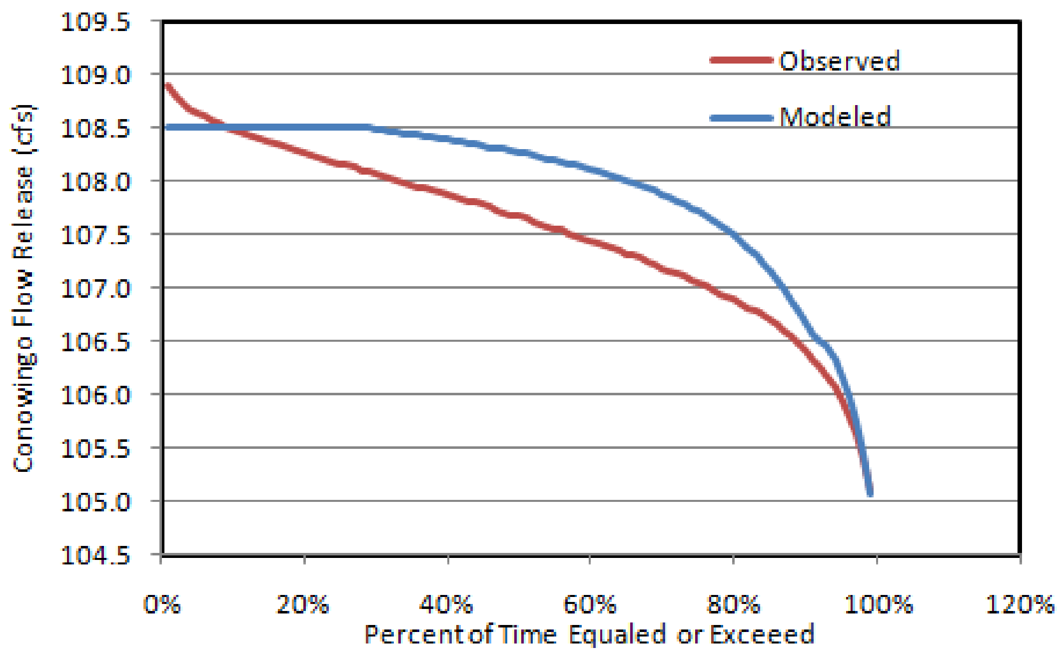
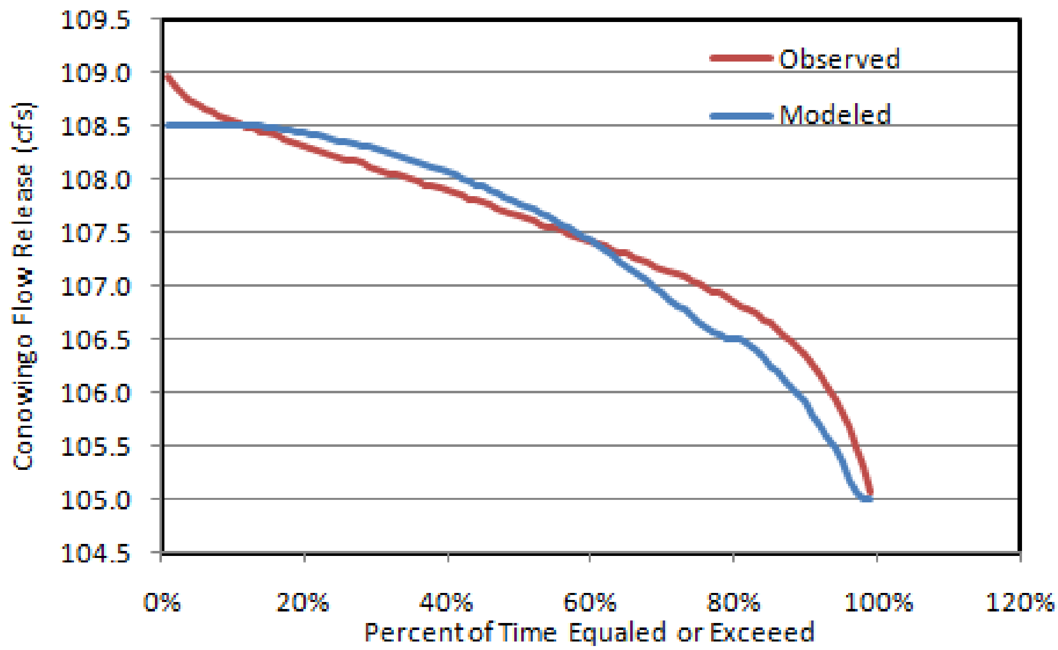


FIGURE 5.2-2: HOURLY ELEVATION DURATION CURVE COMPARING SUMMER (JULY-SEPTEMBER) MODELED AND OBSERVED CONOWINGO POND ELEVATION DISTRIBUTIONS



FINAL STUDY REPORT
HYDROLOGIC STUDY OF THE LOWER SUSQUEHANNA RIVER
CONOWINGO HYDROELECTRIC PROJECT
RSP 3.11

FERC PROJECT NUMBER 405

Prepared for:

Exelon.

Prepared by:

Gomez and Sullivan Engineers

August 2012

EXECUTIVE SUMMARY

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt Conowingo Hydroelectric Project (Conowingo Project). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. FERC issued the final study plan determination for the Conowingo Project on February 4, 2010, approving the revised study plan with certain modifications.

FERC's final study plan determination required Exelon to conduct a hydrologic study of the lower Susquehanna River, which is the subject of this report. The objectives of this study are to: 1) describe the history of flow management practices in the lower Susquehanna River basin; 2) confirm the accuracy of the Conowingo USGS gage; 3) perform a statistical analysis to describe the lower Susquehanna River flow regime; 4) evaluate changes in Conowingo Project operations since energy deregulation laws came into effect in 1998; 5) conduct operations modeling production runs to evaluate various operating scenarios to understand how operational changes may impact water use in the lower Susquehanna River; and 6) develop a bathymetry map of the tailwater area below Conowingo Dam.

An initial study report (ISR) was filed on April 29, 2011, containing Exelon's 2010 study findings. A meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

There are eight main water users along the lower Susquehanna River, four of which are related to hydroelectric generation. This study describes the timeline of hydroelectric power in the lower Susquehanna River, as well as physically describes the layout of the water users in relation to the river.

Comparisons to downstream stage gages showed that there are questions about the Conowingo USGS gage's accuracy. Data collected in association with a June 2010 bathymetry survey showed nearly constant downstream water surface elevations at several gages, while the Conowingo USGS gage appeared to show relatively large stage variations. Though there are several potential reasons for gage inaccuracy, the most likely reason appears to be turbine interference. The gage is located on the downstream face of the dam, and is very close to one of the turbine generation units. The inaccuracies observed were associated with flows between 30,000 cfs and 50,000 cfs, but there was insufficient data to examine whether inaccuracies extended beyond this flow range. Results indicate that gage error may be nearly 20% under certain circumstances.

A statistical analysis of the Conowingo and Marietta USGS gages compared the flow regimes observed at both stations. Several comparison methodologies were utilized, with similar conclusions shown for all methods. The Marietta and Conowingo daily average flows matched reasonably well, with longer (weekly) flow comparisons matching nearly perfectly. Sub-daily (30-minute) flow data showed more substantial flow differences, with Conowingo's flow regime resembling that of a peaking or regulated system rather than the more natural-looking flow regime at Marietta. This was expected, as the cumulative effects of the four hydroelectric stations on the lower Susquehanna have the ability to substantially alter the river's natural hydrology.

Analyses were run to evaluate how Project operations had changed since energy deregulation laws came into effect on January 1, 1998. Pre and post-deregulation comparisons showed that there appeared to be little to no observable change in project operations. Flow exceedance curves showed little difference between pre and post-deregulation years. Sub-daily IHA-type metrics showed roughly the same number of days exceeding flashiness thresholds per year for both periods. A peaking analysis found post-deregulation years had approximately the same or less peaking days than pre-deregulation years. While flows change greatly year-to-year and the sub-daily flow data period of record was rather short (7 years), the limited data available indicates little evidence of any substantial pre and post-deregulation project operation changes.

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CDV	Coefficient of Diel Variation
CWA	Chester Water Authority
FERC	Federal Energy Regulatory Commission
IHA	Indicators of Hydrologic Alteration
ILP	Integrated Licensing Process
MW	Megawatt
NGO	Non-Government Organization
NOI	Notice of Intent
NREVS	Number of Reversals
OASIS	Operational Analysis and Simulation of Integrated Systems
PAD	Pre-Application Document
PBAPS	Peach Bottom Atomic Power Station
PPL	PPL Holtwood, LLC
PSP	Proposed Study Plan
PTF	Percent of Total Flow
RBF	Richards-Baker Flashiness Index
RSP	Revised Study Plan
SRBC	Susquehanna River Basin Commission
USGS	United States Geological Survey
WSE	Water Surface Elevation
WY	Water Year

1. INTRODUCTION

Exelon Generation Company, LLC (Exelon) has initiated with the Federal Energy Regulatory Commission (FERC) the process of relicensing the 573-megawatt (MW) Conowingo Hydroelectric Project (Project). Exelon is applying for a new license using the FERC's Integrated Licensing Process (ILP). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014.

As required by the ILP, Exelon filed their Pre-Application Document (PAD) and Notice of Intent (NOI) with FERC on March 12, 2009. On June 11 and 12, 2009, a site visit and two scoping meetings were held at the Project for resource agencies and interested members of the public. Following these meetings, formal study requests were filed with FERC by several resource agencies. Many of these study requests were included in Exelon's Proposed Study Plan (PSP), which was filed on August 24, 2009. On September 22 and 23, 2009, Exelon held a meeting with resource agencies and interested members of the public to discuss the PSP.

Formal comments on the PSP were filed with FERC on November 22, 2009 by Commission staff, and several resource agencies. Exelon filed a Revised Study Plan (RSP) for the Project on December 22, 2009. FERC issued the final study plan determination for the Project on February 4, 2010, approving the RSP with certain modifications.

The final study plan determination required Exelon to conduct a Hydrologic Study of the Lower Susquehanna River, which is this report's subject. This study's objectives are to:

1) Describe the history of flow management practices in the lower Susquehanna River basin
2) Confirm the accuracy of the Conowingo USGS gage
3) Perform a statistical analysis to describe the lower Susquehanna River flow regime
4) Evaluate changes in Conowingo Project operations since energy deregulation laws came into effect in 1998
5) Conduct operations modeling production runs to evaluate various operating scenarios to understand how operation changes may impact water use in the Lower Susquehanna River
6) Develop a bathymetric map of the tailwater area below Conowingo Dam

An initial study report (ISR) was filed on April 29, 2011, containing Exelon's 2010 study findings. A meeting was held on August 23 and 24, 2011 with resource agencies and interested members of the public. Formal comments on the ISR including requested study plan modifications were filed with FERC on March 21, 2012 by several resource agencies and interested members of the public. Exelon filed responses to the ISR comments with FERC on April 20, 2012. On May 21, 2012, FERC issued a study plan modification determination order. The order specified what, if any, modifications to the ISR should be made. For this study, FERC's May 21, 2012 order required no modifications to the original study plan. This final study report is being filed with the Final License Application for the Project.

2. BACKGROUND

The Susquehanna River is one of the United States mid-Atlantic region's major freshwater sources. In addition to the abundant natural resources provided by the basin, the river is an important energy source. The lower Susquehanna has several hydroelectric projects that collectively influence the river's flow characteristics greatly. In the approximately 45 miles between the Marietta, PA United States Geological Survey (USGS) gage (No. 01576000) and the mouth of the Susquehanna at Chesapeake Bay, there are three main channel dams and one pumped storage facility, all constructed for the purpose of hydroelectric energy generation. In addition to the hydroelectric energy generation, there are several other withdrawals for various uses, including power generation cooling water as well as drinking water withdrawals.

2.1 Flow Timeline and Water Users

The three major hydroelectric dams on the Lower Susquehanna, from upstream to downstream, are: Safe Harbor Hydroelectric Project, Holtwood Hydroelectric Project, and Conowingo Hydroelectric Project. All three dams were constructed in the early 20th century, and had licenses that were set to expire in 1980. Muddy Run Pumped Storage Project was granted a 50-year license in 1964, with an expiration date of 2014.

On August 14, 1980, FERC issued new licenses for Conowingo, Holtwood and Safe Harbor, but hearings were set to determine what measures would be necessary to implement an anadromous fish restoration program in the Susquehanna River. Stakeholders in the restoration program measures included the Conowingo licensees, the Fish and Wildlife Service of the United States Department of the Interior, the Pennsylvania Fish Commission, the Maryland Department of Natural Resources, the Pennsylvania Department of Environmental Resources, the Susquehanna River Basin Commission, the Upper Chesapeake Watershed Association Inc., and the Pennsylvania Federation of Sportsmen's Clubs. The restoration measures considered included permanent minimum flow releases and fish passage facilities. The FERC-issued license orders also required all three licensees to conduct water quality and fish/wildlife resource studies.

After several years of discussion between FERC, the licensees and the stakeholders an agreement was reached in 1985 which released Holtwood and Safe Harbor from maintaining minimum flow releases. No settlement was reached at that time involving Conowingo. In exchange for no minimum flow releases, Safe Harbor and Holtwood agreed to participate in and fund an anadramous fish restoration demonstration program and to build fish passage facilities in the future. Disputes with the Conowingo licensees, stakeholders and FERC continued through 1989, at which time a settlement was agreed to. The settlement stated that Conowingo would, among other stipulations, maintain a seasonally-varying minimum flow release.

Two of the projects' licenses do not expire until 2030. When Safe Harbor was relicensed in 1980, it proposed to add five new turbines to increase the authorized installed capacity of the project from 230 MW to 417.5 MW. Because of this substantial redevelopment, FERC issued a 50-year license for the project, to expire in 2030, even though the new licenses for Conowingo and Holtwood would expire in 2014. No minimum flow requirements were included in the new license for any of the projects. In 2009 Holtwood applied to expand their project capacity and as part of the expansion was granted a 16-year license extension, from 2014 to 2030. As part of the project expansion, Holtwood agreed to supply Conowingo with a continuous inflow of 800 cfs, and a daily volumetric flow equivalent to 98.7% of Conowingo's minimum continuous flow requirement aggregated over a 24 hour period, or net inflow. The agreement is contingent on Holtwood completing construction on the expansions, though the minimum flows must be supplied by no later than 2012.

There are eight main water users along the lower Susquehanna downstream of the Marietta, PA USGS gage, which is at river mile (RM) 45 (Figure 2.1-1). The Safe Harbor Hydroelectric Project is the farthest upstream, located at RM 32. This is followed by Holtwood Hydroelectric Project, located at RM 24. Downstream of Holtwood is Muddy Run Pumped Storage Project at RM 22. Peach Bottom Atomic Power Station (PBAPS) withdraws cooling water from Conowingo Pond, and is located at approximately RM 18. Conectiv Mid Merit, LLC has a proposed an 1,100 MW electric generation facility that would withdraw cooling water approximately 7 miles upstream of Conowingo Dam, at RM 17. The City of Baltimore and the Chester Water Authority (CWA) both have permitted drinking water withdrawals from Conowingo Pond. The most downstream water use facility is Conowingo Dam, located at RM 10. Described below are the major water withdrawal facilities within the Project area.

2.1.1 Safe Harbor Hydroelectric Project

The Safe Harbor Hydroelectric Project is located at RM 32. Safe Harbor is a peaking project, with an installed capacity of 417.5 MW and an estimated hydraulic capacity of 110,000 cfs. The Safe Harbor Project is owned by the Safe Harbor Water Power Corporation. The project dam impoundment forms Lake Clarke, with a surface area of 7,424 acres and a usable storage capacity of 53,750 acre-feet. The Safe Harbor Project does not currently have a minimum flow requirement. Construction of the Safe Harbor Project was started in November 1929 and the project was placed in operation in December 1931. The original project license expired in 1980. When the project was relicensed, Safe Harbor Water Power Corporation proposed to add an additional five generating units to increase the authorized installed capacity from 230 MW to the current capacity of 417.5 MW. Because of this substantial redevelopment, FERC issued a 50-year license for the project. Safe Harbor's current license expires in 2030.

In 1998, FERC amended the license for the Safe Harbor Project to enable the licensee to increase the normal maximum reservoir elevation of Lake Clarke by 0.8 feet to 228 feet, which would increase the reservoir storage capacity usable for energy generation by approximately 5,900 acre-feet. FERC noted that the proposal, under extremely low flow conditions, could typically result in slightly less water released downstream of the project during the weekend, but slightly more water released during the week, which could restrict Conowingo from meeting its minimum flow and weekend minimum pond level requirements. Safe Harbor Water Power Corporation and the Conowingo licensees therefore entered into an agreement, the "Safe Harbor Pool Raise and Storage Volume Limitation Agreement," to ensure that Conowingo's operations would not be exposed to any greater risk of flow interruptions than were possible prior to implementation of the 0.8 foot increase in the reservoir elevation.

2.1.2 Holtwood Hydroelectric Project

PPL Holtwood, LLC (PPL) owns and operates the Holtwood Hydroelectric Project located at RM 24 on the Susquehanna River. The Project began operation in 1910, and includes an eight-mile long reservoir (Lake Aldred) and a powerhouse with a total hydraulic capacity of approximately 31,500 cfs and an installed capacity of 107 MW. FERC recently issued PPL a License Amendment to expand the capacity at the Holtwood Project. Construction began in 2010, and when completed will result in a total generation capacity of 196 MW and total hydraulic capacity of 61,460 cfs. As part of the project expansion license agreement, Holtwood agreed to supply Conowingo with a continuous inflow of 800 cfs, and a daily volumetric flow equivalent to 98.7% of Conowingo's minimum continuous flow requirement aggregated over a 24 hour period, or net inflow. The agreement is contingent on Holtwood completing construction on the expansions, though the minimum flows must be supplied by no later than 2012. Holtwood's current license expires in 2030.

2.1.3 Muddy Run Pumped Storage Project

Conowingo Pond acts as the lower reservoir for the 800-MW Muddy Run Pumped Storage Project. Muddy run is owned by Exelon, and was constructed beginning in 1964. The Muddy Run Project is located at RM 22. The powerhouse turbines have a total discharge capacity from the powerhouse of 32,000 cfs. The total powerhouse pumping capability is 28,000 cfs.

Typical operations consist of pumping water from Conowingo Pond to the Muddy Run Reservoir. Pumping occurs during low electrical load periods while generation at Muddy Run occurs during high electrical load periods. Muddy Run's current license expires in 2014.

2.1.4 City of Baltimore

Conowingo Pond has been used as a partial domestic water supply for the City of Baltimore since 1966. The Maryland Legislative Acts of 1955, Chapter 203, gave the City of Baltimore rights to withdraw water from the Susquehanna River.

Currently, the City of Baltimore is approved by the SRBC to withdraw a maximum of 250 MGD (387 cfs) from the Conowingo Pond, but is currently limited by its pumping capacity to a withdrawal of approximately 137 MGD (212 cfs). During low flow periods[1] on the Susquehanna River, the maximum 30-day average withdrawal is reduced to 64 MGD (99 cfs). The Conowingo Pond withdrawal is principally used during major drought periods or under emergency operating conditions.

The infrastructure associated with the withdrawal was built in the late 1950s and early 1960s. It consists of an intake structure with a 500 MGD (774 cfs) capacity located 1,000 feet upstream of Conowingo Dam; a 144-inch and 108-inch tunnel and pipeline with a potential capacity of 500 MGD (774 cfs); the Deer Creek Pumping Station, currently equipped with three pumps at a rating of 50 MGD (77 cfs) each and expandable to five pumps with a combined safe capacity of over 250 MGD (387 cfs); and approximately 35 miles of 108-inch and 96-inch transmission main to the Montebello Filtration Plants located in Baltimore, Maryland. The transmission main on the discharge side of the pumping station has a design capacity of approximately 250 MGD (387 cfs).

2.1.5 Chester Water Authority (CWA)

The SRBC has permitted CWA to withdraw up to 30 MGD (46 cfs) of water from Conowingo Pond. Increasing water supply demands may lead CWA to request an increase in its maximum withdrawal to 40 MGD (62 cfs). The intake works are located just north of Brown's Run mouth on the east bank, approximately seven miles upstream of Conowingo Dam. CWA began withdrawals in 1970 and supplies public water to areas in southeast Pennsylvania and northern Delaware.

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[1] Baltimore's low flow withdrawal restriction refers to when Marietta flow is below Conowingo's seasonal minimum flow (QFERC).

The infrastructure associated with the withdrawal consists of a pumping station with a submerged 12-foot-diameter grated intake located about 10 feet below normal pool elevation (109.2 feet). A 54-inch pipe delivers the water from the intake to the sump of the Susquehanna Pumping Station. Three 15-MGD (23 cfs) vertical turbine pumps, each driven by a 1,500 hp constant speed motor, are used to pump the water through approximately 13 miles of 42-inch and 36-inch transmission main to the CWA Octoraro Treatment Plant. The station capacity with one pump running is approximately 17 MGD (26 cfs); with two pumps running it is 30 MGD (46 cfs). The third pump is for back-up purposes only.

2.1.6 Peach Bottom Atomic Power Station (PBAPS)

Conowingo Pond also is used as a cooling water source for the Peach Bottom Atomic Power Station (PBAPS). PBAPS has two units, with a total generating capacity of 2,186 MW. A total of approximately 2,230 MGD (3,450 cfs) is required at full power operation. Peach Bottom is co-owned by Exelon Generation and Public Service Electric and Gas of New Jersey, and began operation in 1974.

2.1.7 Conectiv Mid Merit, LLC

A new electric generating facility, having a maximum capacity of 1,100 MW, has been proposed by Conectiv Mid Merit, LLC for construction in Peach Bottom Township, Pennsylvania. Currently, the proposed project is under review by several regulatory agencies. The facility would be located inland approximately 2.5 miles from the Conowingo Pond. Major water needs for the proposed project would be met by a withdrawal from Conowingo Pond.

Water withdrawn from Conowingo Pond could be pumped at a maximum daily rate of 19.0 MGD (29 cfs) using three pumps. Under normal operating conditions, it is planned for two pumps to be active with a withdrawal rate ranging from 3.5 MGD (5 cfs) to 12.6 MGD (19 cfs), depending on the mode of operation at the power plant. The amount of consumptive use would vary depending on plant operations with a maximum average daily loss of 8.7 MGD (13 cfs). The intake and discharge structures for this facility were completed on December 29, 2010, and are located seven miles upstream of Conowingo Dam, or approximately at RM 17.

2.1.8 Conowingo Hydroelectric Project

The Conowingo Project is owned by Exelon and was constructed beginning in 1926. The Conowingo Project has an installed capacity of 573 MW and a hydraulic capacity of 86,000 cfs. The reservoir, known as Conowingo Pond and formed by Conowingo Dam, extends approximately 14 miles upstream from Conowingo Dam to the lower end of the Holtwood Project tailrace. The Conowingo Pond serves many diverse uses including hydropower generation, water supply, industrial cooling water, recreational activities and various environmental resources.

The Conowingo Project license allows for the Conowingo Pond to normally fluctuate between elevation 101.2 to 110.2 NGVD 1929[2]. The following factors also influence the management of water levels within the Conowingo Pond:

- The Conowingo Pond must be maintained at an elevation at or above 107.2 ft on weekends between Memorial Day and Labor Day to meet recreational needs;
- The Muddy Run Project cannot operate its pumps below pond elevation 104.7 ft due to cavitation;
- PBAPS begins experiencing cooling problems when the pond elevation of the pool drops to 104.2 ft or below;
- The CWA cannot withdraw water below elevation 100.5 ft;
- The Nuclear Regulatory Commission license for PBAPS requires the plant to shut down completely at 99.2 ft; and
- The City of Baltimore cannot withdraw water below elevation 91.5 ft.

The current minimum flow regime below Conowingo Dam was formally established with the signing of a settlement agreement in 1989 between the project owners and several federal and state resource agencies. The established minimum flow regime below Conowingo Dam is the following:

- March 1 – March 31 3,500 cfs or natural river flow[3], whichever is less
- April 1 – April 30 10,000 cfs or natural river flow, whichever is less
- May 1 – May 31 7,500 cfs or natural river flow, whichever is less
- June 1 – September 14 5,000 cfs or natural river flow, whichever is less
- September 15 – November 30 3,500 cfs or natural river flow, whichever is less

[2] All elevations in this report are referring to the NGVD 1929 datum.

[3] Natural river flow is defined as the flow measured at the Marietta USGS gage.

- December 1 – February 28 3,500 cfs intermittent (maximum six hours off followed by equal amount on)

During periods of regional drought and low river flow, Exelon has requested and received FERC approval for a temporary variance in the required minimum flow release from the Conowingo Project. Specifically, Exelon has sought approval to count the leakage from the Conowingo Project (approximately 800 cfs) as part of the minimum flow discharge. When implemented, the temporary variance allows Exelon to maintain an adequate pond level elevation and storage capacity throughout a low flow period. Conowingo's current license expires in 2014.

2.2 Operations Model

During the period 2002 – 2005, the Susquehanna River Basin Commission (SRBC) developed an operations model ("the SRBC model") of the Susquehanna River Basin to use in its "Conowingo Pond Management Alternatives Analysis" project (SRBC 2006). This model included the various hydrologic inputs, water withdrawals and returns within the Susquehanna River Basin, and operated on a daily time step.

The SRBC model utilized the Operational Analysis and Simulation of Integrated Systems (OASIS) software, which is a generalized program for modeling the water resource system operations. OASIS simulates water movement through a river system represented by nodes (any point of interest in the system is a node such as reservoirs or junctions) and arcs (any hydraulic connection between two nodes such as river reaches, pumps, and turbines). While an OASIS model can model a system's physical constraints, its primary purpose is to simulate the operating policies that result from human control of the system. For the most part, the operating policies and human control constitute a decision-making process about how much water to release or divert. In the context of the SRBC model, this means maintaining certain model constraints such as maintaining minimum required flows, and/or maintaining the reservoirs within prescribed minimum and maximum stages (elevations).

In 2007, Exelon began development of its own operations model for its FERC licensing proceeding. The Exelon model is based on the SRBC model; however, the Exelon model also includes the Lower Susquehanna River hydropower projects, namely Safe Harbor, Holtwood, Muddy Run and Conowingo. The Exelon model operates on an hourly time step to simulate hydropower generation, as well as the impacts of alternative flow management scenarios. The results from an alternative operating scenario can be compared to the baseline condition to determine the relative impacts to reservoir water levels, streamflow, and energy generation.

The calibration results for the Exelon OASIS model are described in a separate report that will be submitted once additional model runs are completed.

2.3 USGS Flow Gages

There are two USGS flow gages located on the lower Susquehanna River. One is located at Marietta, PA (USGS Gage No. 01576000). The other is located on the downstream face of Conowingo Dam (USGS Gage No. 01578310). Both gages have daily and sub-daily flow data available.

The Marietta, PA USGS Gage No. 10576000 (Marietta) is located on the upper end of the lower Susquehanna River (RM 45), just upstream of the Safe Harbor Dam impoundment. The drainage area at this gage is 25,990 mi^2. The gage has daily average flow data available beginning 10/1/1931. As of 4/1/2011, USGS-approved daily average flows range from 10/1/1931 to 12/9/2010 (79+ years). The gage also has 30-min instantaneous flow data, available from 10/1/1985 to 9/30/2009, with no data available for October 1990 through September 1991. Marietta is generally considered reflective of the lower Susquehanna River's natural flow regime.

The Conowingo, PA USGS Gage No. 01578310 is located on the downstream face of Conowingo Dam (RM 10). The drainage area is 27,100 mi^2. The gage has daily average flow data available beginning 10/1/1967. As of 4/1/2011, USGS-approved daily average flows range from 10/1/1967 to 1/31/2011 (44+ years). The gage also has 15-min instantaneous flow data[4], available from 2/2/1988 to 9/30/2009, with no data available for October 1993 through September 1994. The Conowingo gage is immediately downstream of Conowingo Dam, and thus directly reflects Project operations and the influences of the other lower Susquehanna water users.

To accurately compare flow statistics, only common data should be compared, preferably over a natural comparison period such as a calendar year (January-December) or water year (WY) (October-September). The two gages do not have equal periods of record, as Marietta daily and sub-daily flow data begins at an earlier date than is available for the Conowingo gage. For the daily average flow data, the common period of record is WY 1968-2009, a total of 42 years. For the sub-daily flow data, the common period of record is WY 1989-1990, 1992-1993, and 1995-2009, a total of 19 years.

[4] For consistency with the Marietta gage, all 15-minute Conowingo flow data were converted to 30-min flow data for all analyses

3. METHODS

The following methods were specified in the RSP or specifically requested by resource agencies for use in meeting the study objectives:

- Daily flow statistics for the Conowingo and Marietta USGS gages for the common period of record (WY 1968-2009), including
  - Flow exceedance analyses
  - Annual low flow statistics (1Q-10, 3Q-10, 7Q-10).
- Daily (period of record WY 1968-2009) and 30-min (period of record WY 1989-2009) comparison of Conowingo and Marietta USGS gages versus FERC-mandated minimum flows
- 30-min flow exceedance calculations (period of record WY 1989-2009) from the Conowingo and Marietta USGS gages
- Daily minimum flows, computed using 30-min flows (period of record WY 1989-2009) at the Conowingo and Marietta USGS gages, along with a flow exceedance analysis
- Indicators of Hydrologic Alteration (IHA) metrics were used to analyze Conowingo and Marietta USGS gage (period of record WY 1968-2009) daily average flows. IHA analyses compare pre and post impact annual and sub-annual flow data. IHA's hydrologic parameters and definitions are described in Table 3-1, which is taken directly from the IHA software documentation. IHA groups metrics into five main categories, which are described as:
  - The *magnitude* of discharge at any given time interval is the amount of water moving by a fixed location per unit time. The flow magnitude has an effect on available river habitat- as wetted area shrinks typically aquatic habitat also shrinks.
  - The *frequency* of occurrence refers to how often a flow above a given magnitude recurs over some specified time interval. Extreme events such as droughts or floods may be tied to reproduction or mortality events for various species, thereby influencing population dynamics.
  - The *duration* is the period of time associated with a specific flow condition. For example a flow duration curve might provide information on the percent of time or number of days in a year a specific flow is equaled or exceeded. The duration of flow may determine whether a particular life-cycle phase can be completed or the degree to which stressful effects such as inundation or desiccation can occur.
  - The *timing* of flows refers to the regularity with which specific flows occur. Timing of flows can determine whether certain life-cycle requirements are met or can influence the degree of stress or mortality associated with extreme water conditions such as drought or floods.
  - The *rate of change* or flashiness refers to how quickly flow changes from one magnitude to another. The rate of change in flow may cause stranding of certain organisms along the river's edge or in ponded depressions.

- Sub-daily hydrologic alteration analyses described in Zimmerman et al. 2009 were conducted for the Conowingo and Marietta USGS gage 30-min flow data. There are four metrics used to quantitatively describe sub-daily flow flashiness. Zimmerman et al. (2009) determined daily flashiness thresholds for each metric based on flow data from unregulated rivers in the Connecticut River watershed. Values above the flashiness threshold indicate that the flow for that day exceeded the typical values of those expected for unregulated rivers (determined from the Connecticut River watershed unregulated river flow gages). The metrics used were:

    1) Richards-Baker Flashiness Index (RBF): A measure of the flow change magnitude versus the total daily flow. Calculated as the sum of all sub-daily flow changes (sum of the flow difference between 12:00 and 12:30 plus the flow difference between 12:30 and 1:00, and so on) divided by the sum of each recorded flow (sum of flow at 12:00 plus flow at 12:30 and so on). The daily flashiness threshold is 0.05.

    2) Number of Reversals (NREVS): The number of daily hydrograph reversals. The daily flashiness threshold is 9.

    3) Percent of Total Flow (PTF): Calculated as the daily flow range (daily maximum flow – daily minimum flow) divided by the total daily flow volume. The daily flashiness threshold is 0.03.

    4) Coefficient of Diel Variation (CDV): Standard deviation of daily flow divided by daily average flow. The daily flashiness threshold is 0.15.

4. RESULTS AND DISCUSSION

4.1 Gage Accuracy Assessment

The accuracy of the Conowingo USGS gage has recently come into question with some agencies. The gage accuracy questions were initially investigated through conversations with the USGS. Conversations revealed that there are no known issues at the Conowingo gage, but that gage validation has been difficult due lack of an easily accessible and non-tidal cross-section for measuring flows.

The bathymetry survey downstream of Conowingo Dam on the week of 6/14/10 allowed the gage accuracy to be further investigated. The survey required a peaking discharge of 40,000 cfs for several hours each day for five days. The provided flow was based on station estimates calculated from turbine selection and pond elevation, not USGS gage feedback. In between the daily peaking at 40,000 cfs, the flow was returned to slightly above the minimum required flow of 5,000 cfs.

15-min instantaneous stage data were collected at several locations between Conowingo Dam and Spencer Island (Figure 4.1-1). Time series plots showed that downstream water surface elevations clearly reflected daily flow peaking, but the USGS gage had additional day-to-day and mid-day changes that were not reflected in downstream water surface elevations (Figure 4.1-2). Conversations with Exelon control room employees indicated that the project was releasing approximately 40,000 cfs during each of those days, although different turbines and turbine combinations were used. While the USGS gage showed varying peak flows from day to day (between 31,800 cfs and 47,000 cfs), the stage recorders downstream showed nearly no difference in peak water surface elevation from day to day. During nighttime and morning hours when the project was releasing just above minimum flow requirements, the USGS gage and downstream water surface elevations were consistent from day to day. This indicates that the USGS gage may be experiencing stage variations due to local influences, such as specific turbine combinations.

Generation schedules were available that described turbine use and Conowingo Pond elevations on an hourly basis, but did not include a flow estimate. The USGS stage and flow is compared to the recorded downstream water surface elevations and turbine schedule in Table 4.1-1. The comparisons showed the USGS gage and gage 2 agreed well during base flows, but not during peaking flows. During peaking flows (~40,000 cfs), the USGS gage varied between 17.82 ft and 19.03 ft, gage 2 varied from between 16.62 ft and 16.79 ft, and gage 3 varied between 12.38 ft and 12.51 ft. During base flows (~5,000 cfs) the USGS gage varied between 14.53 ft and 14.62 ft, gage 2 varied from between 13.37 ft and 13.44 ft and gage 3 varied between 9.48 ft and 9.53 ft. The plant's estimated flow output did not change between those days, and the downstream gages did not show any appreciable water surface elevation differences based on turbine combinations. Except for 6/14/2010 and 6/15/2010, a different turbine combination was used each day. Though the downstream gages are expected to show less variation than the USGS gage due to channel geometry, the stage variations observed at the USGS gage during a supposedly consistent flow appear to be very large (1.21 ft) considering the downstream gages reflected relatively little variation (0.17 ft).

A rating curve was developed comparing USGS flows to downstream stage levels based on flows between 6/14/2010 and 9/15/2010 (Figure 4.1-3). The curve showed that the stage-discharge relationship was inconsistent for flows from 30,000 to 50,000 cfs. For example, a gage 3 water surface elevation of 12.5 ft was matched with various flows ranging from 32,000 to 47,000 cfs. Similar flow ranges were associated with narrow elevation differences at the other gages. Flows greater than 50,000 and less than 30,000 appeared to have a more consistent relationship with downstream stages, though there were fewer readings at each of those flow/elevation combinations. The fact that multiple stage gages experienced varying flows at a single elevation points toward a flow gage inaccuracy, rather than several erroneous readings at independent stage gages.

Stage data at each location was correlated to USGS gage elevations. This provided an idea of each gage's relative consistency versus the USGS gage and other gages. The results (Table 4.1-2) show that while the USGS gage correlated well versus gage 2, 3 and 4 (R^2 between 0.963 and 0.978), this was noticeably lower than the correlation between the downstream gages (R^2 between 0.994 and 0.999). The extremely high correlation between the gages 2, 3 and 4 indicates that the gages experienced nearly identical variations and consistently made similar stage observations, relative to each other. The high correlation between each of the three stage gages indicates there is a low likelihood of error, as it is unlikely that all three independent stage gages would experience simultaneous errors. The relatively lower correlation of all three gages to the USGS gage indicates that the USGS gage was generally experiencing elevation variations that none of the three downstream gages were experiencing.

In addition to the USGS gage on the downstream side of the dam located in turbine unit 8, Exelon has installed a gage in turbine unit 2. The elevation difference between the two gages ranged between -0.02 ft and 1.32 ft (Table 4.1-1), indicating that under certain conditions there can be a large water surface elevation gradient from one edge of the dam to the other. This gradient is likely driven by which turbines are used. The difference between the two turbines does not appear to be influenced by any single turbine. Rather, each turbine combination appears to cause a unique differential between the two gages.

4.2 Streamflow Statistical Analysis[5]

4.2.1 Daily Average Flow Statistics

The average annual flows between 1968 and 2009 measured at the Marietta and Conowingo USGS gages were 39,686 and 41,026 cfs, respectively. Annual average and median flows showed considerable year-to-year variation, but Conowingo flows were generally greater than Marietta flows (Table 4.2.1-1). Monthly average flows are also similar (Table 4.2.1-2), with Conowingo flows typically 900 to 2,100 cfs greater. Flows were greatest in March and April, and were lowest in August. Correlations between Conowingo and Marietta daily average flows (Figure 4.2.1-1) show a high correlation between the flow of both locations (R^2 = 0.974). This agreement is even greater over longer time periods, as the 7-day average flows had an R^2 = 0.992.

Annual and monthly flow exceedances were calculated for daily average flow data. Daily average annual flow exceedance plots showed that Conowingo and Marietta typically experience similar flow distributions, with Conowingo experiencing slightly more days in the 20,000 cfs to 60,000 cfs range (Figure 4.2.1-2). Slightly higher flows at Conowingo are expected, as Conowingo drains an additional 1,100 mi^2 compared to Marietta. Monthly daily average flow exceedances were similar, showing that Conowingo flow exceedances (Table 4.2.1-3) were generally greater than Marietta flow exceedances (Table 4.2.1-4). One notable exception was the monthly minimum observed daily average flows (0^{th} percentile) were always lower at Conowingo than at Marietta, and were often below 1,000 cfs though the minimum daily average flow observed at Marietta was 2,150 cfs. This reflects the period prior to the 1989 settlement agreement, under which Conowingo and the other upstream hydroelectric projects did not have any minimum flow requirements. Daily average flow exceedance plots are shown for all months in Appendix A.

Several low-flow statistics were calculated using the daily average flow data, including 1-day 10-yr low flow event (Q1-10), Q3-10, Q7-10, and one-in-20 year monthly low flows (95% monthly average flow exceedance). The annual low-flow metrics (i.e Q1-10) showed that Conowingo low flows were lower than any flows experienced at Marietta (Table 4.2.1-5), with more pronounced differences over smaller time intervals. 95% monthly average flow exceedances were also calculated (Table 4.2.1-6), and showed that Conowingo flows were generally slightly greater than Marietta flows, with November being the only

[5] All flow statistics in this section are calculated referring to water years (i.e 1995 is October 1994 - September 1995) to coincide with the beginning and end dates of most available USGS flow data.

exception. Generally, the shorter-term low flow statistics (1-day and 3-day) showed larger differences between the two gages than longer-term low flow statistics (7-day and monthly).

Daily average flows exceedances were compared to seasonally-varying FERC-mandated minimum flows (QFERC)[6]. Table 4.2.1-7 shows the exceedance percentile of the four minimum flows (3,500 cfs, 5,000 cfs, 7,500 cfs and 10,000 cfs) for each month. Generally, Marietta flows were above the QFERC, while Conowingo flows dropped below the QFERC thresholds more frequently. Table 4.2.1-8 compares each minimum flow to a Marietta flow exceedance percentile by month, and then relates each Marietta exceedance percentile to the flow with the same exceedance percentile at Conowingo. This showed the historic cumulative effect of the multiple hydroelectric projects between Marietta and Conowingo, as the equivalent flows at Conowingo are lower for every month.

4.2.2 Sub-Daily (30-min) Flow Statistics

Time series plots reveal that the sub-daily flows do not match as well as daily flow data (Figure 4.2.2-1). While the Marietta gage shows a typical unregulated hydrograph with gradual rising and falling limbs, the Conowingo gage experiences sharp flow increases and decreases typical of a peaking hydropower system. 30-min flow correlations were weaker between the two gages than daily average flow correlations, though they still match moderately well ($R^2 = 0.819$).

Annual and monthly flow exceedances were calculated for sub-daily flows using 30-min instantaneous flow data. While the Conowingo and Marietta median flows are very similar (25,200 cfs and 27,000 cfs, respectively), sub-daily annual flow exceedance curves (Figure 4.2.2-2) show that Conowingo experiences more frequent low (< 10,000 cfs) and high (> 60,000 cfs) flows. Monthly sub-daily flow exceedances showed a similar pattern (Tables 4.2.2-1 and 4.2.2-2), though the flow magnitudes were different depending on the time of year. Sub-daily flow exceedance plots are shown for all months in Appendix B.

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[6] This analysis was done to compare the FERC-mandated minimum flows to historic flow records at the Marietta and Conowingo gages as a means to relate seasonal minimum flows to the river's flow regime. This is not meant to check for minimum flow compliance, as the many of the flow observations (W.Y. 1968-2009) predate the 1989 settlement agreement establishing minimum flows.

4.2.3 Daily Minimum Flow Statistics

Annual and monthly flow exceedances were also calculated for daily minimum flows (i.e. lowest instantaneous flow for each day) using the 30-min instantaneous flow data. Results showed that Conowingo daily minimum flows were always lower than Marietta daily minimum flows (Figure 4.2.3-1). Notably, 75% of all days had a minimum daily flow slightly above one of the FERC-mandated minimum flow values, indicating that most days see flows reduced to minimum flow for at least a short period of time. Monthly daily minimum flow exceedances showed the same trend, typically with a large percentage of days having a minimum flow slightly greater than the FERC-mandated minimum flow (Tables 4.2.3-1 and 4.2.3-2). Daily minimum flow exceedance plots are shown for all months in Appendix C.

4.2.4 IHA Flow Statistics

Indicators of Hydrologic Alteration (IHA) metrics were used to analyze Conowingo and Marietta USGS gage daily average flows (1967-2009). Sub-daily flows (1989-1990, 1992-1993, and 1995-2009) were analyzed using metrics similar to the IHA analyses as described in Zimmerman et al. (2009).

4.2.4.1 Daily Flow Statistics

A nonparametric[7] IHA analysis was conducted on the Marietta and Conowingo USGS gages. A nonparametric analysis was chosen because the highly regulated nature of the river downstream of the four hydroelectric projects contained a largely different flow distribution than upstream (Figure 4.2.2-2), thus using standardized parameters would likely result in a weaker ability to compare results. Previous sections examined some of the same (or similar) metrics contained within the IHA analysis. However, the full set of IHA results have been provided here for both gages for completeness purposes. The metrics were typically very close for all months (Table 4.2.4.1-1), though Conowingo's median one and three-day minimum flows were lower than Marietta flows (Table 4.2.4.1-2). Maximum and minimum flows tended to occur at the same time of year (Table 4.2.4.1-3). The median low pulse count was higher at Conowingo, while the duration was lower (Table 4.2.4.1-4). Median rise and fall rates were much higher at Conowingo than Marietta (Table 4.2.4.1-5).

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[7] IHA analyses can be parametric or nonparametric. Nonparametric means the analysis thresholds are based off of median and percentile (25th and 75th) values, rather than using means and standard deviations.

4.2.4.2 Sub-Daily Flow Statistics

Sub-daily flow statistics based on IHA-type analyses were conducted using Marietta and Conowingo USGS gage 30-min flow data, as described in Zimmerman et al. (2009). The four metrics calculated were the Richards-Baker flashiness index (RBF), number of reversals (NREVS), the percent of total flow (PTF), and coefficient of diel variation (CDV) metrics. The number of days that each location's indices exceeded thresholds determined by Zimmerman et al. (2009) were summed and compared. Three of the four metrics showed that Conowingo flows exceed flashiness thresholds more frequently than Marietta flows (Table 4.2.4.2-1). The percent of total flow metric showed no flashiness threshold exceedances for either station. It should be noted that several of the Conowingo flow reversals were a result of slight flow oscillations at minimum flow (Figure 4.2.4.2-1).

4.3 Energy Deregulation

The energy generation market was deregulated beginning January 1, 1998. After the establishment of the minimum flow regime at the Conowingo Project there were 7 years of pre-deregulation (1989-1990, 1992-1993, 1995-1997) and 12 years of post-deregulation (1998-2009) sub-daily (30 minute) flow data available from the Conowingo USGS gage.

Analyses were conducted to determine if energy deregulation altered the Conowingo Project's generation (and thus flow release) characteristics. Flow exceedance percentiles were compared for the entire periods, as well as for representative dry, normal, and wet years based on flows in Table 4.2.1-1. Additionally, IHA sub-daily flow statistics were calculated for pre and post-deregulation periods.

Annual sub-daily flow exceedance percentiles were calculated for the pre and post-regulation periods (Tables 4.3-1 and 4.3-2). Exceedance percentiles were similar, with a slight difference in the 60,000 cfs to 80,000 cfs range (Figure 4.3-1). Monthly pre and post-deregulation sub-daily flow exceedance curves are shown in Appendix D.

Pre and post-deregulation dry, average and wet years were chosen based on annual average and median flows (Table 4.2.1-1) and compared. Exceedance percentile plots showed similar shapes when matched for similar dry (Figure 4.3-2) and wet (Figure 4.3-3) years from each period. Exceedance percentiles were fairly similar for a selected average year from each period (Figure 4.3-4), but there appeared to be somewhat more flows in the 79,000 cfs to 86,000 cfs range for the post-deregulation year (2007). Overall, the flow exceedances showed similar pre and post-deregulation flow distributions, but one year did show that full generation flows were reached slightly more often.

Sub-daily IHA flow statistics were calculated for pre and post-deregulation periods. Table 4.3-3 shows the number of days that exceeded the flashiness threshold for each year. Table 4.3-4 shows that the average number of days exceeding the flashiness threshold per year for each period is fairly close. The average number of days exceeding the flashiness thresholds is lower for the post-deregulation period for three of the four metrics.

Flow variations before and after deregulation were also assessed by comparing sub-daily flow variations to monthly flow percentiles to assess the relative "peaking" frequency. The number of days containing a minimum instantaneous flow below the monthly 75th flow exceedance percentile and a maximum instantaneous flow above the monthly 25th flow exceedance percentile were summed by water year, assuming days that met these criteria were days during which flow peaking occurred (Table 4.3-5). Results showed that the mean and median number of "peaking" days was similar for pre-deregulation (60 and 76, respectively) and post-deregulation (58 and 61, respectively), with the post-deregulation numbers being slightly less than the pre-deregulation numbers.

4.4 Water Management Alternatives

A baseline operations model has been completed, which emulates existing conditions. In consultation with the resource agencies, additional model production runs will be conducted. At that time, a comparison of the baseline and alternative water management operations will be presented.

4.5 Bathymetric Map

The final objective of this study was to develop a bathymetric map of the tailrace area below Conowingo Dam. The data used for this map were collected in June 2010 in association with Conowingo Study 3.16: Instream Flow Habitat Assessment below Conowingo Dam. Figure 4.5-1 shows the tailrace bathymetry in the form of a bed elevation colorplot. The bathymetry map extents from the downstream face of Conowingo Dam to the downstream tip of Spencer Island, including the spillway area downstream of the eastern part of the dam.

5. DISCUSSION

5.1 Conowingo USGS Gage Accuracy

The comparison between the Conowingo USGS gage and the downstream stage gages indicated that there were inconsistencies with the USGS gage stage and thus flow data. In one instance, though there were no in-stream or direct flow measurements made, project operation logs and downstream stage gages showed that the mid-day river stage was nearly constant for several consecutive days (6/14/2010 – 6/18/2010), yet the USGS gage showed flows ranging between 31,800 and 47,000 cfs. In addition, the rating curve shows that there is an inconsistent relationship between USGS measured flow and observed downstream water surface elevations. Since the inconsistency is shown in all three monitoring gages, it appears that errors in the USGS measurements are more likely than all three stage gages reading erroneously. Though there were no direct flow measurements made on those days, the disparity between the downstream stage measurements and the USGS gage indicates that the USGS gage is not accurately representing the river flow. If the peak flow on the studied days was 40,000 cfs as station records suggest, then this means the USGS gage may be erroneously reporting flows by +/-20%.

The gage inaccuracies appear to be related to the lateral gradient that is shown in Table 4.1-1. This gradient is likely influenced by turbine combinations. Since the USGS gage is in the tailrace of unit 8, it is likely impacted when that turbine or nearby turbines are run. In addition, not all of the turbines have the same hydraulic capacity, so it is possible a lateral gradient may be created even when all of the turbines are running. While not all of the turbine and flow combinations were explored, the brief analysis done showed that turbine operations do appear to impact Conowingo gage accuracy. Though the inaccuracies were only shown for mid-level (30,000 to 50,000 cfs) flows, it is possible that there are inaccuracies at lower and higher flows that were simply not observed in the brief period analyzed.

The results do not appear to indicate a bias toward over or under-predicting flows. Thus, it appears possible that the unbiased nature of the gage's errors may not greatly affect flow longer-term cumulative flow statistics. While acknowledging the uncertainty in reported flows is high, the Conowingo gage data represents the only flow estimates downstream of Conowingo Dam. Regardless of overall bias, it appears that the physical location of the gage negatively impacts its accuracy. Thus if accurate readings are desired, the gage may have to be relocated far enough from the dam such that turbine gradients are negligible.

5.2 Statistical Hydrology Analysis

Marietta and Conowingo USGS gage flows were similar on a daily and longer timestep, particularly weekly average flows. Further investigation into low flow periods and 30-min instantaneous flows revealed several differences between the unregulated Marietta gage and regulated Conowingo gage flow observations. It appears that flow differences between the two gages are likely due to the cumulative effect of Safe Harbor, Holtwood, Muddy Run and Conowinogo sub-daily peaking operations and low-flow period operations.

Several analyses showed there are substantial differences between Marietta and Conowingo flows on a sub-daily basis. 30-min flow correlations between the two gages are weaker than daily average correlations. This is likely due to peaking operations on the river, but also may slightly reflect the time lag between the two gages. Time series plots show that Marietta generally experiences a typical natural-looking hydrograph, with rising limbs driven by precipitation events and followed by gradual falling limbs (Figure 4.2.2-1). Conowingo daily average flows indicate a somewhat natural system, but 30-min hydrographs show numerous flow increases and decreases due to sub-daily peaking operations (Figure 4.2.2-1). 30-min flow exceedance plots showed notable differences between the Marietta and Conowingo gages, with Conowingo experiencing more extreme flows at the 25th and 75th percentile, even though the median and maximum flows were very close (Figure 4.2.2-2) . In addition, two flow ranges occur much more frequently in Conowingo than in Marietta, from approximately 3,500 to 10,000 cfs and 60,000 cfs to 80,000 cfs. This is likely because of the peaking cycle at the station, when flows fluctuate primarily between FERC-mandated seasonal minimum flows (between 3,500 and 10,000 cfs) and generation flows which are up to 86,000 cfs.

Though Conowingo flows are approximately 900 to 2,100 cfs greater than Marietta flows on average, Conowingo experienced lower extreme flows than Marietta, particularly on a 1 to 3 day period. This was shown in daily minimum flow exceedance plots, low-flow statistics (1Q-10, etc.), and the IHA metrics. Flows over longer periods, such as weekly and longer, were generally about the same between both gages. This could be due to several factors. Since the gage observations date back to 1967, this may indicate that prior to minimum flow requirements, the multiple hydroelectric projects may have released little to no water during low flow periods. This also may still be the case for the upper two hydroelectric projects (Safe Harbor and Holtwod), as they currently have no minimum flow requirements[8]. It is also possible that the Conowingo gage experiences inaccuracies at low flows, though there was no specific evidence collected at low flows to confirm this.

IHA metrics showed that Conowingo flows are generally more variable than Marietta flows on daily and sub-daily timesteps, though more so for sub-daily flows. IHA metrics showed that Conowingo typically experienced more high and low pulses that were of shorter duration compared to the Marietta gage (Table 4.2.4.1-4). It was also shown that Conowingo experienced nearly twice as many reversals per year on a daily timestep (Table 4.2.4.1-5). The daily IHA metrics were supported by the sub-daily flashiness index

[8] As stated in Section 2.1, Holtwood will begin minimum flow releases no later than 2012.

thresholds, which indicated that Conowingo exceeded flashiness thresholds more often than Marietta for three of the four metrics (RBF, NREVS, CDV). Compared to the results of Zimmerman et al. (2009), Project operations appear to be closer to those of peaking hydroelectric projects than run-of-river projects. This was certainly a result of the sub-daily peaking operations conducted at Conowingo and upstream hydroelectric stations, which often result in one or two flow peaking releases per day.

5.3 Energy Deregulation

Resource agencies expressed concern that energy deregulation would result in more sporadic and frequent flow releases. However, there appears to be little evidence of this in the energy deregulation analysis. Results showed that there appeared to be little to no observable change in pre and post-deregulation flow statistics. Flow exceedance comparisons showed generally similar shapes, though some slight differences were observed. Sub-daily IHA flow analyses showed slightly less days exceeded the flashiness thresholds for the post-deregulation period than the pre-deregulation period. Additionally, the flow peaking analysis showed that the median and average number of peaking days was slightly less during the post-deregulation period. There were substantial flow differences year-to-year and between the pre and post-deregulation periods (Table 4.2.1-1). Additionally, the total number of pre-deregulation years with sub-daily flow data was relatively small (7 years). Yet, the limited records available show that there appears to be no large difference between pre-deregulation and post-deregulation flow records, as had been suspected.

6. REFERENCES

Zimmerman, J. K. H., Letcher, B. H., Nislow, K. H., Lutz, K. A. and Magilligan, F. J. (2010), Determining the effects of dams on subdaily variation in river flows at a whole-basin scale. River Research and Applications, 26: 1246–1260. doi: 10.1002/rra.1324

TABLE 3-1: IHA SOFTWARE DOCUMENTATION DESCRIBING IHA METRICS AND ANALYSIS GROUPS

IHA Parameter Group	Hydrologic Parameters	Ecosystem Influences
1. Magnitude of monthly water conditions	Mean or median value for each calendar month *Subtotal 12 parameters*	· Habitat availability for aquatic organisms · Soil moisture availability for plants · Availability of water for terrestrial animals · Availability of food/cover for fur-bearing mammals · Reliability of water supplies for terrestrial animals · Access by predators to nesting sites · Influences water temperature, oxygen levels, photosynthesis in water column
2. Magnitude and duration of annual extreme water conditions	Annual minima, 1-day mean Annual minima, 3-day means Annual minima, 7-day means Annual minima, 30-day means Annual minima, 90-day means Annual maxima, 1-day mean Annual maxima, 3-day means Annual maxima, 7-day means Annual maxima, 30-day means Annual maxima, 90-day means Number of zero-flow days Base flow index: 7-day minimum flow/mean flow for year *Subtotal 12 parameters*	· Balance of competitive, ruderal, and stress-tolerant organisms · Creation of sites for plant colonization · Structuring of aquatic ecosystems by abiotic vs. biotic factors · Structuring of river channel morphology and physical habitat conditions · Soil moisture stress in plants · Dehydration in animals · Anaerobic stress in plants · Volume of nutrient exchanges between rivers and floodplains · Duration of stressful conditions such as low oxygen and concentrated chemicals in aquatic environments · Distribution of plant communities in lakes, ponds, floodplains · Duration of high flows for waste disposal, aeration of spawning beds in channel sediments
3. Timing of annual extreme water conditions	Julian date of each annual 1-day maximum Julian date of each annual 1-day minimum *Subtotal 2 parameters*	· Compatibility with life cycles of organisms · Predictability/avoidability of stress for organisms · Access to special habitats during reproduction or to avoid predation · Spawning cues for migratory fish · Evolution of life history strategies, behavioral mechanisms

4. Frequency and duration of high and low pulses	Number of low pulses within each water year Mean or median duration of low pulses (days) Number of high pulses within each water year Mean or median duration of high pulses (days)	· Frequency and magnitude of soil moisture stress for plants · Frequency and duration of anaerobic stress for plants · Availability of floodplain habitats for aquatic organisms · Nutrient and organic matter exchanges between river and floodplain · Soil mineral availability · Access for waterbirds to feeding, resting, reproduction sites · Influences bedload transport, channel sediment textures, and duration of substrate disturbance (high pulses)
	Subtotal 4 parameters	
5. Rate and frequency of water condition changes	Rise rates: Mean or median of all positive differences between consecutive daily values Fall rates: Mean or median of all negative differences between consecutive daily values Number of hydrologic reversals	· Drought stress on plants (falling levels) · Entrapment of organisms on islands, floodplains (rising levels) · Desiccation stress on low-mobility streamedge (varial zone) organisms
	Subtotal 3 parameters	
	Grand total 33 parameters	

TABLE 4.1-1: USGS GAGE INFORMATION VS. DOWNSTREAM WATER SURFACE ELEVATIONS AND TURBINE COMBINATIONS. STAGE GAGES RECORDED WATER LEVELS ACCURATE TO +/- 0.01 FT.

Date/Time	USGS Flow (cfs)	USGS Stage (ft)	Gage 1 (ft)	Gage 2 (ft)	Gage 3 (ft)	Turbines	Headwater (ft)	Tailwater (ft)	Unit 2-7 Difference (ft)
6/14/2010 8:45	6,270	14.54	N/A	13.37	9.49	2,5	107.15	14.54	-0.01
6/14/2010 14:00	45,800	18.94	N/A	16.79	12.51	2,3,4,5,6,7,8	107.79	19.09	0.3
6/15/2010 5:00	6,670	14.62	N/A	13.44	9.53	2,5	107.44	14.64	0.04
6/15/2010 12:00	44,700	18.86	N/A	16.74	12.44	2,3,4,5,6,7,8	107.1	19.02	0.32
6/16/2010 5:00	6,270	14.54	N/A	13.37	9.49	2,5	107.52	14.55	0.02
6/16/2010 12:00	31,800	17.82	16.93	16.76	12.51	2,3,4,5,8,9	106.44	18.48	1.32
6/17/2010 5:00	6,220	14.53	13.30	13.37	9.48	2,5	106.09	14.52	-0.02
6/17/2010 11:00	33,900	18.00	16.86	16.74	12.46	2,5,6,7,8,9	105.67	18.54	1.08
6/17/2010 15:00	35,400	18.13	16.83	16.69	12.44	2,5,6,7,8,9	105.62	18.59	0.92
6/18/2010 1:30	6,220	14.53	13.29	13.37	9.48	2,5	106.74	14.53	0.00
6/18/2010 17:00	47,000	19.03	16.96	16.62	12.38	1,2,4,5,6,7,9	107.12	19.15	0.24

TABLE 4.1-2: CORRELATIONS (R^2) BETWEEN THE STAGE GAGES AND THE USGS GAGE.

	Gage 2	Gage 3	Gage 4
Gage 2	-	-	-
Gage 3	0.994	-	-
Gage 4	0.999	0.996	-
USGS Gage	0.978	0.963	0.975

TABLE 4.2.1-1: CONOWINGO AND MARIETTA ANNUAL MEAN AND MEDIAN FLOW (WY 1968-2009)

	Marietta		Conowingo		Difference (Conowingo - Marietta)	
Water Year	Mean Flow (cfs)	Median Flow (cfs)	Mean Flow (cfs)	Median Flow (cfs)	Mean Flow (cfs)	Median Flow (cfs)
1968	34,498	23,500	35,173	28,350	676	4,850
1969	26,962	18,800	27,672	22,200	710	3,400
1970	37,008	21,800	38,359	25,100	1,351	3,300
1971	40,143	26,500	41,224	31,900	1,081	5,400
1972	59,899	37,100	60,815	41,000	916	3,900
1973	47,940	38,800	48,178	42,300	238	3,500
1974	43,266	29,100	43,343	31,800	77	2,700
1975	46,410	33,000	48,566	35,800	2,155	2,800
1976	43,644	33,100	44,898	36,300	1,254	3,200
1977	41,928	20,400	43,259	24,600	1,331	4,200
1978	58,868	36,900	61,086	38,800	2,218	1,900
1979	42,871	21,900	45,330	25,600	2,459	3,700
1980	35,540	20,850	37,512	23,750	1,972	2,900
1981	26,027	14,800	26,569	16,400	542	1,600
1982	36,430	22,400	37,755	26,400	1,325	4,000
1983	34,382	19,400	35,126	21,900	744	2,500
1984	50,498	29,650	53,388	33,450	2,890	3,800
1985	25,363	15,400	26,894	17,600	1,531	2,200
1986	38,280	22,800	40,282	26,600	2,001	3,800
1987	34,577	24,000	36,137	26,200	1,560	2,200
1988	27,873	21,300	29,915	24,600	2,042	3,300
1989	35,848	22,900	38,017	26,100	2,169	3,200
1990	35,245	25,800	37,477	28,400	2,232	2,600
1991	40,721	34,400	43,076	36,100	2,355	1,700
1992	27,996	23,000	29,024	24,250	1,028	1,250
1993	48,734	21,300	52,181	24,700	3,447	3,400
1994	52,671	26,500	54,136	29,100	1,464	2,600
1995	27,177	21,300	27,864	22,600	686	1,300
1996	51,723	32,900	51,871	34,150	148	1,250
1997	42,679	28,900	42,909	30,200	230	1,300
1998	47,141	32,400	46,240	31,300	-900	-1,100
1999	23,368	8,390	22,847	11,400	-521	3,010
2000	37,296	24,800	35,576	24,650	-1,721	-150
2001	25,513	15,100	24,469	16,500	-1,044	1,400
2002	27,315	17,800	28,214	19,000	899	1,200
2003	51,299	40,600	51,124	42,900	-175	2,300
2004	60,425	47,000	66,565	54,800	6,139	7,800
2005	43,384	28,600	50,892	36,700	7,508	8,100
2006	43,030	29,100	46,633	34,200	3,604	5,100
2007	38,464	23,000	40,390	26,200	1,926	3,200
2008	42,258	30,650	40,847	27,150	-1,411	-3,500
2009	32,032	25,500	31,152	26,500	-880	1,000

TABLE 4.2.1-2: CONOWINGO AND MARIETTA MEAN AND MEDIAN FLOW BY MONTH, COMPUTED FROM DAILY AVERAGE FLOW RECORDS (WY 1968-2009)

Month	Average		Median	
	Marietta Flow (cfs)	Conowingo Flow (cfs)	Marietta Flow (cfs)	Conowingo Flow (cfs)
January	43,253	45,340	27,000	30,250
February	48,958	50,783	32,200	36,800
March	73,258	73,846	56,200	58,900
April	76,024	76,957	60,700	61,800
May	46,122	47,092	37,000	39,400
June	33,310	34,894	22,450	24,500
July	19,022	20,001	13,900	15,700
August	14,015	14,917	9,570	10,650
September	17,669	19,109	8,655	10,400
October	22,479	23,755	11,200	13,800
November	34,512	36,037	26,250	28,700
December	48,522	50,533	37,000	40,300

TABLE 4.2.1-3: CONOWINGO ANNUAL AND MONTHLY DAILY AVERAGE FLOW EXCEEDANCE PERCENTILES, IN CFS (WY 1968-2009).

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,120,000	622,000	470,000	462,000	467,000	235,000	1,120,000	213,000	202,000	662,000	245,000	272,000	357,000
5	121,000	131,000	139,000	184,000	188,050	104,000	80,645	50,575	41,300	56,480	84,690	90,320	129,950
10	85,400	93,980	98,500	139,000	144,000	81,100	59,000	37,500	28,280	35,240	57,170	70,410	98,350
15	70,600	76,140	81,420	119,000	116,150	70,685	49,015	31,985	24,100	26,315	42,285	60,215	80,000
20	60,300	62,160	70,860	102,000	102,200	64,000	42,240	28,080	20,600	22,120	32,480	53,600	71,380
25	52,600	53,775	60,500	88,600	89,175	58,700	37,725	25,500	18,400	19,325	26,825	46,800	64,050
30	46,100	47,800	54,240	81,400	82,700	53,400	33,900	23,170	16,300	17,100	22,700	42,500	57,200
35	40,700	42,800	48,890	73,500	76,870	49,300	31,400	20,665	14,900	14,900	20,265	39,035	52,630
40	35,700	38,060	44,800	68,360	70,900	45,760	28,900	18,900	13,300	13,100	17,460	35,200	47,820
45	31,600	33,955	41,060	63,155	66,545	43,000	26,800	17,355	12,000	11,900	15,355	31,700	43,900
50	27,800	30,250	36,800	58,900	61,800	39,400	24,500	15,700	10,650	10,400	13,800	28,700	40,300
55	24,800	27,600	33,500	54,100	57,700	36,245	22,555	14,400	9,489	8,861	12,100	26,000	36,900
60	21,700	25,040	30,840	50,440	53,900	33,200	20,300	13,100	8,380	7,410	10,900	23,460	33,880
65	19,000	22,635	27,900	46,335	50,500	30,700	18,600	11,800	6,837	6,393	9,690	20,200	31,235
70	16,200	20,800	25,680	42,130	45,470	28,030	17,170	10,400	6,143	5,337	8,320	17,700	28,330
75	13,700	18,700	23,050	38,025	42,000	26,200	15,400	8,373	5,663	4,953	6,890	14,775	25,800
80	11,200	16,240	20,700	34,100	38,200	23,520	13,580	6,946	5,290	4,368	4,912	12,400	22,040
85	8,270	13,200	18,490	30,300	34,500	21,100	11,385	6,152	5,002	3,799	4,460	9,459	18,815
90	5,840	10,210	15,500	24,410	29,690	18,100	8,658	5,421	4,490	3,037	3,750	5,807	13,610
95	4,300	5,465	10,790	18,415	24,485	14,005	6,179	4,527	2,702	1,420	1,212	3,838	7,831
100	269	511	758	287	6,090	5,220	622	269	367	363	295	303	777

TABLE 4.2.1-4: MARIETTA ANNUAL AND MONTHLY DAILY AVERAGE FLOW EXCEEDANCE PERCENTILES, IN CFS (WY 1968-2009).

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	1,040,000	556,000	446,000	444,000	431,000	223,000	1,040,000	223,000	199,000	545,000	246,000	265,000	348,000
5	123,000	130,000	139,700	185,900	182,000	109,000	76,930	48,390	38,775	56,770	81,990	91,615	125,950
10	86,500	93,990	103,000	140,000	146,100	80,980	55,110	35,080	26,000	32,010	51,460	68,450	96,000
15	68,400	72,055	80,730	120,000	120,000	67,985	46,415	29,700	20,385	23,100	37,485	57,575	77,670
20	58,000	59,800	66,680	105,000	104,000	62,480	39,900	25,800	17,600	18,600	29,180	49,120	68,900
25	49,300	50,675	58,100	92,475	92,700	56,300	35,700	22,700	16,075	16,100	23,250	42,450	60,075
30	42,800	43,370	50,520	81,240	83,590	51,870	31,930	20,300	14,600	13,830	20,100	38,000	53,400
35	37,400	38,500	45,280	72,665	76,170	47,100	29,535	18,600	12,965	12,200	17,000	34,435	49,400
40	33,000	35,000	40,560	67,100	70,040	43,360	26,900	16,760	11,500	10,900	14,900	32,000	44,360
45	29,100	30,855	36,030	61,500	65,100	40,255	24,390	15,000	10,400	9,489	12,800	28,745	40,800
50	25,700	27,000	32,200	56,200	60,700	37,000	22,450	13,900	9,570	8,655	11,200	26,250	37,000
55	22,600	24,300	30,000	50,645	56,055	34,000	20,255	12,745	8,809	7,960	10,245	24,100	34,200
60	19,800	21,840	27,700	46,700	51,420	32,000	18,760	11,800	8,062	7,426	9,310	21,360	31,100
65	17,300	19,900	26,000	43,200	47,100	29,270	17,600	10,900	7,520	6,900	8,574	18,800	28,235
70	15,000	18,000	23,800	39,830	43,300	26,800	16,100	9,986	6,989	6,277	7,913	16,270	25,400
75	12,700	16,600	21,600	36,300	39,500	24,825	14,400	9,273	6,493	5,790	7,090	13,600	22,800
80	10,700	15,420	19,000	31,800	35,980	22,420	13,100	8,446	5,892	5,390	6,514	11,400	20,600
85	8,720	13,800	17,000	27,900	33,000	20,900	12,100	7,618	5,530	4,870	5,940	9,434	18,600
90	7,050	12,110	15,000	24,210	28,370	18,600	11,000	6,721	5,091	4,429	5,360	7,935	16,110
95	5,530	9,600	12,030	17,805	23,500	15,205	8,577	5,401	4,361	3,800	4,453	5,809	10,400
100	2,150	4,200	6,600	9,000	17,500	11,500	4,830	3,710	2,630	2,150	3,570	4,490	5,110

TABLE 4.2.1-5: ANNUAL LOW-FLOW STATISTICS FOR CONOWINGO AND MARIETTA, CALCULATED USING DAILY AVERAGE FLOW DATA (WY 1968-2009)

Low-Flow Statistic	Conowingo (cfs)	Marietta (cfs)	Difference [Conowingo-Marietta] (cfs)
1Q-10	537	3,009	-2,472
3Q-10	1,336	3,137	-1,801
7Q-10	2,780	3,256	-476

TABLE 4.2.1-6: MONTHLY 95% EXCEEDANCE AVERAGE FLOW PERCENTILES, CALCULATED USING DAILY AVERAGE FLOW DATA (WY 1968-2009)

Month	Marietta Flow (cfs)	Conowingo Flow (cfs)
January	9,600	5,465
February	12,030	10,790
March	17,805	18,415
April	23,500	24,485
May	15,205	14,005
June	8,577	6,179
July	5,401	4,527
August	4,361	2,702
September	3,800	1,420
October	4,453	1,212
November	5,809	3,838
December	10,400	7,831

TABLE 4.2.1-7: DAILY AVERAGE FLOW EXCEEDANCE PERCENTILES AT MARIETTA AND CONOWINGO FOR SEASONAL MINIMUM FLOW THRESHOLDS[9], BY MONTH (WY 1968-2009)

	Month	January	February	March	April	May	June	July	August	September	October	November	December
Minimum Flow[10] (cfs)		3,500*	3,500*	3,500	10,000	7,500	5,000	5,000	5,000	3,500 and 5,000	3,500	3,500	3,500*
3500	Marietta	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	98.0%	96.7%	100.0%	100.0%	100.0%
	Conowingo	97.2%	98.9%	99.2%	100.0%	100.0%	99.3%	96.7%	93.7%	88.1%	91.8%	95.6%	98.0%
5000	Marietta	100.0%	100.0%	100.0%	100.0%	100.0%	99.9%	96.8%	91.1%	83.8%	91.8%	98.8%	100.0%
	Conowingo	95.6%	98.1%	99.2%	100.0%	100.0%	97.9%	92.8%	85.3%	74.6%	79.4%	90.6%	97.4%
7500	Marietta	97.3%	99.9%	100.0%	100.0%	100.0%	96.3%	85.9%	65.2%	59.3%	72.7%	91.3%	97.4%
	Conowingo	93.2%	96.8%	98.9%	100.0%	99.3%	92.2%	78.0%	62.8%	59.7%	73.0%	87.7%	95.1%
10000	Marietta	94.7%	98.7%	99.7%	100.0%	100.0%	92.7%	70.0%	47.4%	43.2%	56.2%	83.8%	95.2%
	Conowingo	90.3%	95.5%	98.5%	99.9%	98.8%	88.3%	71.0%	52.9%	51.5%	63.4%	84.1%	93.2%

*The minimum flow from December through February is intermittent, allowing 6 hours at 3,500 cfs followed by 6 hours with no release

[9] These flow records predate the 1989 settlement agreement establishing minimum flow releases, and are not intended to evaluate minimum flow compliance.

[10] All minimum flows are on an "or inflow" basis

TABLE 4.2.1-8: MONTHLY MINIMUM FLOW THRESHOLDS[11] COMPARED TO DAILY AVERAGE MARIETTA FLOW EXCEEDANCES, AND CONOWINGO DAILY AVERAGE FLOWS AT THE EQUIVALENT EXCEEDANCE PERCENTILE (WY 1968-2009)

Month	Minimum Flow (cfs)	Marietta Flow Exceedance Percentile at Monthly Minimum Flow	Conowingo Flow at Marietta Exceedance Percentile(cfs)
January	3,500*	100.0%	511
February	3,500*	100.0%	758
March	3,500	100.0%	287
April	10,000	100.0%	6,090
May	7,500	100.0%	5,220
June	5,000	99.9%	865
July	5,000	96.8%	3,276
August	5,000	91.1%	4,196
September 1-14	5,000	86.3%	4,258
September 15-30	3,500	97.9%	887
October	3,500	100.0%	295
November	3,500	100.0%	303
December	3,500*	100.0%	777

[11] These flow records predate the 1989 settlement agreement establishing minimum flow releases, and are not intended to evaluate minimum flow compliance.

TABLE 4.2.2-1: CONOWINGO ANNUAL AND MONTHLY SUB-DAILY (30-MINUTE) FLOW EXCEEDENCE PERCENTILES, IN CFS (WY 1989-1990, 1992-1993, 1995-2009)

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	909,000	909,000	264,000	416,000	500,000	278,000	459,000	235,000	179,000	446,000	233,000	302,000	295,000
5	122,000	176,000	126,000	173,000	189,000	123,000	86,400	70,230	59,100	74,500	81,100	95,900	138,000
10	85,600	133,000	89,200	132,000	128,000	87,200	72,500	57,800	45,100	58,100	68,100	80,700	97,800
15	79,000	99,000	81,600	106,000	104,000	81,700	65,000	47,745	32,400	45,900	52,000	74,900	82,700
20	73,000	84,000	78,100	87,500	88,200	76,200	58,000	38,200	22,800	32,900	41,100	67,200	79,800
25	67,000	80,200	74,900	82,900	83,800	69,100	50,600	30,400	11,600	23,600	32,800	60,500	75,500
30	60,800	77,700	71,600	79,320	80,700	65,500	42,700	22,200	6,820	10,500	25,900	53,000	70,400
35	51,200	73,000	68,300	76,300	77,700	60,500	36,600	10,800	6,550	6,450	21,900	44,700	66,300
40	41,400	68,300	64,300	73,500	74,400	54,400	29,900	7,460	6,400	6,070	11,600	36,500	61,200
45	33,000	62,500	59,500	71,100	71,800	46,500	23,900	6,800	6,250	5,790	5,930	30,700	52,800
50	25,200	56,300	48,300	68,600	69,400	39,400	17,600	6,550	6,070	5,340	4,910	24,100	43,900
55	17,100	45,900	38,600	64,700	65,900	34,200	8,850	6,350	5,930	4,950	4,680	13,600	34,400
60	9,650	34,800	30,200	59,100	62,500	27,100	7,280	6,220	5,790	4,630	4,590	6,250	26,600
65	6,800	26,400	23,300	48,000	55,000	23,200	6,650	6,060	5,690	4,410	4,510	5,010	19,500
70	6,150	17,600	13,200	38,400	44,680	12,800	6,300	5,880	5,500	4,280	4,420	4,680	7,780
75	5,690	6,750	6,550	29,800	33,700	10,400	6,070	5,790	5,390	4,040	4,320	4,540	4,500
80	5,100	4,410	4,410	23,000	24,900	9,640	5,920	5,650	5,190	3,800	4,210	4,450	3,510
85	4,550	1,870	1,710	7,250	13,700	9,320	5,830	5,550	4,950	3,650	3,840	4,280	1,450
90	4,120	1,160	1,140	5,100	12,500	9,110	5,650	5,290	4,680	3,470	3,730	3,960	1,020
95	3,280	959	950	4,460	11,900	8,800	5,390	4,950	3,760	3,050	3,620	3,620	879
100	257	297	261	1,380	10,000	6,200	4,410	3,070	2,200	1,700	959	756	257

TABLE 4.2.2-2: MARIETTA ANNUAL AND MONTHLY SUB-DAILY (30-MINUTE) FLOW EXCEEDANCE PERCENTILES, IN CFS (WY 1989-1990, 1992-1993, 1995-2009)

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	588,000	588,000	244,000	352,000	448,000	230,000	421,000	249,000	126,000	390,000	198,000	277,000	272,000
5	119,000	176,000	121,000	172,000	179,000	129,000	84,500	48,000	44,900	73,600	65,800	89,600	127,000
10	85,800	122,800	98,100	134,000	131,000	82,500	55,100	37,200	26,400	41,900	42,900	68,300	90,800
15	69,000	98,900	77,200	110,000	107,000	68,700	46,408	31,300	21,700	28,700	33,800	56,600	76,700
20	58,800	85,200	65,500	94,300	95,200	63,100	39,700	28,400	18,939	22,500	28,600	50,300	67,000
25	51,000	72,300	58,800	83,000	85,800	56,900	36,300	25,000	16,700	18,300	25,200	42,400	57,826
30	44,300	63,100	53,500	74,600	77,200	52,900	32,800	21,800	14,400	15,700	22,400	38,200	52,500
35	38,800	57,000	49,200	68,900	71,600	48,100	30,100	19,200	12,300	13,400	20,100	35,400	47,300
40	34,200	50,500	45,000	63,900	67,100	43,600	28,300	17,200	11,100	11,600	17,900	32,500	42,100
45	30,200	44,700	41,200	58,700	62,800	40,100	25,000	14,900	9,630	9,895	15,256	29,000	37,800
50	27,000	40,600	37,700	52,300	58,500	35,801	22,400	13,400	8,680	8,380	12,800	26,300	34,500
55	24,000	36,600	32,900	47,400	54,700	33,400	20,000	12,000	7,960	7,320	10,649	24,360	30,700
60	21,100	31,500	29,900	44,700	50,500	30,800	18,300	11,100	7,340	6,620	9,290	21,500	28,200
65	18,200	27,500	27,600	41,081	46,800	27,900	16,600	10,300	6,560	6,040	8,243	17,700	25,700
70	15,600	23,600	25,900	37,800	43,600	25,690	14,900	9,440	6,040	5,590	7,370	14,100	23,600
75	12,900	21,300	24,100	34,900	39,500	23,700	13,600	8,750	5,630	5,190	6,823	11,000	21,300
80	10,500	19,600	21,200	31,700	35,700	21,800	12,700	7,740	5,350	4,820	6,307	9,330	19,000
85	8,130	17,633	18,400	28,800	32,448	19,300	11,900	7,010	5,000	4,400	5,960	7,810	16,800
90	6,270	15,900	16,691	25,400	27,900	16,700	10,900	6,130	4,400	3,890	5,330	5,920	14,200
95	5,180	13,900	14,700	23,200	23,400	14,600	8,150	5,270	3,530	3,010	4,500	5,350	8,130
100	2,130	7,920	8,930	15,100	17,900	10,900	4,580	3,470	2,600	2,130	3,070	4,220	4,700

TABLE 4.2.3-1: CONOWINGO ANNUAL AND MONTHLY DAILY MINIMUM FLOW EXCEEDANCE PERCENTILES, IN CFS (WY 1989-1990, 1992-1993, 1995-2009)

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	548,000	548,000	181,000	319,000	429,000	194,000	336,000	175,000	111,000	241,000	164,000	240,000	239,000
5	88,800	146,500	88,980	140,000	169,300	97,440	67,910	7,863	7,225	60,270	56,255	74,290	106,000
10	73,500	94,000	81,290	99,800	94,700	71,130	27,740	6,930	6,500	6,590	7,684	53,140	80,000
15	55,480	80,100	72,300	82,500	84,060	59,125	10,066	6,628	6,350	6,110	5,352	34,810	69,515
20	28,300	76,100	39,220	77,400	80,660	40,460	7,526	6,500	6,250	5,880	4,720	23,040	52,000
25	12,700	56,800	23,600	70,100	73,150	26,300	6,878	6,358	6,150	5,760	4,630	5,905	31,675
30	9,640	44,700	12,000	64,600	66,920	12,730	6,600	6,250	6,020	5,340	4,550	5,310	12,800
35	8,070	26,000	4,458	47,800	60,370	10,100	6,400	6,170	5,930	5,100	4,500	4,720	4,376
40	6,450	6,620	4,308	32,800	41,260	9,754	6,200	6,110	5,830	4,860	4,450	4,582	1,306
45	6,110	4,280	1,292	23,600	31,790	9,380	6,110	6,010	5,690	4,501	4,380	4,472	1,090
50	5,790	1,320	1,130	12,000	23,300	9,260	6,010	5,830	5,650	4,370	4,330	4,450	993
55	5,550	1,140	1,070	6,550	13,540	9,170	5,930	5,790	5,600	4,280	4,280	4,380	933
60	5,150	1,090	1,030	6,170	12,800	9,060	5,830	5,690	5,440	4,240	4,240	4,320	908
65	4,630	1,040	985	4,950	12,500	9,060	5,790	5,650	5,290	4,080	4,160	4,250	886
70	4,410	967	949	4,720	12,200	8,988	5,740	5,575	5,195	3,960	4,012	4,160	856
75	4,240	925	917	4,500	12,000	8,850	5,690	5,450	5,050	3,760	3,800	4,040	827
80	3,840	893	893	4,330	11,900	8,740	5,600	5,350	4,860	3,650	3,730	3,928	791
85	3,400	848	854	4,210	11,900	8,543	5,500	5,240	4,680	3,550	3,650	3,757	754
90	1,050	772	724	4,120	11,500	8,310	5,340	5,150	4,455	3,400	3,580	3,580	657
95	866	551	571	3,920	11,200	8,010	5,100	4,860	3,400	2,770	3,440	3,370	504
100	257	297	261	1,380	10,000	6,200	4,410	3,070	2,200	1,700	959	756	257

TABLE 4.2.3-2: MARIETTA ANNUAL AND MONTHLY DAILY MINIMUM FLOW EXCEEDANCE PERCENTILES, IN CFS (WY 1989-1990, 1992-1993, 1995-2009)

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	488,000	488,000	196,000	329,000	405,000	209,000	363,000	199,000	112,000	225,000	174,000	240,000	240,000
5	106,000	157,000	108,000	156,000	163,000	115,150	68,650	41,225	37,064	61,850	57,280	81,490	108,350
10	77,500	106,000	85,547	116,000	117,400	75,710	50,000	33,100	24,000	35,360	38,770	62,980	82,800
15	63,900	92,000	70,060	98,900	97,320	65,800	42,445	29,101	19,774	25,140	31,405	53,010	69,900
20	54,900	76,800	61,080	87,300	89,100	59,140	36,940	26,500	17,200	19,725	26,980	44,180	60,600
25	47,300	65,350	54,748	75,400	79,800	54,225	34,000	23,000	15,300	16,600	23,600	39,400	54,850
30	41,300	58,900	50,370	69,000	73,020	49,530	30,345	20,428	13,500	13,780	21,400	36,320	48,640
35	36,300	54,000	45,715	64,200	67,900	44,735	28,600	18,097	11,300	11,755	18,915	33,190	44,615
40	32,000	48,200	42,620	59,400	63,600	41,791	26,720	15,700	10,100	10,300	16,700	30,760	38,960
45	28,600	42,800	39,305	54,500	60,030	37,545	23,335	14,084	8,930	8,630	13,905	27,320	35,410
50	25,400	37,800	35,750	49,200	55,700	34,613	21,200	12,500	8,105	7,550	11,700	25,200	33,000
55	22,500	33,600	31,090	45,400	52,050	32,500	19,000	11,400	7,513	6,900	9,729	23,600	29,600
60	19,500	29,100	28,460	41,500	47,800	29,200	17,560	10,500	6,900	6,230	8,733	19,700	27,000
65	17,100	25,740	26,385	39,400	44,910	26,838	16,000	9,793	6,260	5,900	7,769	16,700	24,470
70	14,500	21,900	24,900	35,700	41,654	24,740	14,100	9,000	5,645	5,356	6,935	13,303	22,130
75	11,900	20,400	22,725	33,500	37,998	22,900	12,900	8,393	5,390	4,945	6,404	10,500	20,300
80	9,620	18,100	19,620	30,400	34,600	20,680	12,200	7,380	5,030	4,610	6,020	8,950	18,100
85	7,550	16,500	17,630	27,400	31,037	18,300	11,385	6,790	4,790	4,202	5,620	7,425	16,065
90	5,960	15,053	15,655	24,700	27,300	15,900	10,500	5,910	4,010	3,686	5,111	5,654	13,020
95	4,920	13,350	13,807	22,900	22,620	14,100	7,734	5,038	3,305	2,802	4,355	5,150	7,572
100	2,130	7,920	8,930	15,100	17,900	10,900	4,580	3,470	2,600	2,130	3,070	4,220	4,700

TABLE 4.2.4.1-1: CONOWINGO AND MARIETTA DAILY AVERAGE IHA PARAMETER GROUP 1 (MAGNITUDE) STATISTICS (WY 1967-2009)

Parameter Group #1	Median Flow (cfs)		Dispersion Coefficient[12]		Minimum Flow (cfs)		Maximum Flow (cfs)	
	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo
October	11,400	13,350	1.267	1.312	4,040	4,520	73,000	77,800
November	27,950	30,050	0.7813	0.7879	5,440	4,455	58,350	62,950
December	37,900	40,000	0.9077	0.8256	5,720	6,100	92,600	100,000
January	23,500	27,950	1.198	1.069	6,300	7,520	82,500	95,800
February	34,300	39,350	0.7832	0.729	11,500	14,200	84,550	86,100
March	54,050	56,300	0.6762	0.6088	15,000	17,400	115,000	125,000
April	63,330	66,330	0.6145	0.5247	26,450	30,700	212,000	220,000
May	37,950	39,500	0.7484	0.7563	17,600	17,800	81,300	93,600
June	22,600	23,830	0.7013	0.7513	6,710	6,475	66,800	75,950
July	13,800	16,450	0.7138	0.6398	5,170	4,830	57,000	56,500
August	9,155	11,750	0.9072	0.8772	3,770	4,310	39,400	46,000
September	8,415	10,330	1.186	1.189	3,140	3,120	74,300	97,250

[12] The dispersion coefficient is defined as the difference of the 25th and 75th flow exceedance percentiles divided by the sum of the 25th and 75th flow exceedance percentiles, or $(Q_{75}-Q_{25})/(Q_{75}+Q_{25})$. It is intended to evaluate the flow variation experienced in the river.

TABLE 4.2.4.1-2: CONOWINGO AND MARIETTA DAILY AVERAGE IHA PARAMETER GROUP 2 (DURATION) STATISTICS (WY 1967-2009)

Parameter Group #2	Median		Dispersion Coefficient		Minimum		Maximum	
	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo
1-day minimum flow (cfs)	4,530	1,280	0.4989	2.059	2,150	269	11,800	9,910
3-day minimum flow (cfs)	4,698	3,601	0.5234	0.7217	2,197	788	11,970	11,630
7-day minimum flow (cfs)	4,822	4,770	0.5198	0.6704	2,351	1,807	12,500	13,000
30-day minimum flow (cfs)	6,529	6,994	0.6196	0.6016	3,117	3,199	20,290	21,750
90-day minimum flow (cfs)	12,960	13,900	0.7078	0.6767	5,044	5,584	37,360	39,990
1-day maximum flow (cfs)	242,000	240,500	0.6539	0.658	134,000	130,000	1,040,000	1,120,000
3-day maximum flow (cfs)	220,500	219,300	0.6036	0.6007	122,700	111,900	950,000	1,057,000
7-day maximum flow (cfs)	177,400	176,500	0.6053	0.6162	98,110	88,570	642,900	711,900
30-day maximum flow (cfs)	112,900	112,900	0.4082	0.44	61,400	63,410	243,900	259,600
90-day maximum flow (cfs)	75,960	77,130	0.3385	0.3423	43,820	44,460	124,200	127,700
Number of zero flow days	0	0	0	0	0	0	0	0
Base flow index	0.138	0.1279	0.3953	0.552	0.07597	0.04817	0.2145	0.2301

TABLE 4.2.4.1-3: CONOWINGO AND MARIETTA DAILY AVERAGE IHA PARAMETER GROUP 3 (TIMING) STATISTICS (WY 1967-2009)

Parameter Group #3	Medians		Dispersion Coefficient		Minimum		Maximum	
	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo
Julian day[13] of minimum flow	270.5	265	0.08607	0.2657	188	1	314	352
Julian day of maximum flow	79.5	82.5	0.1776	0.1496	10	10	364	344

[13] Julian day refers to the day of the year, with Jan 1 being Julian day 1, Jan 2 being Julian day 2, etc. Normal years have 365 days, with leap years containing 366.

TABLE 4.2.4.1-4: CONOWINGO AND MARIETTA DAILY AVERAGE IHA PARAMETER GROUP 4 (FREQUENCY) STATISTICS (WY 1967-2009). LOW PULSES ARE FLOWS BELOW THE 75% FLOW EXCEEEENCE PERCENTILE. HIGH PULSES ARE FLOWS ABOVE THE 25% FLOW EXCEEDENCE PERCENTILE.

Parameter Group #4	Medians		Dispersion Coefficient		Minimum		Maximum	
	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo
Low pulse count	5	21	0.8	0.4405	1	5	10	36
Low pulse duration	7.25	2	1.397	0	2	1	181	6
High pulse count	8	11	0.375	0.2955	4	6	18	26
High pulse duration	6.5	4.75	0.7692	0.6579	3	2	18	14

TABLE 4.2.4.1-5: CONOWINGO AND MARIETTA DAILY AVERAGE IHA PARAMETER GROUP 5 (RATE OF CHANGE) STATISTICS (WY 1967-2009)

Parameter Group #5	Medians		Dispersion Coefficient		Minimum		Maximum	
	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo	Marietta	Conowingo
Rise rate	1,950	5,750	0.5481	0.3171	695	2,800	5,600	9,100
Fall rate	-1,800	-5,704	-0.5903	-0.2871	-4,300	-8,400	-630	-3,035
Number of reversals	92	170	0.1793	0.09706	62	152	111	198

TABLE 4.2.4.2-1: SUB-DAILY IHA-TYPE METRICS FOR MARIETTA AND CONOWINGO (WY 1989-1990, 1992-1993, 1995-2009). METRICS AND THRESHOLDS ARE DESCRIBED IN ZIMMERMAN ET AL. (2009).

Metric	Flashiness Threshold			Days per Year Above Threshold	
	Low	Medium	High	Marietta	Conowingo
RBF	≥0.03	≥0.05	≥0.07	0 (0 - 1)	224 (187 - 261)
NREVS	≥6.00	≥9.00	≥12.00	12 (6 - 28)	204 (139 - 318)
PTF	≥0.02	≥0.03	≥0.04	0 (0 - 0)	0 (0 - 0)
CDV	≥0.12	≥0.15	≥0.18	12 (8 - 19)	282 (274 - 291)

TABLE 4.3-1: CONOWINGO PRE-DEREGULATION (WY 1989-1990, 1992-1993, 1995-1997) ANNUAL AND MONTHLY SUB-DAILY FLOW EXCEEDANCE PERCENTILES

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	909,000	909,000	227,000	416,000	500,000	278,000	191,000	98,000	66,300	126,000	233,000	302,000	295,000
5	124,000	181,000	126,000	131,550	247,000	159,000	86,510	67,300	51,600	57,200	75,100	93,140	120,000
10	82,100	121,000	98,000	95,900	191,000	119,700	66,300	61,000	43,200	52,200	61,900	74,700	82,500
15	74,500	81,090	86,500	83,100	158,000	88,300	60,500	55,000	32,500	40,000	44,900	69,900	76,700
20	69,700	77,400	80,800	81,000	99,700	78,100	54,100	45,900	23,200	32,500	32,700	67,000	71,400
25	64,700	72,500	76,700	77,900	86,100	71,900	48,400	38,700	13,375	23,600	25,200	62,800	68,600
30	59,500	68,900	73,300	74,900	81,000	68,800	42,200	29,500	7,550	13,000	23,100	60,100	66,100
35	50,500	66,900	67,000	73,800	77,200	66,400	38,900	21,800	6,650	6,650	17,300	53,200	62,300
40	40,800	61,700	61,600	72,500	73,500	62,200	32,500	8,900	6,500	6,300	7,440	46,400	59,500
45	32,100	53,135	49,625	69,400	71,600	57,400	23,600	6,700	6,400	6,150	5,100	42,000	48,200
50	23,600	43,500	39,400	66,400	67,800	48,900	22,200	6,450	6,300	5,600	4,810	33,200	39,800
55	16,300	31,900	29,775	63,200	64,300	39,500	11,500	6,350	6,200	5,100	4,630	25,900	30,500
60	9,420	23,400	22,900	56,100	60,500	32,400	6,960	6,250	6,060	4,910	4,590	21,700	23,200
65	6,600	12,300	11,400	44,600	48,700	24,100	6,550	6,200	5,730	4,450	4,540	10,100	11,400
70	6,200	5,730	5,390	34,570	36,320	17,480	6,350	6,110	5,500	4,320	4,450	5,100	4,770
75	5,500	4,410	4,450	23,700	24,000	9,850	6,250	5,830	5,440	4,240	4,370	4,630	4,370
80	5,000	3,070	2,620	11,080	14,500	9,370	6,110	5,500	5,290	3,650	4,280	4,500	2,920
85	4,500	1,410	1,260	6,550	12,500	9,110	5,960	5,390	5,000	3,502	4,080	4,410	1,280
90	4,280	1,120	1,040	5,190	11,800	8,800	5,550	5,290	4,950	3,400	3,690	4,320	1,010
95	2,830	976	950	4,540	11,400	8,370	5,340	5,150	4,720	2,950	3,440	3,960	908
100	744	796	783	1,690	10,000	6,200	4,910	4,630	3,170	2,590	959	2,890	744

TABLE 4.3-2: CONOWINGO POST-DEREGULATION (WY 1998-2009) ANNUAL AND MONTHLY SUB-DAILY FLOW EXCEEDANCE PERCENTILES

Exceedance Percentile	Annual	January	February	March	April	May	June	July	August	September	October	November	December
0	459,000	370,000	264,000	381,000	430,000	234,000	459,000	235,000	179,000	446,000	185,000	250,000	288,000
5	121,000	174,000	125,000	191,000	133,000	88,090	86,400	73,800	64,700	85,600	82,100	96,100	143,000
10	86,800	138,000	84,800	147,000	114,000	84,000	75,800	51,800	48,300	69,300	73,400	81,900	102,000
15	80,500	112,000	80,200	124,000	96,600	80,000	66,400	42,000	31,900	47,000	57,900	80,300	87,400
20	75,800	94,000	77,500	102,000	87,240	76,000	62,000	33,900	20,100	33,900	45,900	69,100	81,300
25	69,400	84,200	73,800	87,200	83,600	66,225	51,400	26,100	8,500	23,600	37,100	53,800	80,000
30	61,900	80,300	70,600	83,300	80,700	61,970	42,900	17,100	6,670	8,090	31,200	45,500	78,100
35	51,500	79,400	68,600	79,000	77,900	55,300	34,300	7,970	6,500	6,270	24,500	35,100	71,600
40	41,900	76,100	65,200	74,900	75,500	47,860	27,600	7,220	6,300	5,880	15,100	30,600	64,180
45	33,600	69,600	62,000	71,600	71,800	43,405	23,900	6,850	6,020	5,650	7,190	24,900	54,700
50	26,000	62,500	53,600	69,700	69,900	36,600	13,700	6,650	5,930	5,290	5,060	13,000	46,600
55	17,400	55,400	43,700	65,800	66,300	32,600	8,500	6,360	5,830	4,910	4,690	6,220	36,700
60	9,850	45,000	34,800	59,800	63,500	25,900	7,500	6,110	5,740	4,600	4,600	5,200	30,720
65	6,960	34,400	26,900	50,300	59,100	21,500	6,700	5,930	5,690	4,370	4,510	4,730	23,700
70	6,070	26,700	21,800	39,440	47,000	12,000	6,150	5,830	5,550	4,200	4,410	4,600	13,200
75	5,740	16,200	12,300	32,700	37,700	10,500	5,930	5,790	5,340	4,040	4,290	4,500	5,690
80	5,190	6,700	6,158	24,700	27,760	9,810	5,830	5,690	5,100	3,800	4,080	4,320	3,510
85	4,590	3,840	2,950	12,220	21,500	9,380	5,790	5,600	4,810	3,690	3,840	4,040	1,730
90	4,080	1,224	1,250	5,050	13,000	9,170	5,690	5,400	4,510	3,550	3,760	3,760	1,040
95	3,470	908	970	4,420	12,200	8,960	5,500	4,910	3,620	3,140	3,650	3,340	828
100	257	297	261	1,380	10,900	6,850	4,410	3,070	2,200	1,700	1,810	756	257

TABLE 4.3-3: NUMBER OF DAYS EXCEEDING SUB-DAILY IHA FLASHINESS THRESHOLDS, BY WATER YEAR

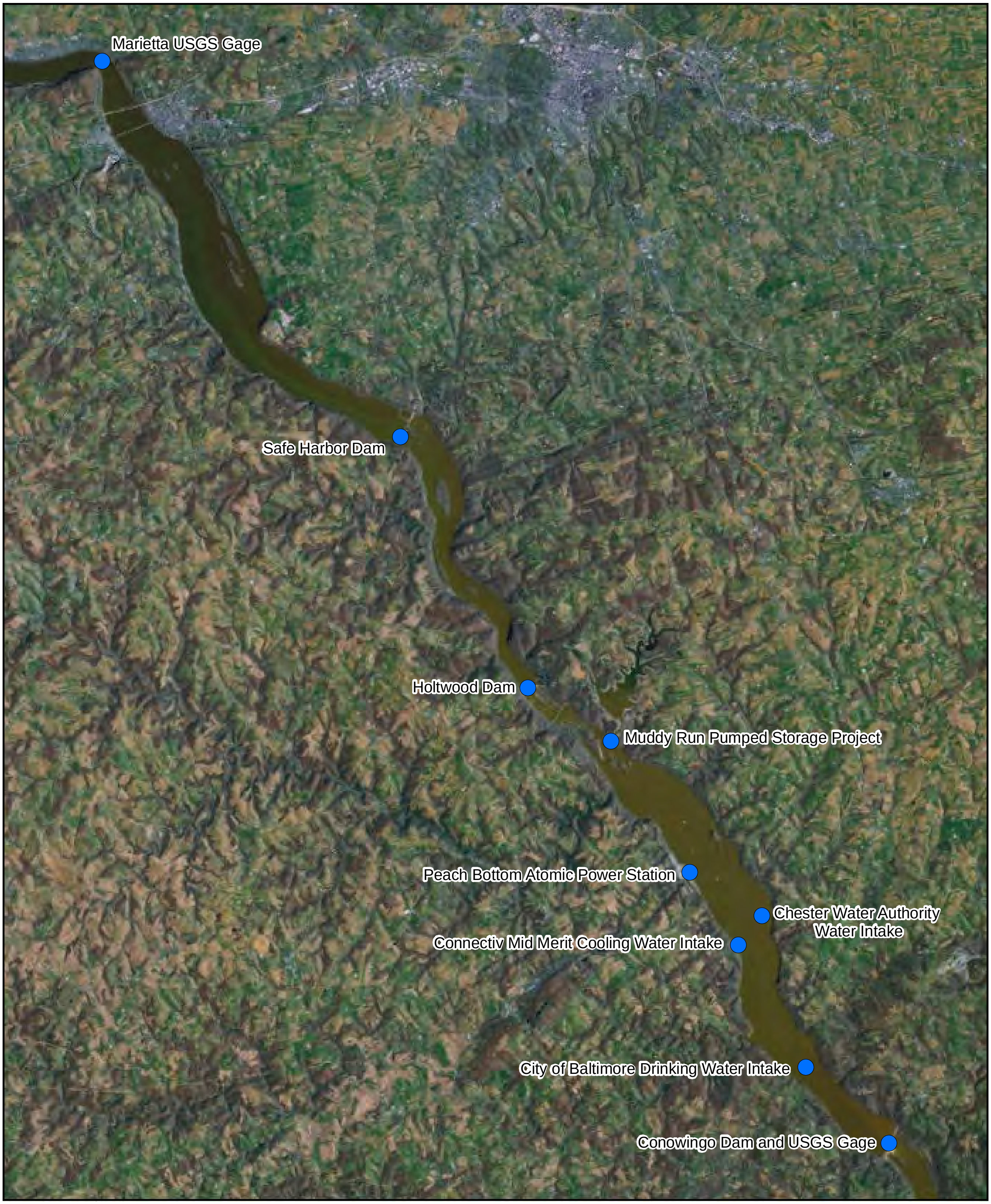
	Threshold	≥0.05	≥9.00	≥0.03	≥0.15
Water Year	Deregulation?	RBF	NREVS	PTF	CDV
1989	Pre-Deregulation	240	207	0	280
1990	Pre-Deregulation	247	217	0	297
1992	Pre-Deregulation	274	194	0	291
1993	Pre-Deregulation	166	225	0	213
1995	Pre-Deregulation	235	160	0	262
1996	Pre-Deregulation	196	236	0	272
1997	Pre-Deregulation	220	212	0	282
1998	Pre-Deregulation	167	251	0	237
1999	Post-Deregulation	209	210	0	242
2000	Post-Deregulation	253	192	0	303
2001	Post-Deregulation	174	156	0	210
2002	Post-Deregulation	203	155	0	244
2003	Post-Deregulation	169	168	0	272
2004	Post-Deregulation	129	141	0	235
2005	Post-Deregulation	198	174	0	256
2006	Post-Deregulation	248	204	0	327
2007	Post-Deregulation	201	187	0	248
2008	Post-Deregulation	217	224	0	281
2009	Post-Deregulation	255	138	0	291

TABLE 4.3-4: COMPARISON OF PRE AND POST-DEREGULATION SUB-DAILY IHA FLASHINESS METRIC, SHOWN AS AVERAGE EXCEEDANCES PER YEAR

Metric	Water Years	RBF	NREVS	PTF	CDV
Pre-Deregulation	1989-1990, 1992-1993, 1995-1997	225	207	0	271
Post-Deregulation	1998-2009	202	183	0	262

TABLE 4.3-5: DAYS PER YEAR WITH A MINIMUM INSTANTANEOUS FLOW BELOW THE MONTHLY 75TH FLOW EXCEEDANCE PERCENTILE AND A MAXIMUM INSTANTANEOUS FLOW ABOVE THE MONTHLY 25TH FLOW EXCEEDANCE PERCENTILE, BY WATER YEAR

Water Year	Deregulation?	Days Per Year
1989	Pre-Deregulation	80
1990	Pre-Deregulation	28
1992	Pre-Deregulation	59
1993	Pre-Deregulation	4
1995	Pre-Deregulation	76
1996	Pre-Deregulation	96
1997	Pre-Deregulation	76
1998	Pre-Deregulation	31
1999	Post-Deregulation	37
2000	Post-Deregulation	49
2001	Post-Deregulation	8
2002	Post-Deregulation	17
2003	Post-Deregulation	61
2004	Post-Deregulation	94
2005	Post-Deregulation	70
2006	Post-Deregulation	69
2007	Post-Deregulation	57
2008	Post-Deregulation	108
2009	Post-Deregulation	71



Exelon.

N

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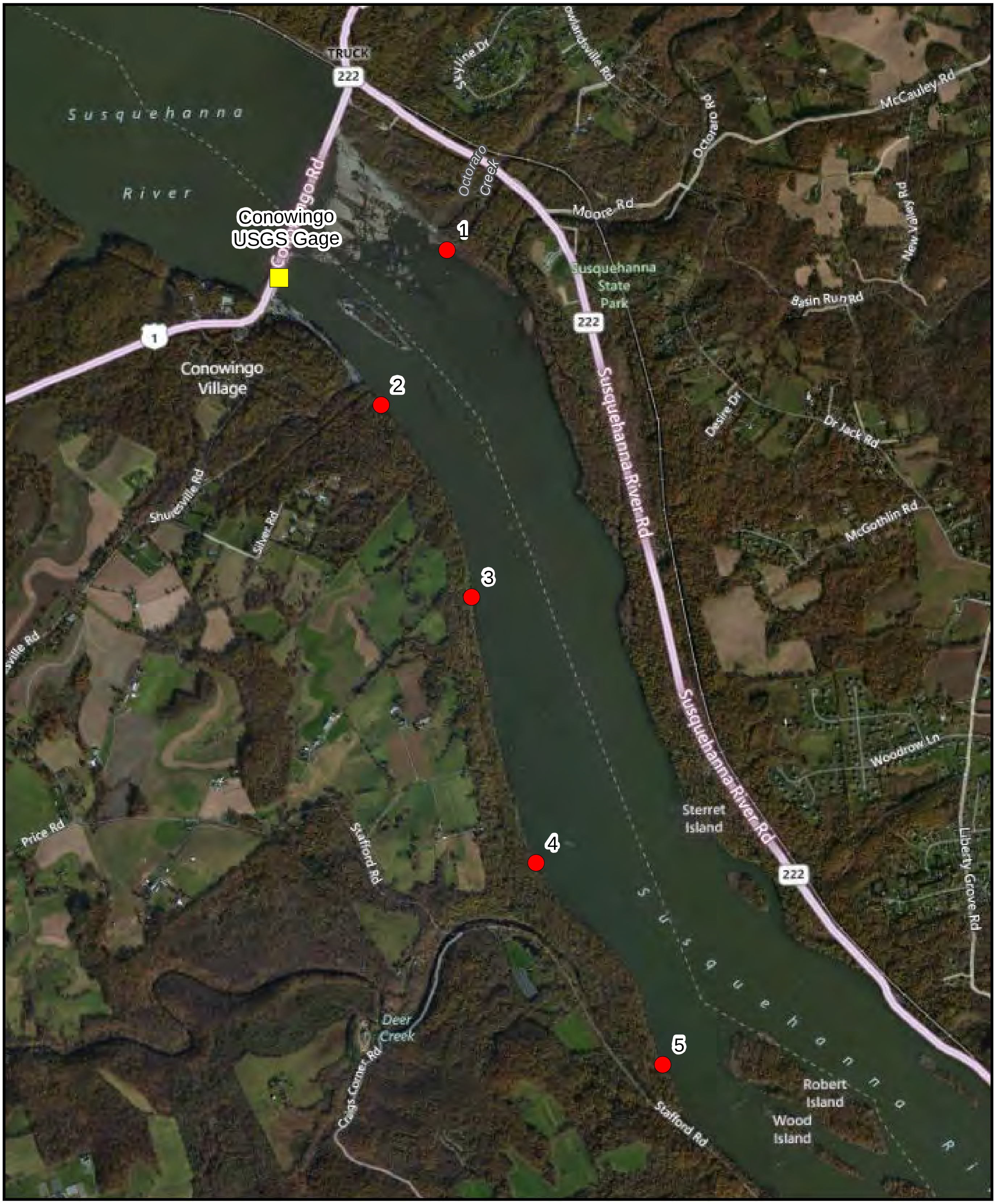
PROJECT NO. 405

1 inch = 3.5 miles

0 1.75 3.5 7 Miles

Figure 2.1-1:
Lower Susquehanna River
Water Use Facilities

Path: X:\GISMaps\project_maps\study_plan\conowingo\study_3_11\con_water_use_facilities.mxd



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PROJECT NO. 405

N

1 inch = 0.5 miles

0 0.25 0.5 1 Miles

Figure 4.1-1: Conowingo USGS Gage and Stage Gage Locations Downstream of Conowingo Dam

Path: X:\GISMaps\project_maps\study_plan\conowingo\study_3_11\usgs_and_stage_gage_locations.mxd

FIGURE 4.1-2: WATER SURFACE ELEVATIONS DOWNSTREAM OF CONOWINGO DAM. SITE 3 DOWNWARD SPIKE ON 6/15/2010 IS FROM THE DATALOGGER BEING PULLED OUT OF THE WATER FOR DATA COLLECTION

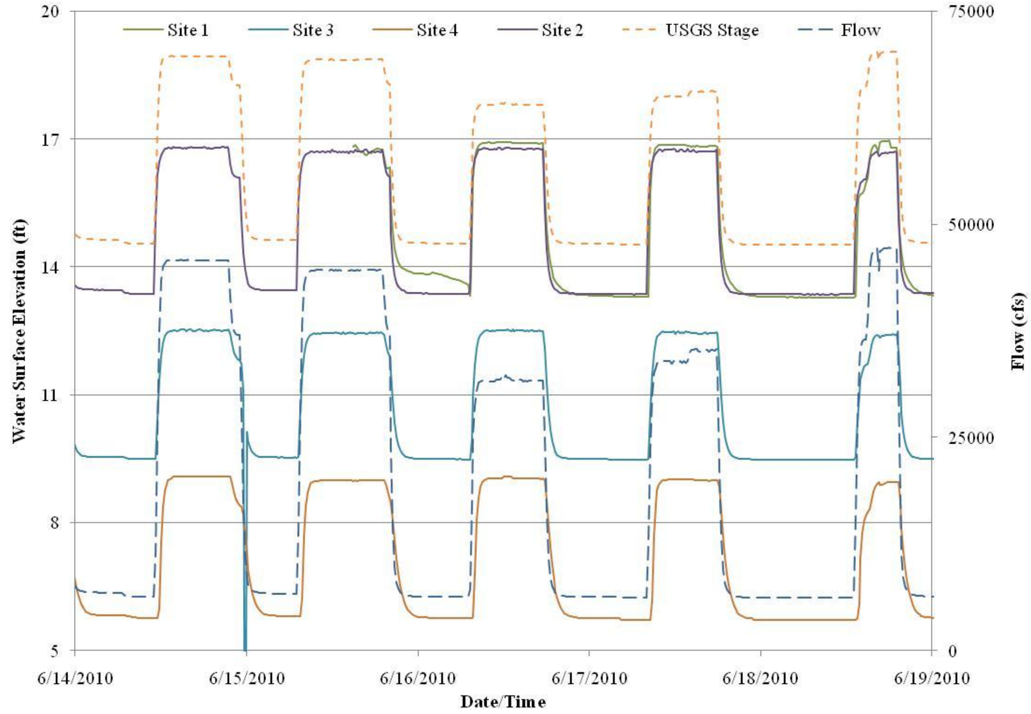


FIGURE 4.1-3: RATING CURVE COMPARING MEASURED DOWNSTREAM WATER SURFACE ELEVATIONS TO USGS GAGE FLOWS

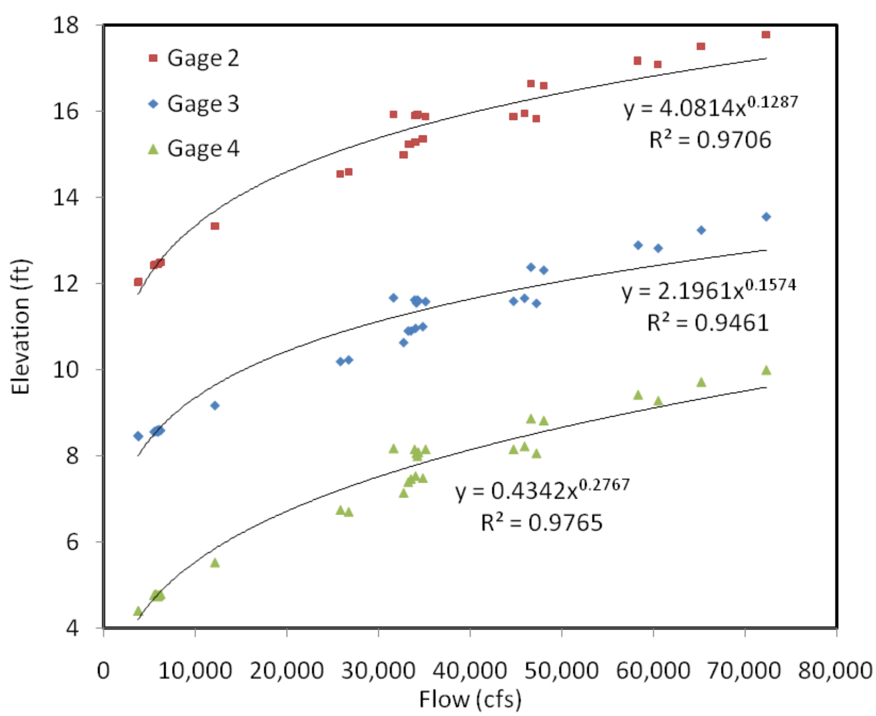


FIGURE 4.2.1-1: CONOWINGO AND MARIETTA DAILY AVERAGE FLOW COMPARISON (WY 1968-2009)

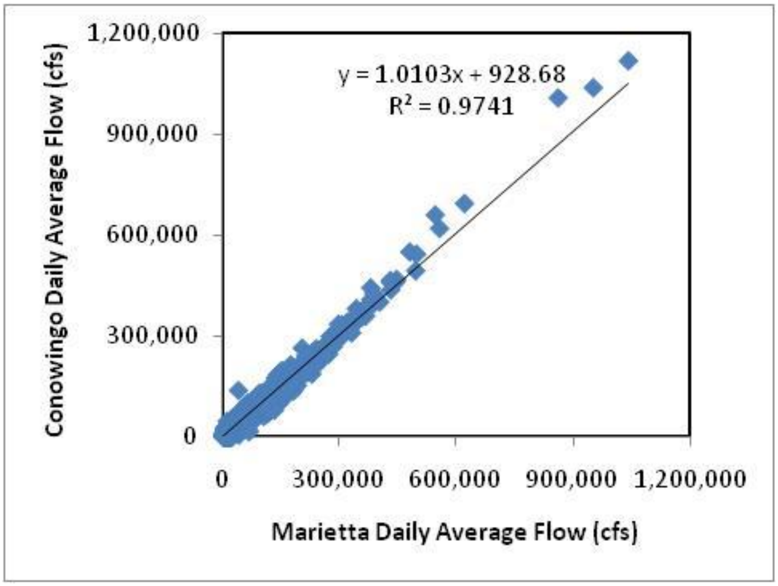


FIGURE 4.2.1-2: CONOWINGO AND MARIETTA DAILY AVERAGE FLOW EXCEEDANCE CURVES (WY 1968-2009)

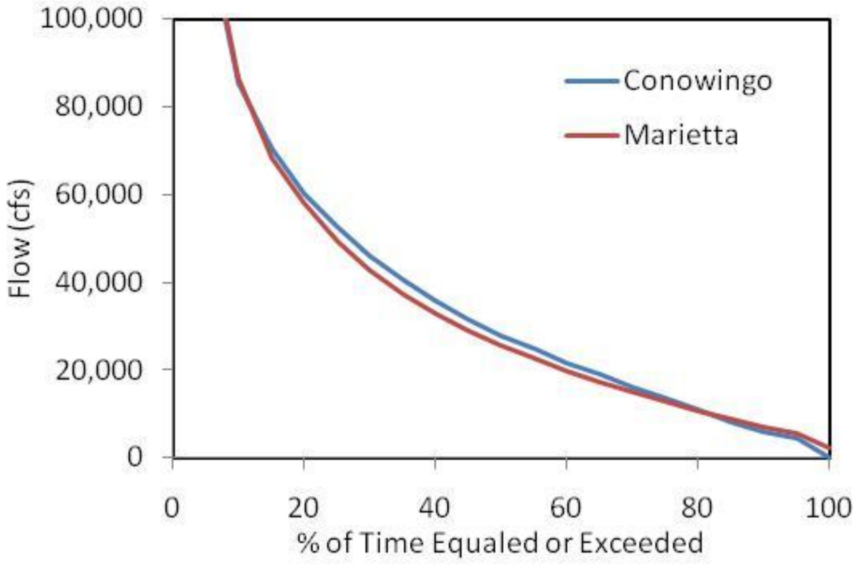


FIGURE 4.2.2-1: COMPARISON OF MARIETTA AND CONOWINGO 30-MINUTE AND DAILY AVERAGE FLOW DATA

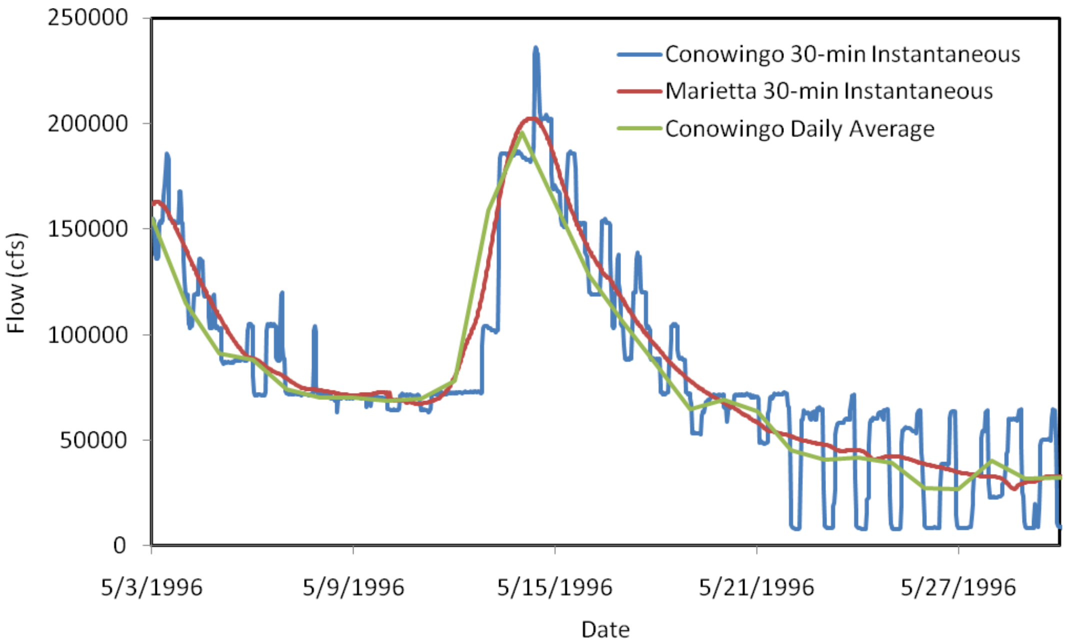


FIGURE 4.2.2-2: CONOWINGO AND MARIETTA ANNUAL SUB-DAILY FLOW EXCEEDANCE CURVES (WY 1989-1990, 1992-1993, 1995-2009)

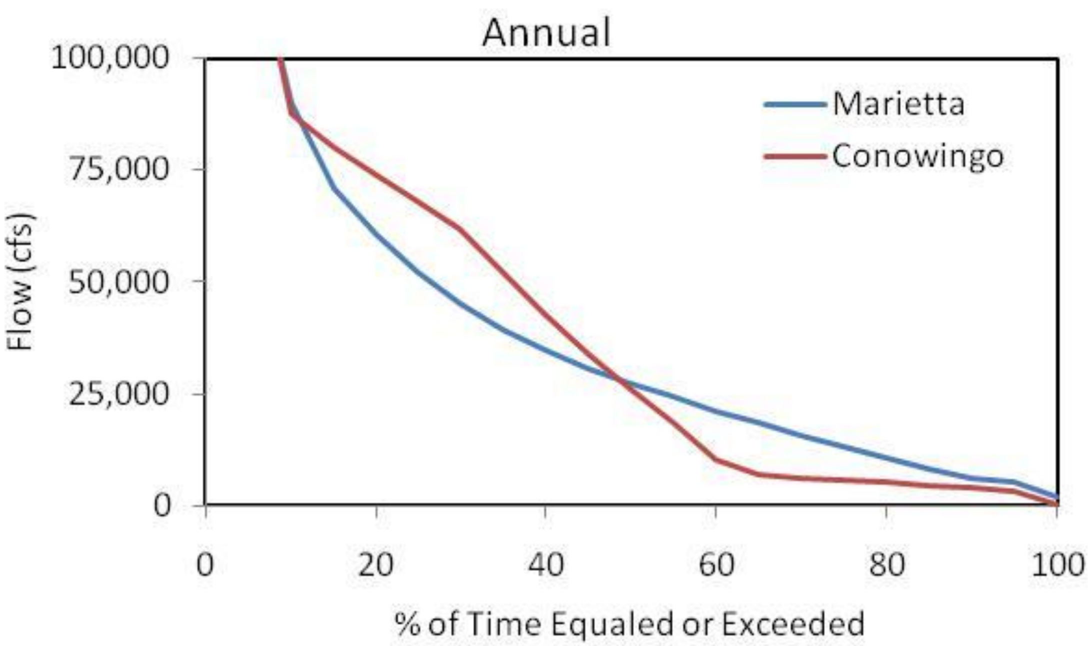


FIGURE 4.2.3-1: CONOWINGO ANNUAL DAILY MINIMUM FLOW EXCEEDANCE CURVES (WY 1989-1990, 1992-1993, 1995-2009)

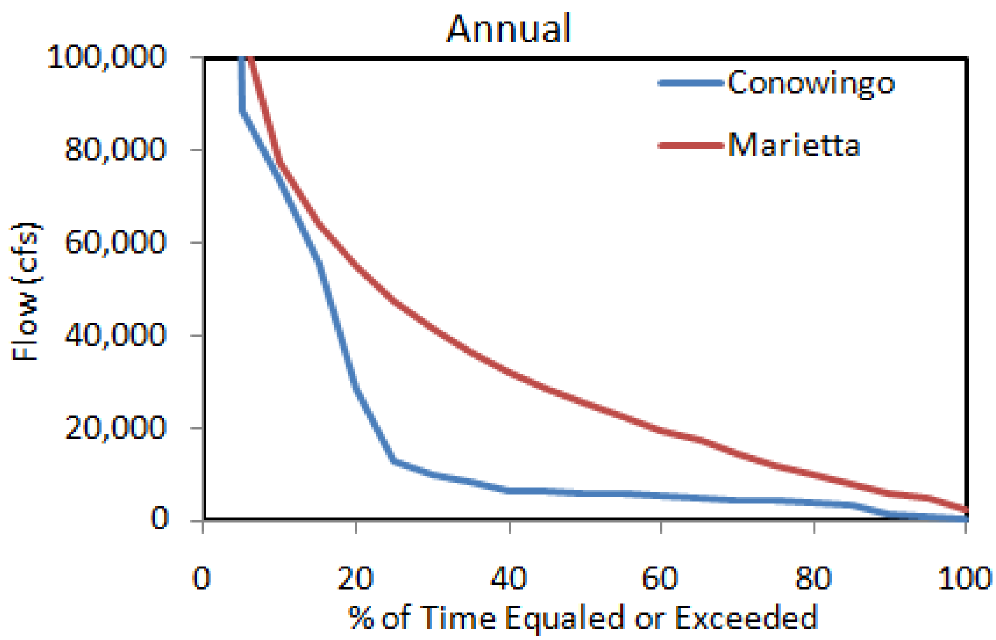


FIGURE 4.2.4.2-1: CONOWINGO FLOW TIME SERIES SHOWING SLIGHT FLOW OSCILLATIONS AT A MINIMUM FLOW OF APPROXIMATELY 5,000 CFS. SUB-DAILY FLOW STATISTICS INDICATED 14 FLOW REVERSALS FOR THIS DAY

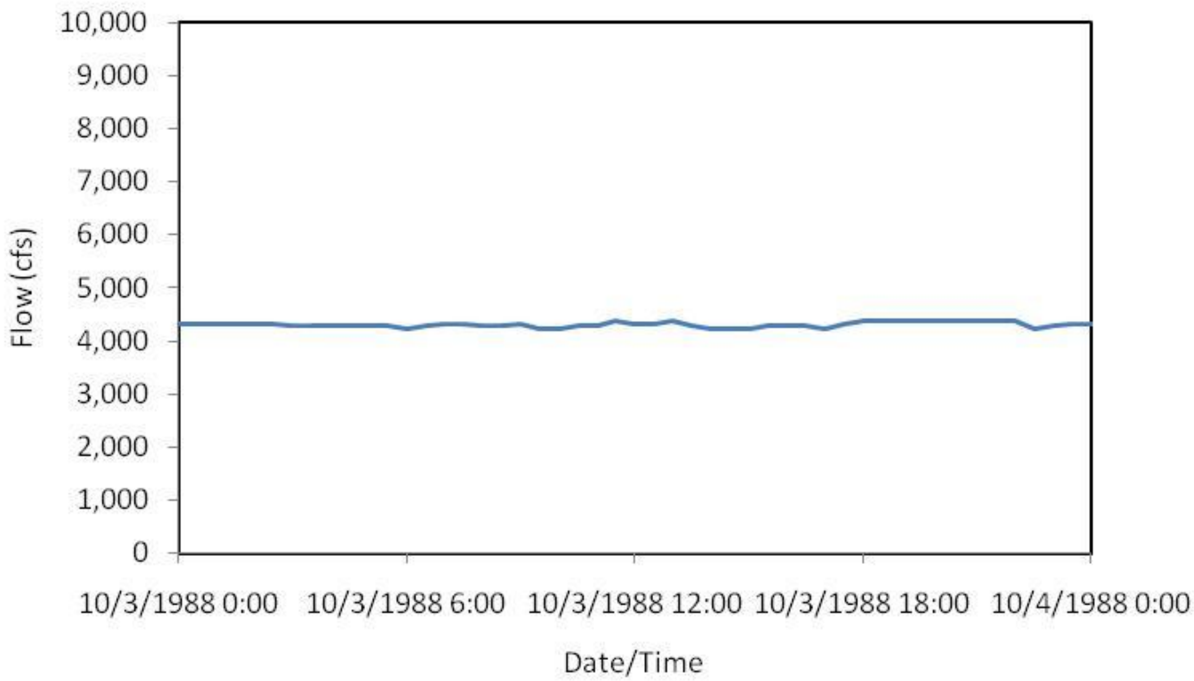


FIGURE 4.3-1: ANNUAL SUB-DAILY FLOW EXCEEDANCE CURVES FOR PRE (WY 1989-1990, 1992-1993, 1995-1997) AND POST-DEREGULATION (WY 1998-2009) PERIODS AT CONOWINGO

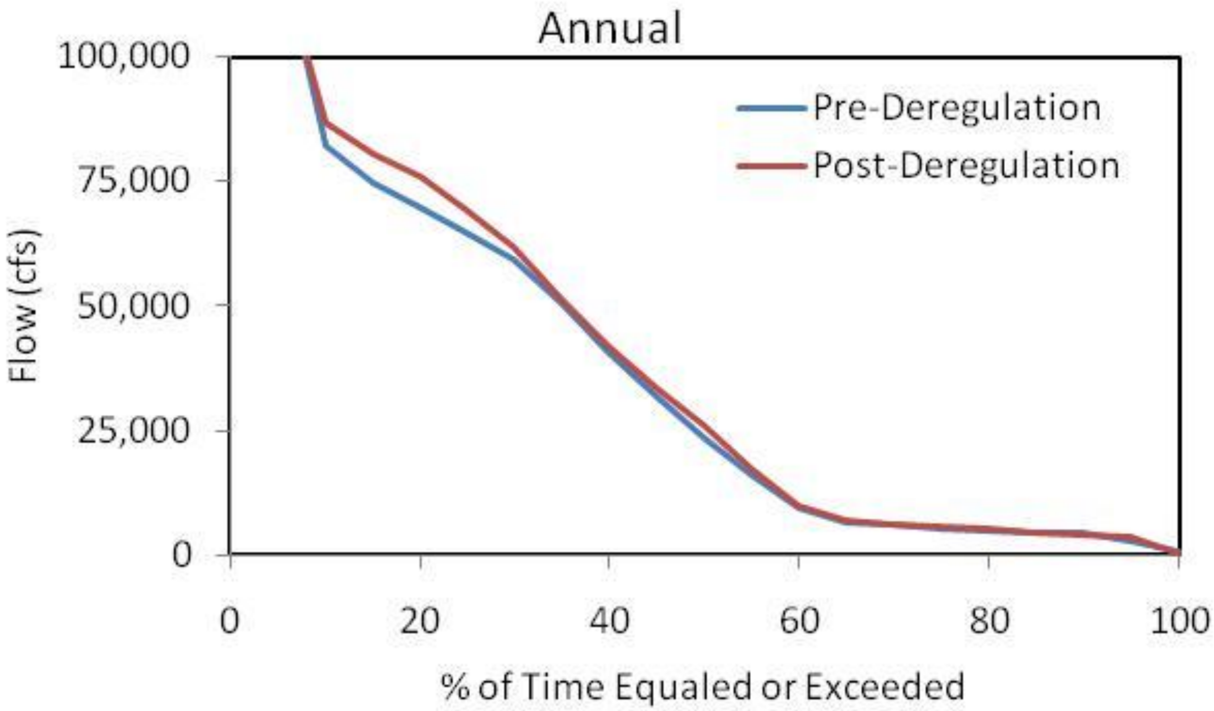


FIGURE 4.3-2: SUB-DAILY FLOW EXCEEDANCE CURVES FOR A PRE AND POST-DEREGULATION DRY YEAR (1995, 2001)

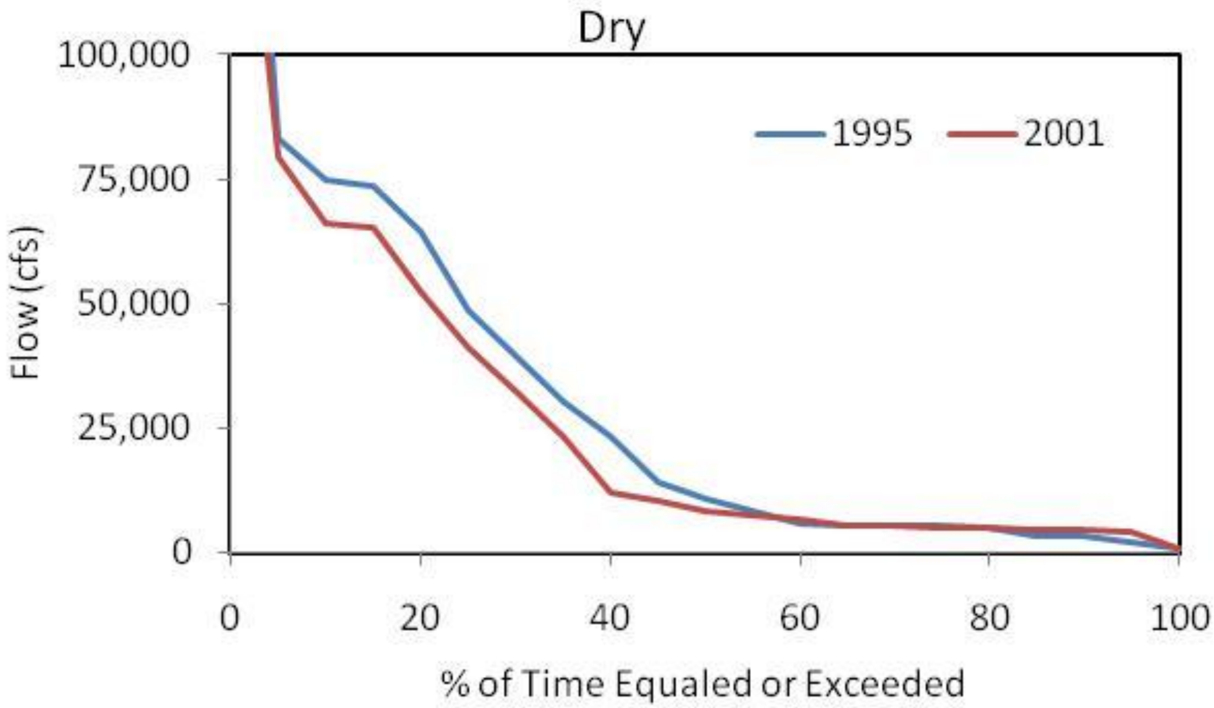


FIGURE 4.3-3: SUB-DAILY FLOW EXCEEDANCE CURVES FOR A PRE AND POST-DEREGULATION WET YEAR (1996, 2003)

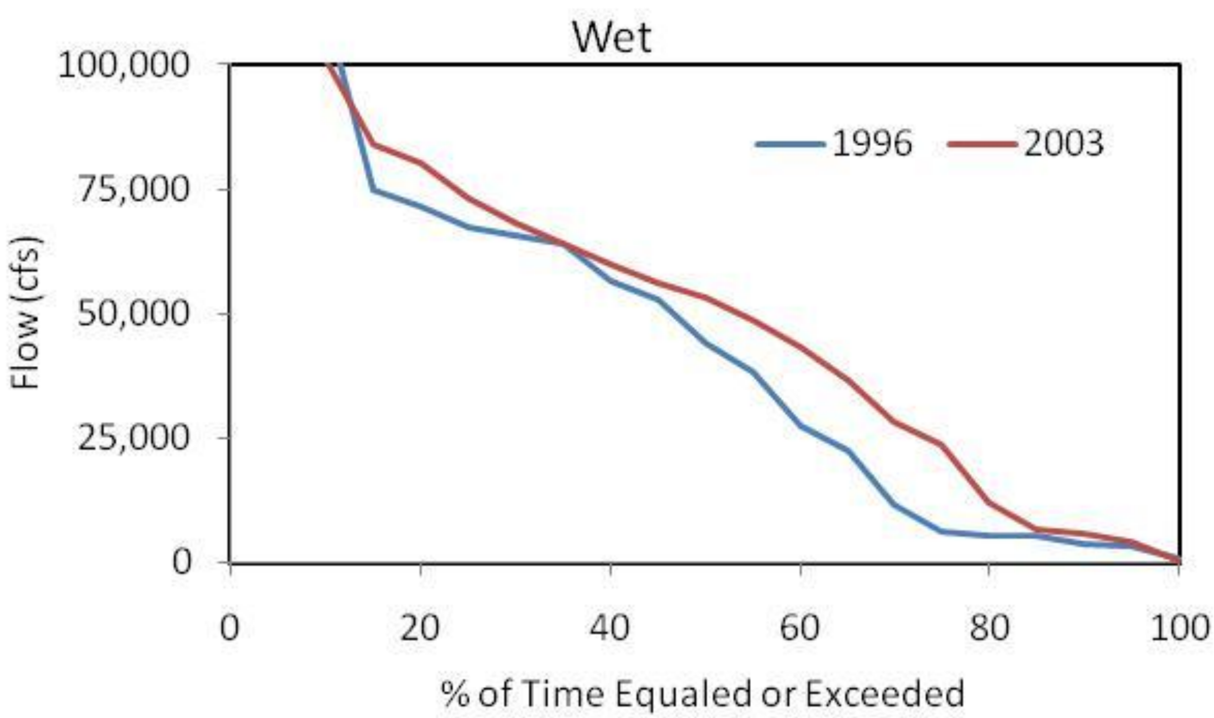
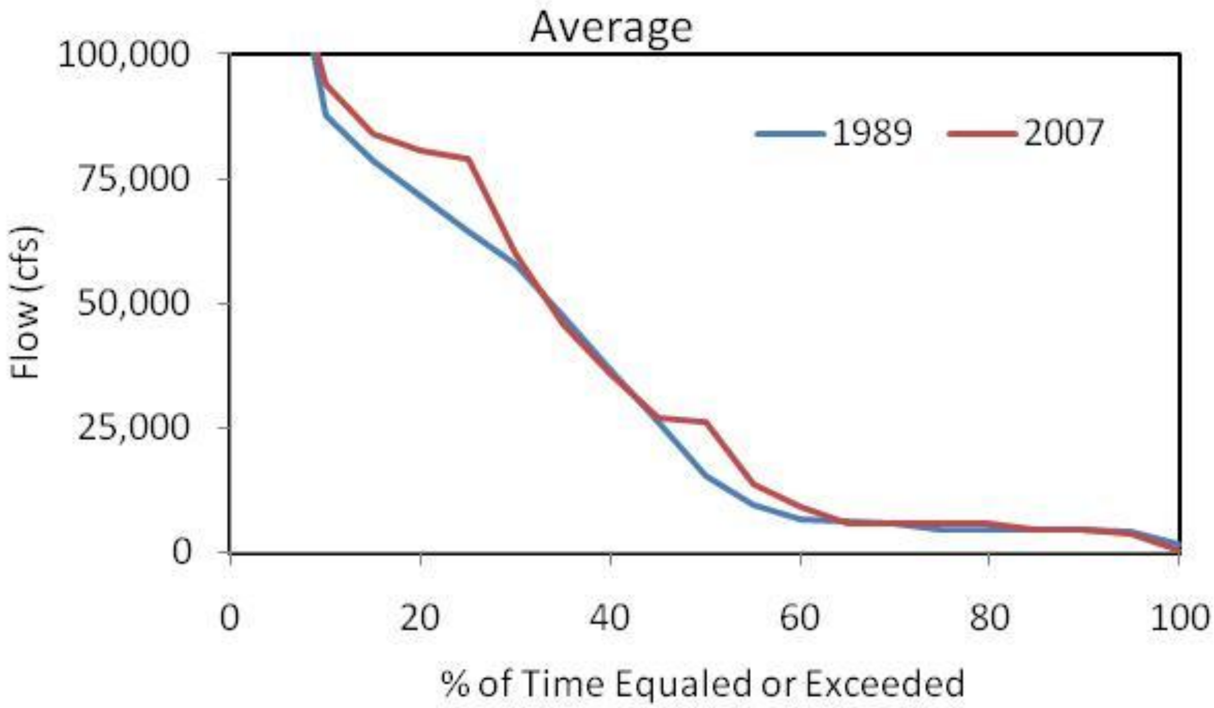
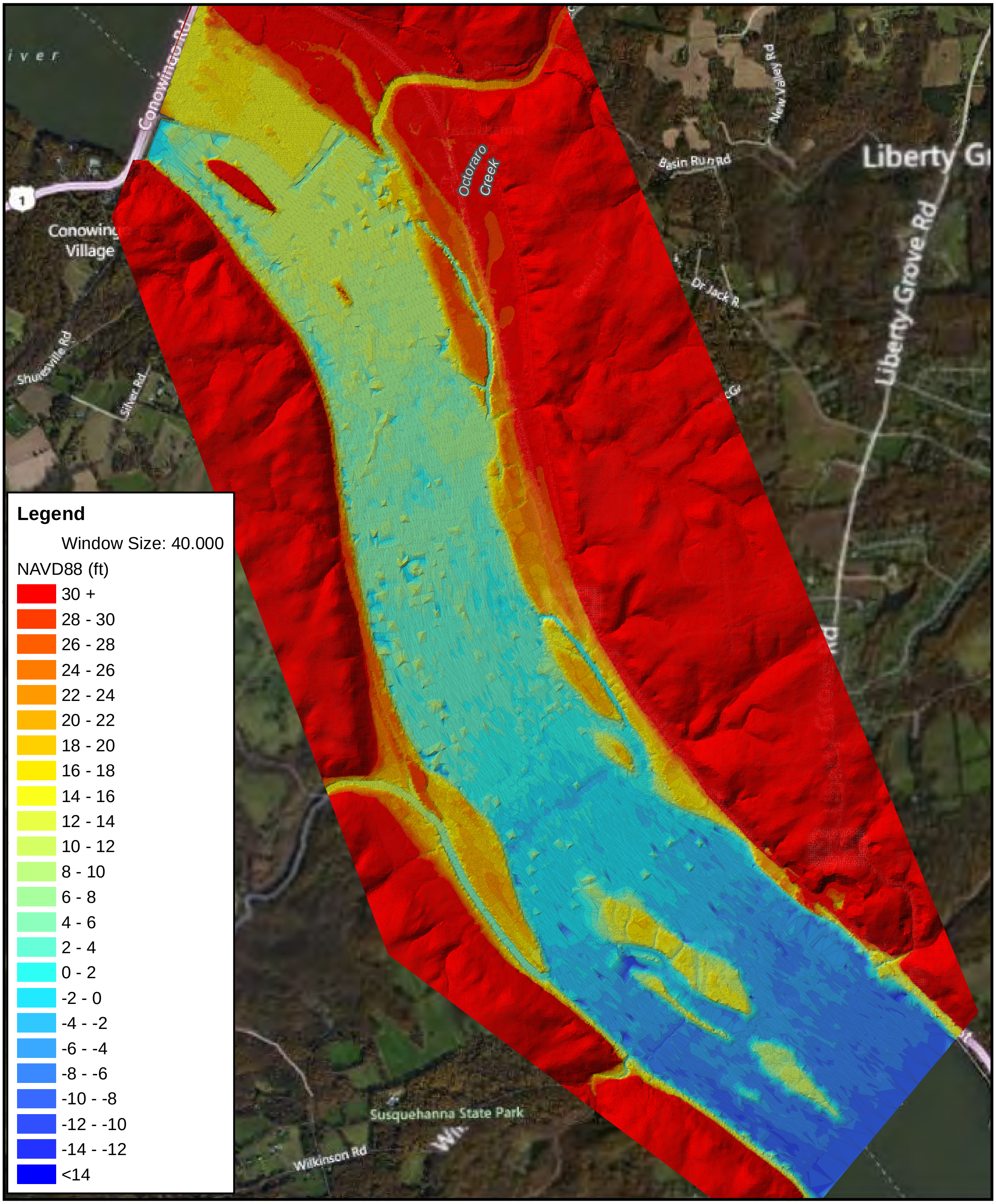


FIGURE 4.3-4: SUB-DAILY FLOW EXCEEDANCE CURVES FOR A PRE AND POST-DEREGULATION AVERAGE YEAR (1989, 2007)





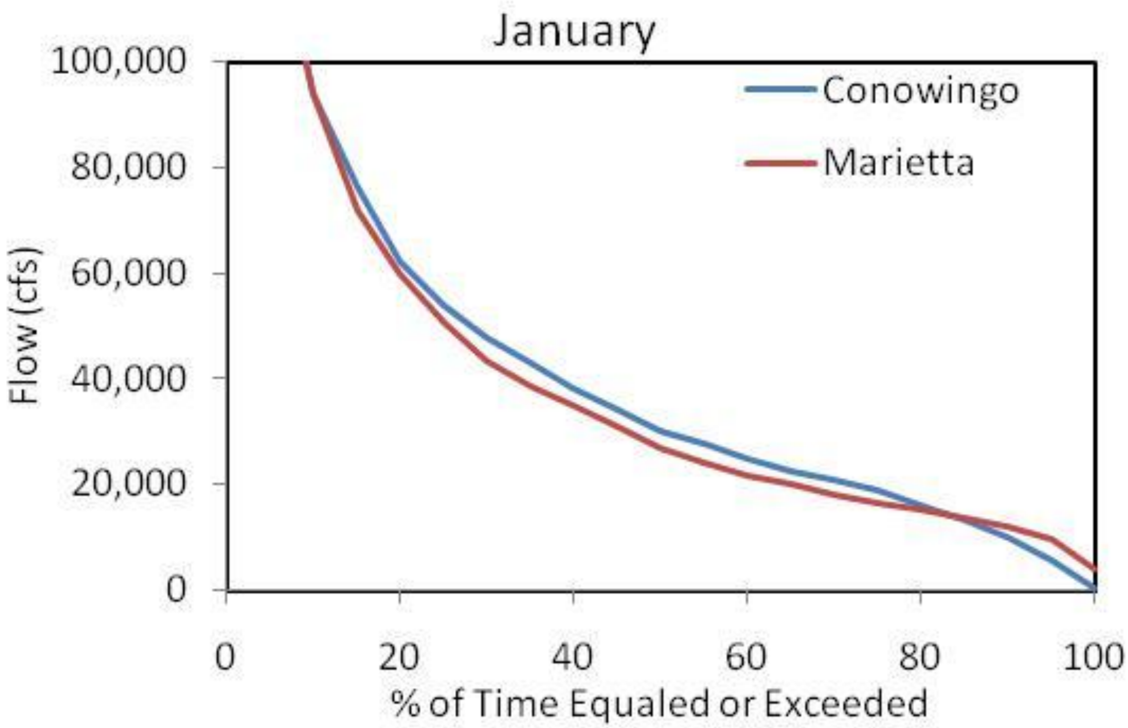
EXELON GENERATION COMPANY, LLC

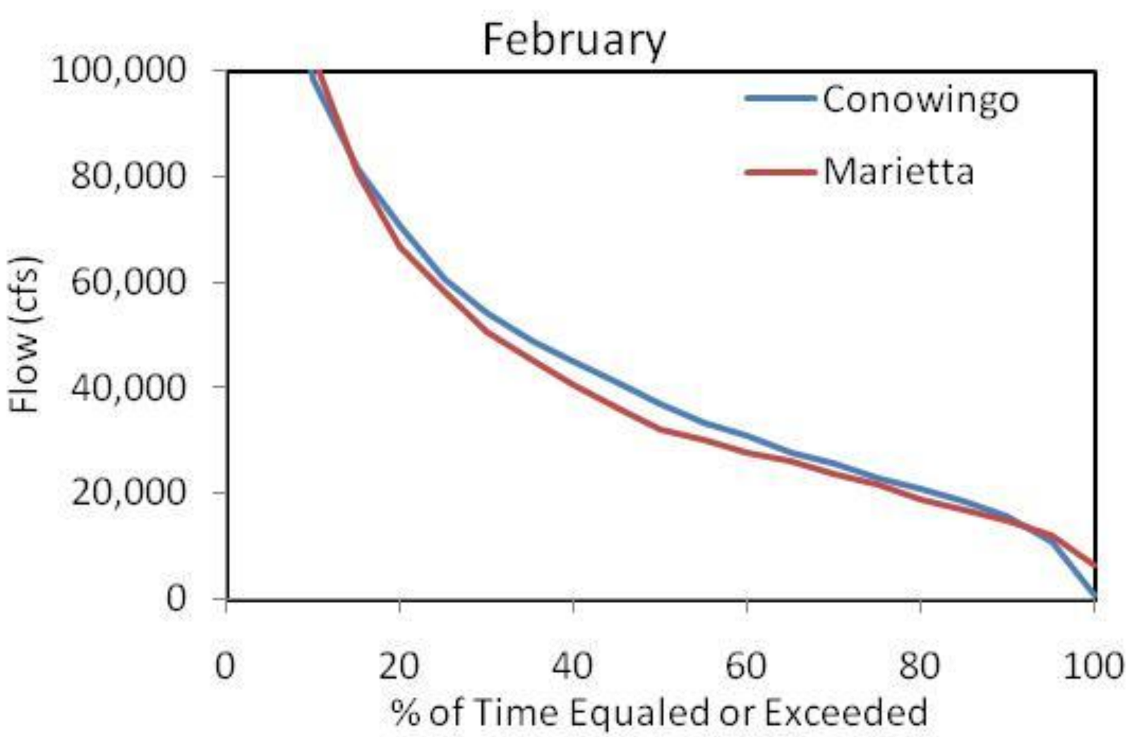
CONOWINGO HYDROELECTRIC PROJECT
PROJECT NO. 405

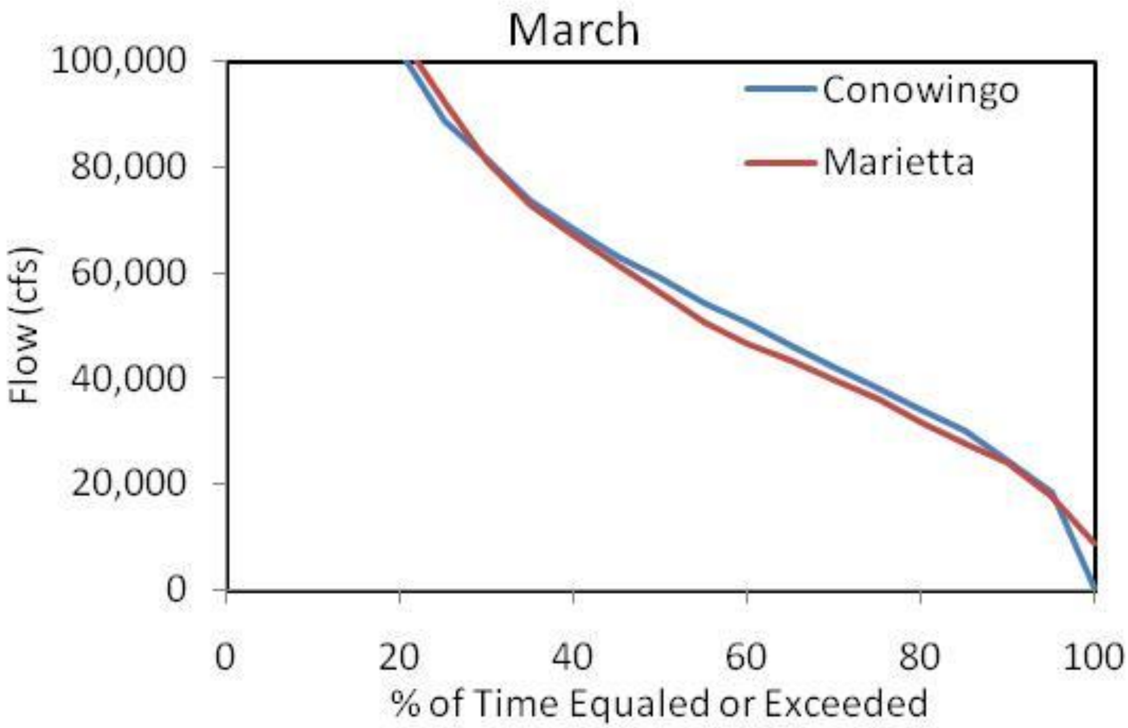
Figure 4.5-1:
Bathymetry and Topographic Map of Conowingo Tailrace

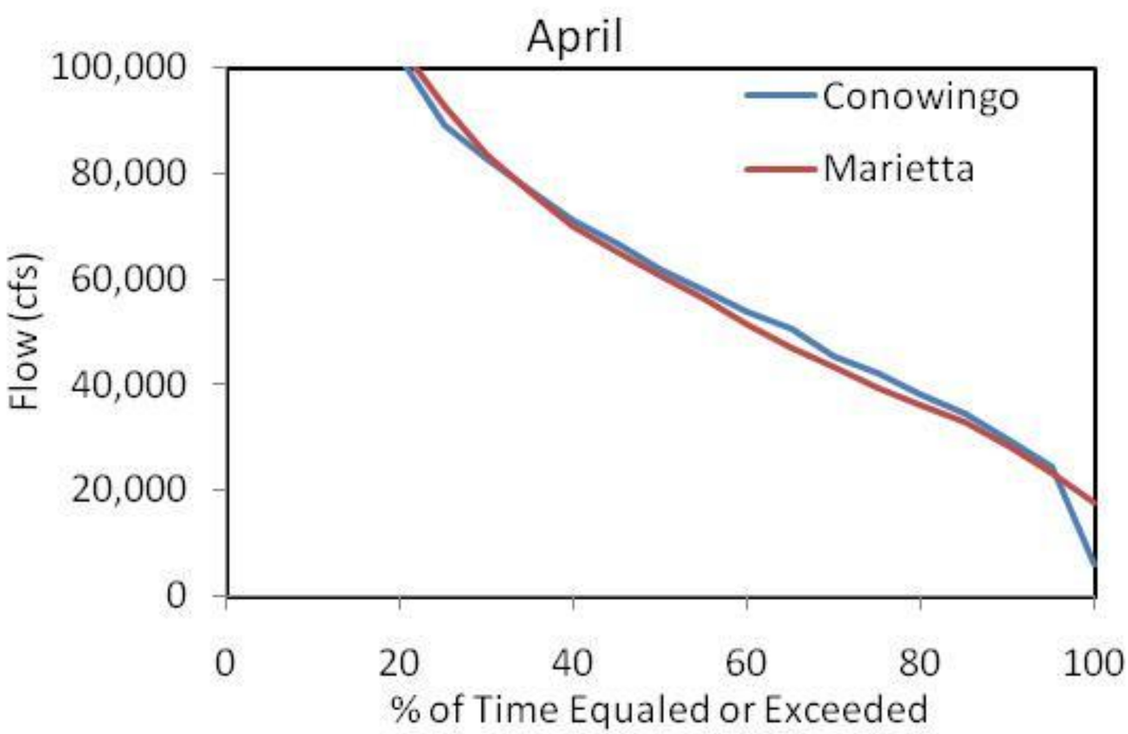
Path: X:\GISMaps\project_maps\study_plan\conowingo\study_3_11\bathymetry_and_topography.mxd

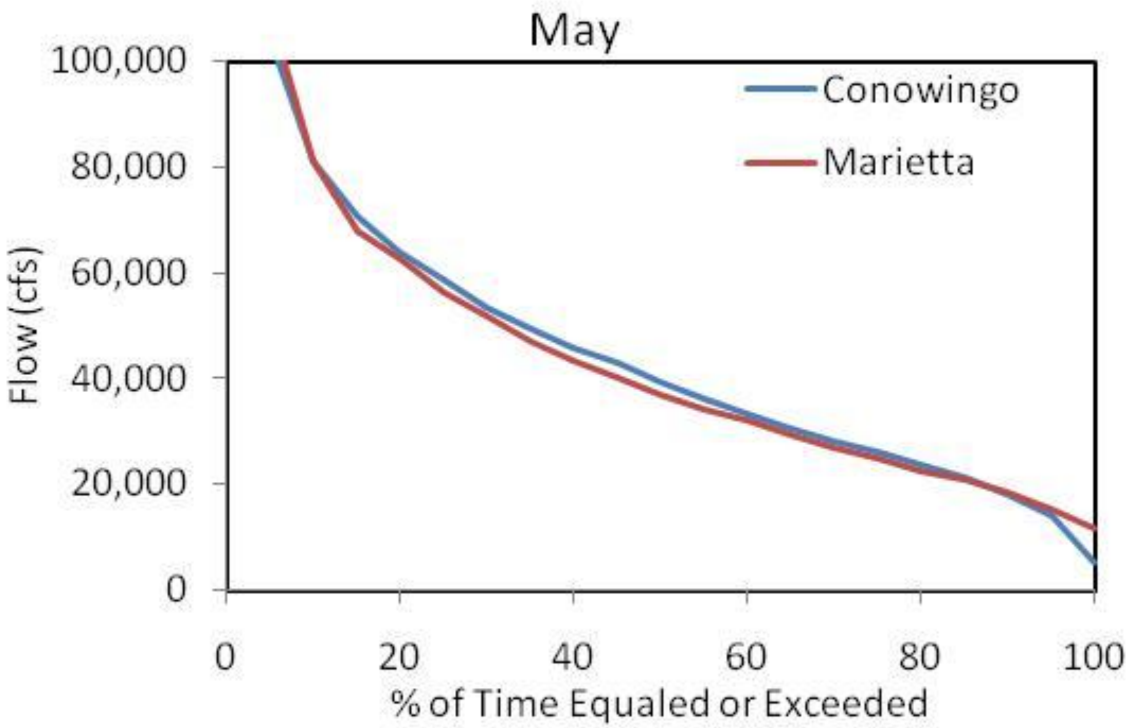
APPENDIX A- DAILY AVERAGE FLOW EXCEEDANCE CURVES BY MONTH

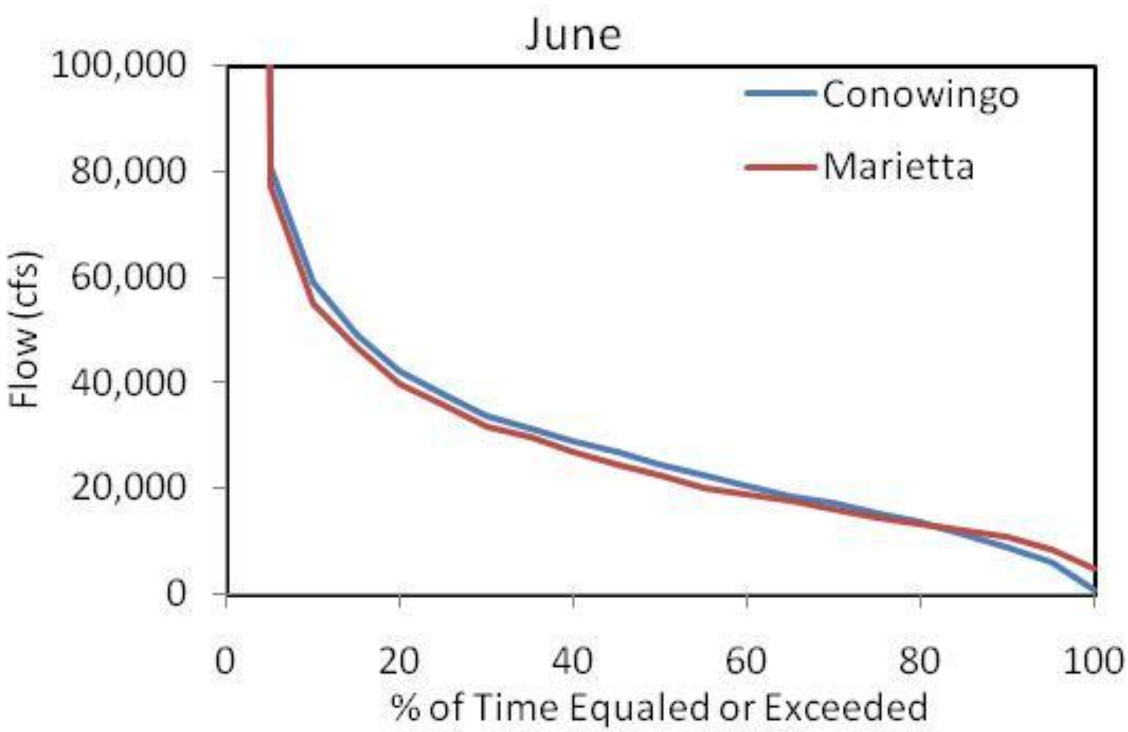

January
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

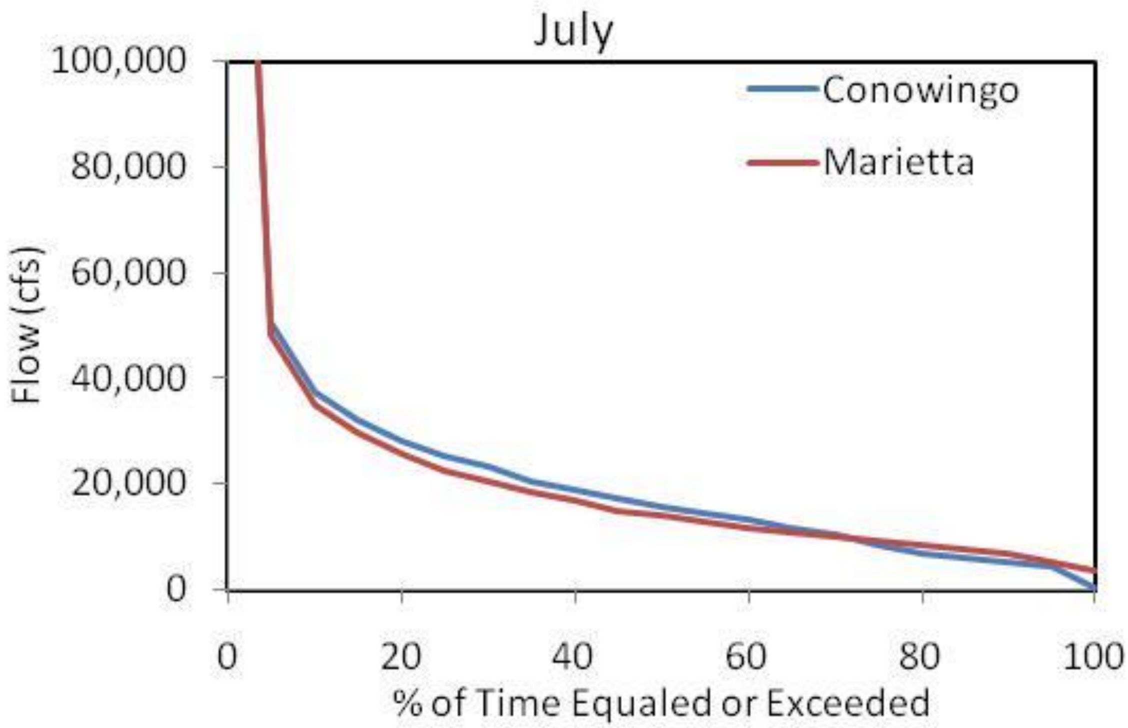

February
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

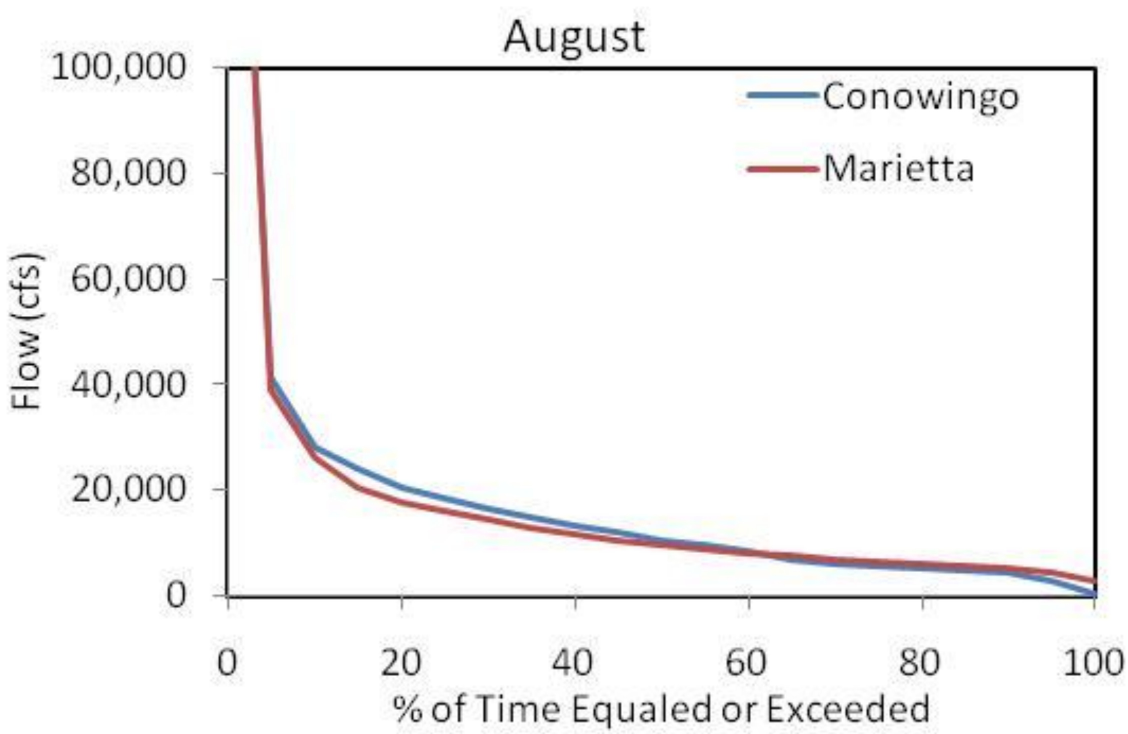

March
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded
Conowingo
Marietta

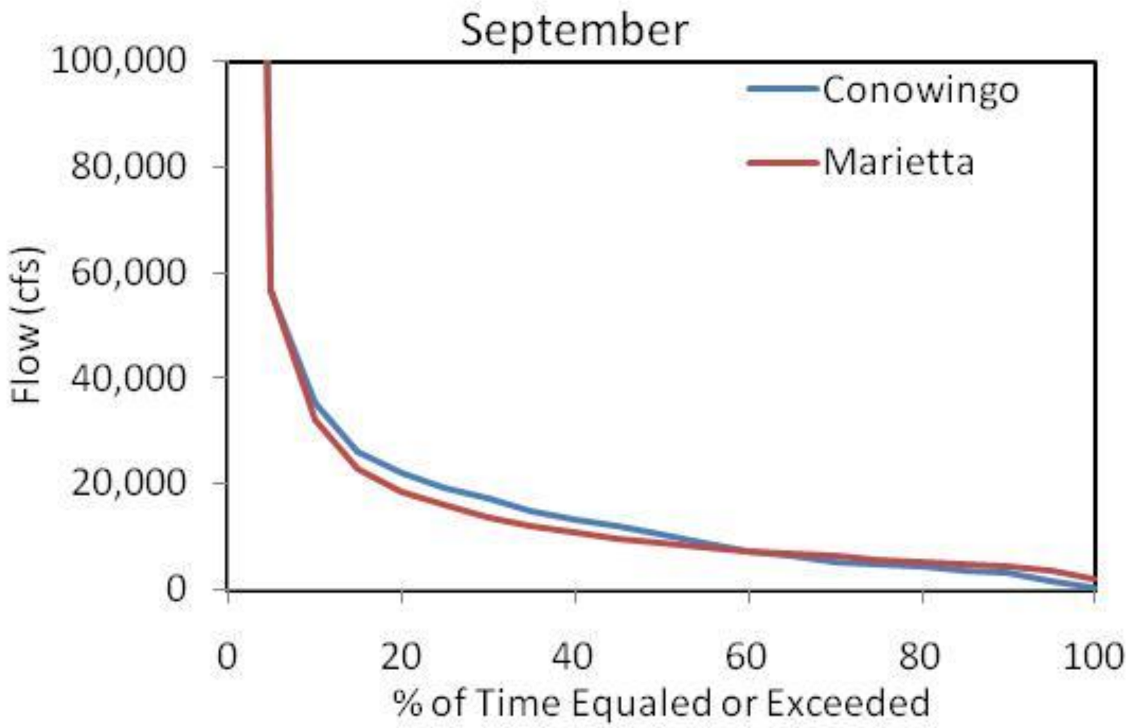

April
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded
Conowingo
Marietta

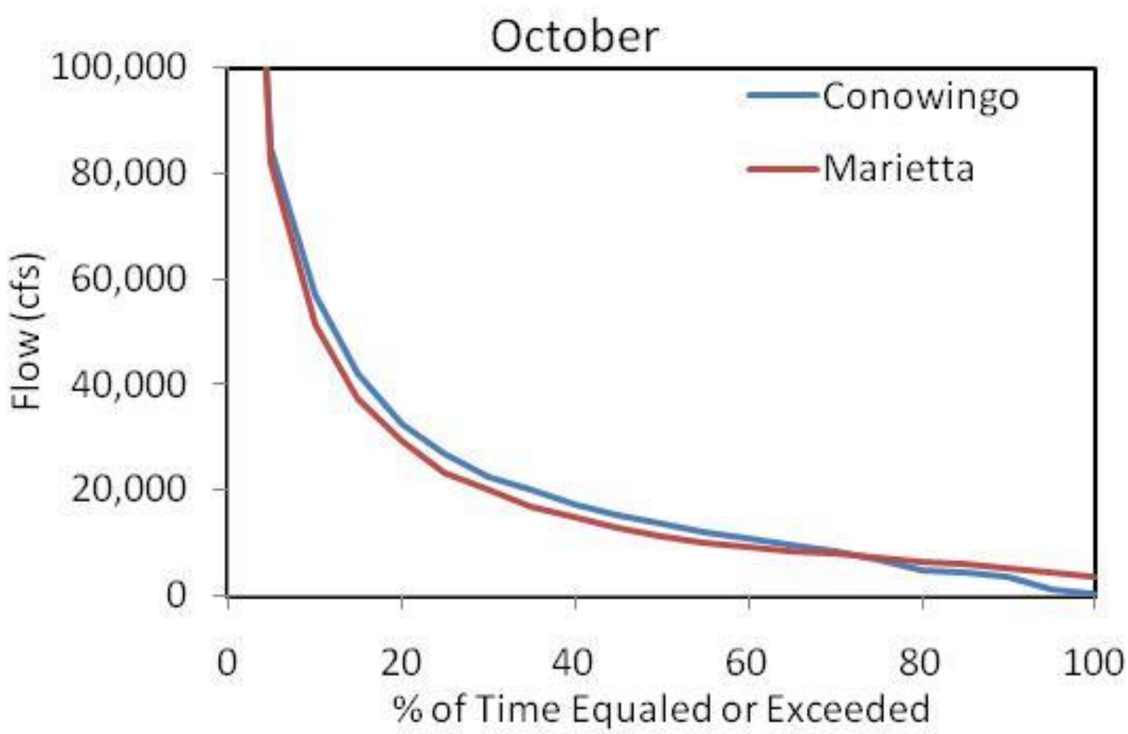

May
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Conowingo
Marietta

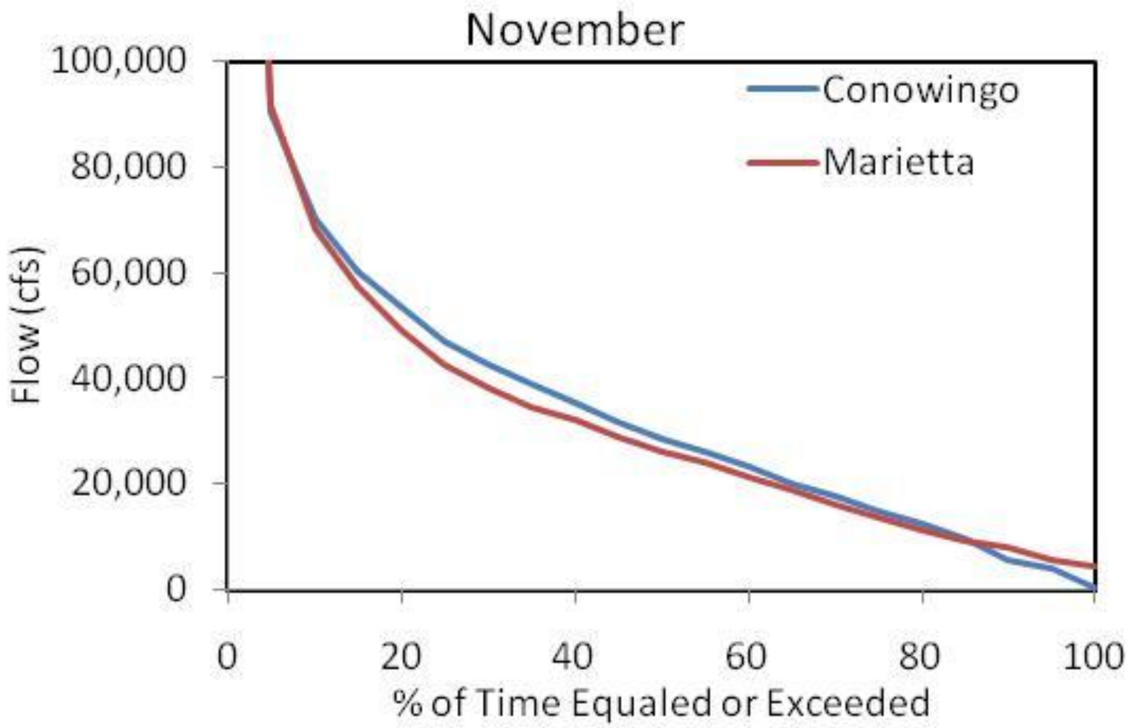

June
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Conowingo
Marietta

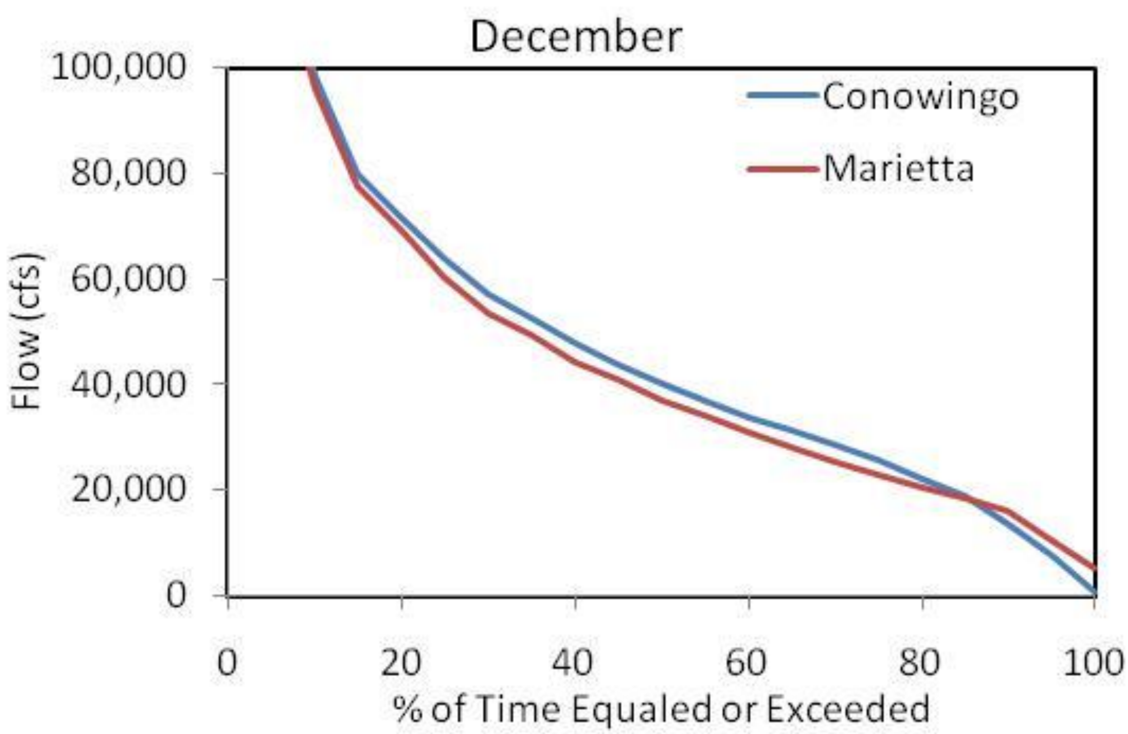

July
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded


August
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

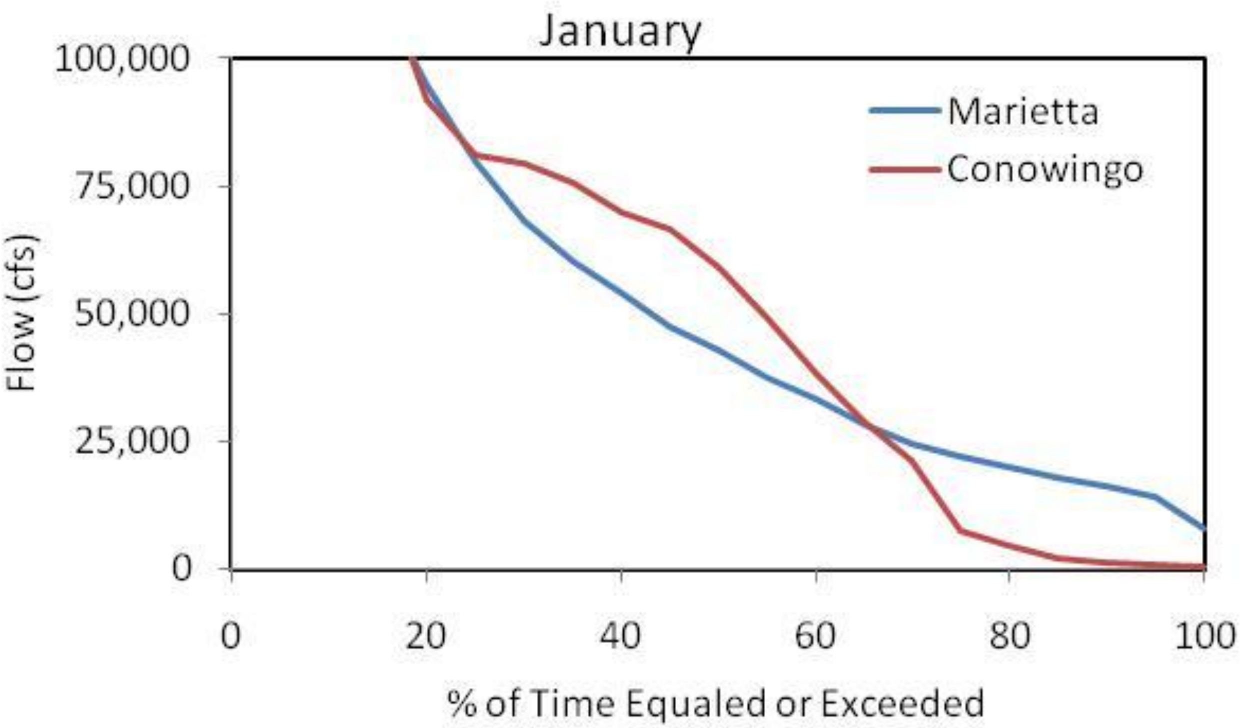

September
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

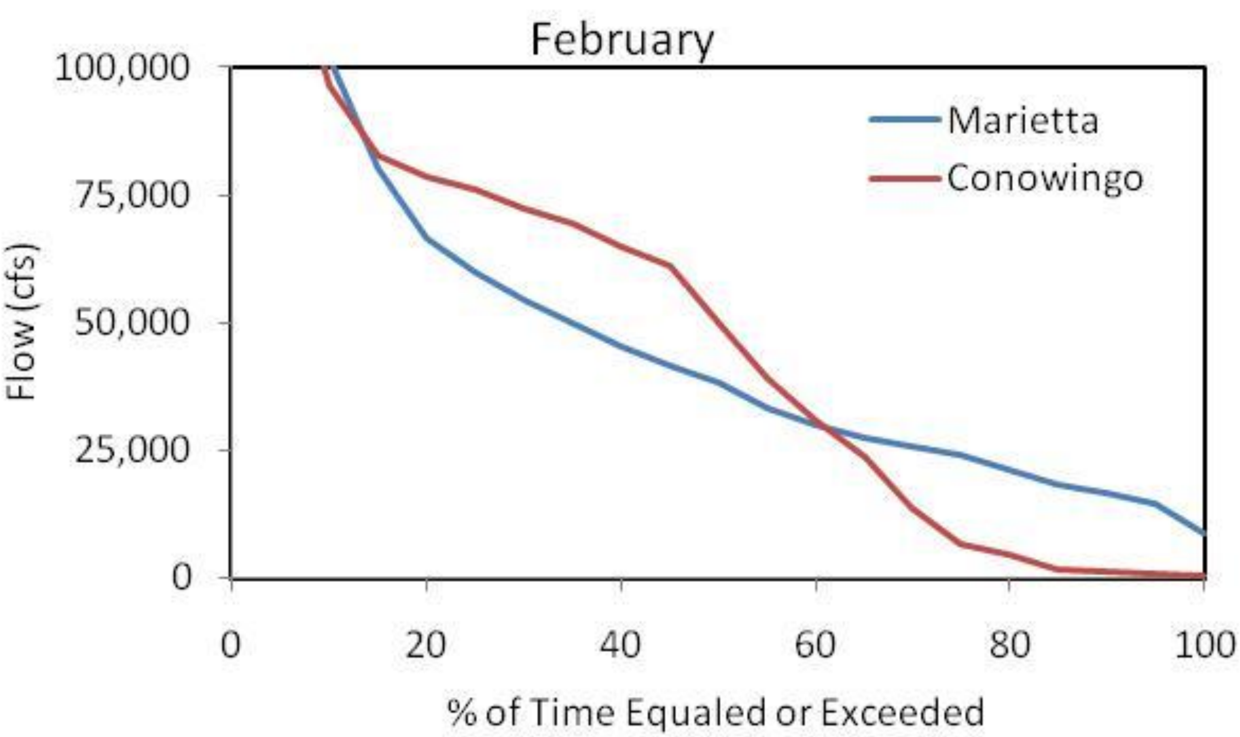

October
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

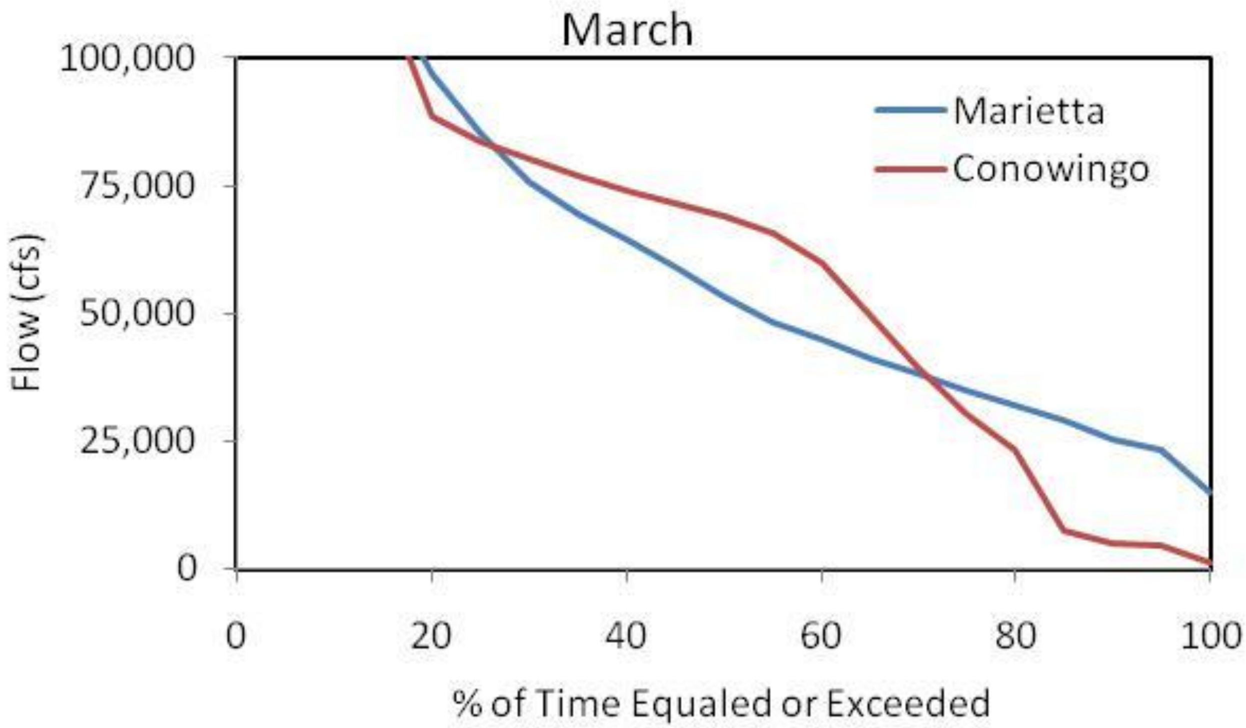

November
Conowingo
Marietta
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded

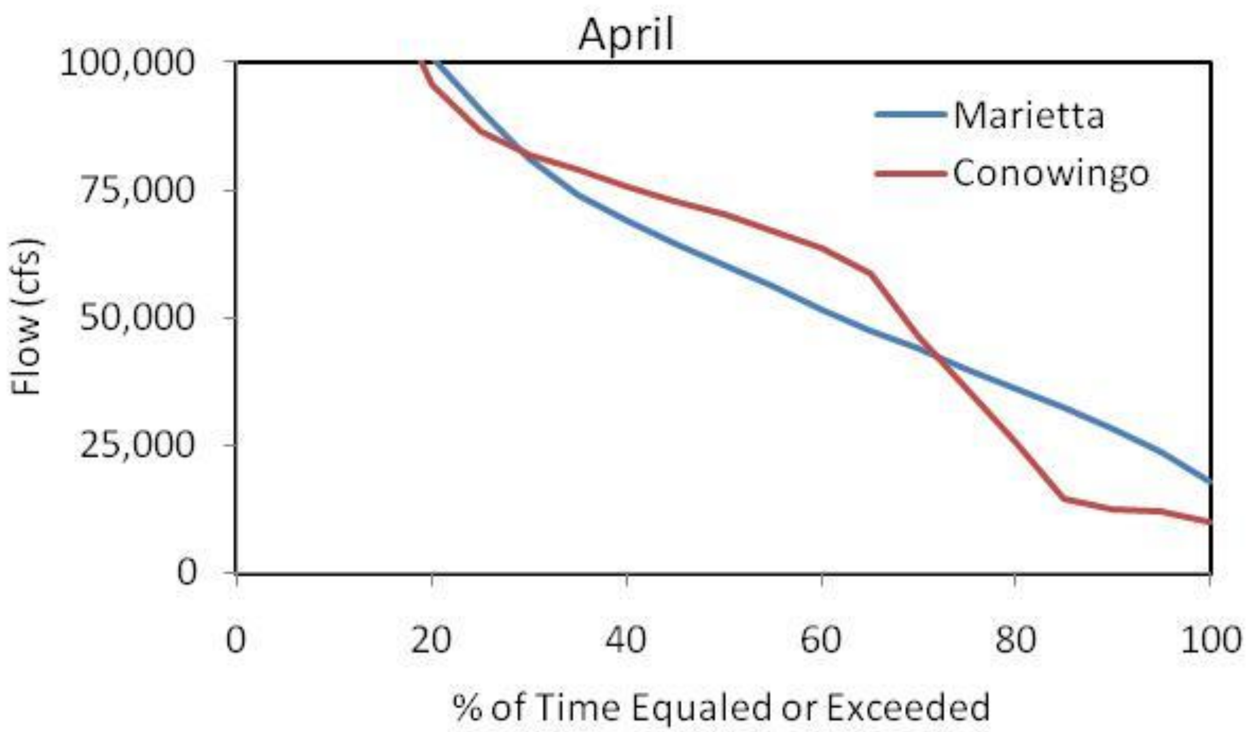

December
Conowingo
Marietta
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded

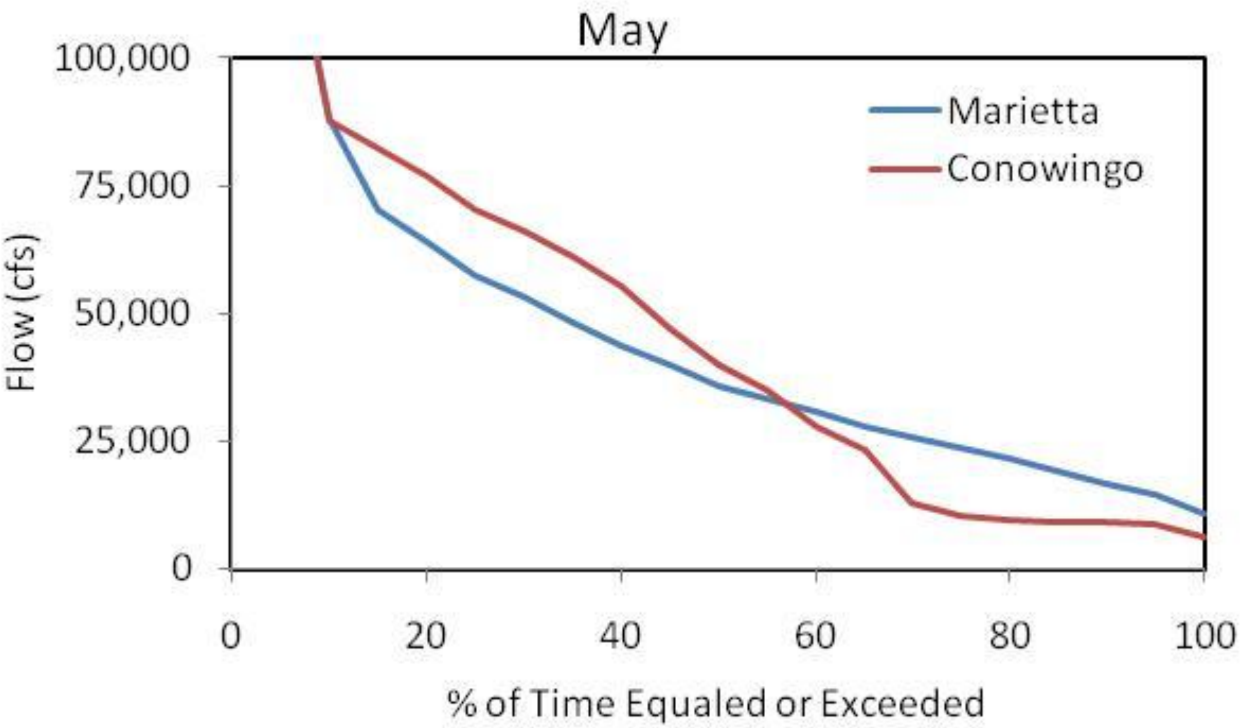
APPENDIX B-SUB-DAILY (30-MINUTE) FLOW EXCEEDANCE CURVES BY MONTH

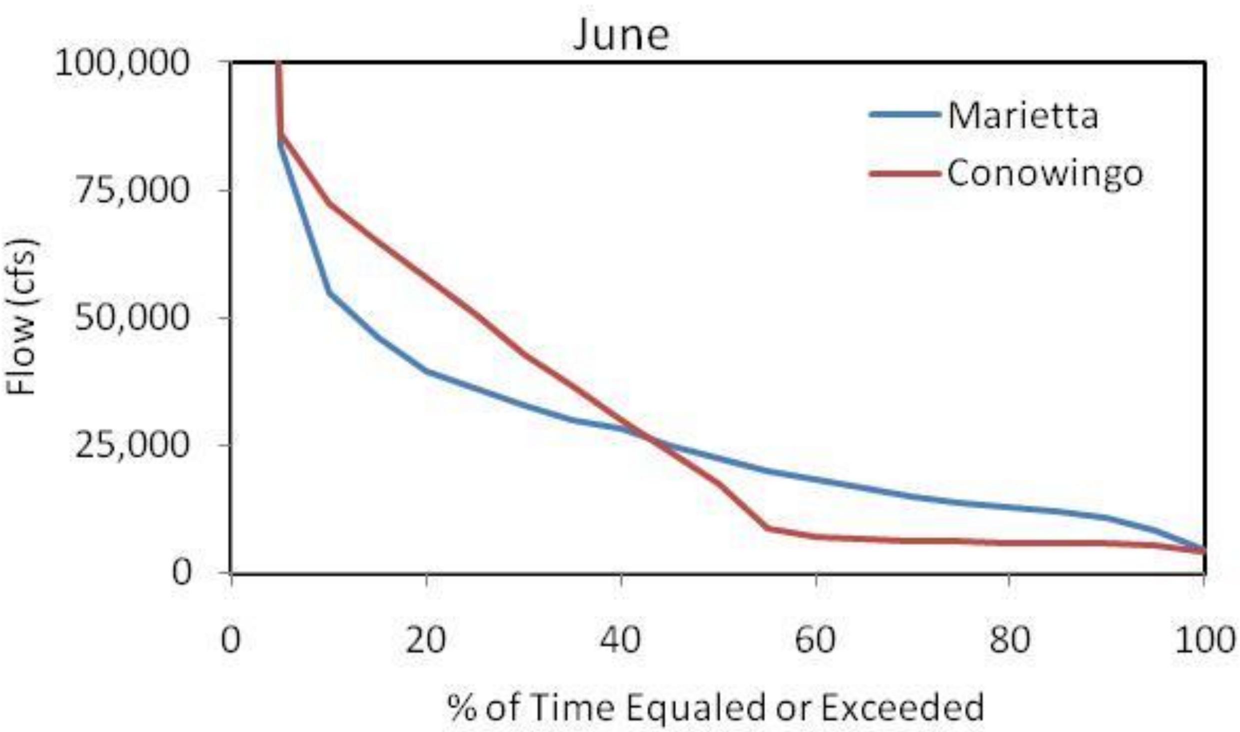

January
100,000
75,000
50,000
25,000
0
Flow (cfs)
Marietta
Conowingo
0
20
40
60
80
100
% of Time Equaled or Exceeded

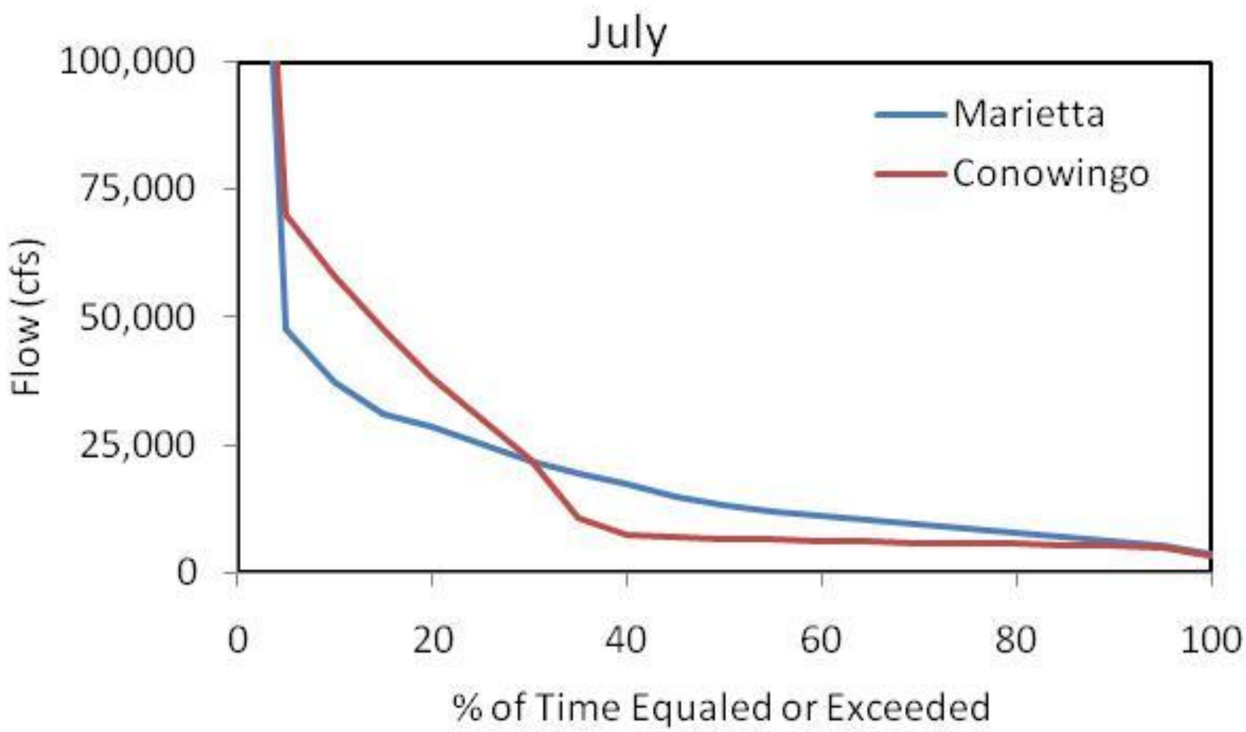

February
100,000
75,000
50,000
25,000
0
Flow (cfs)
Marietta
Conowingo
0
20
40
60
80
100
% of Time Equaled or Exceeded

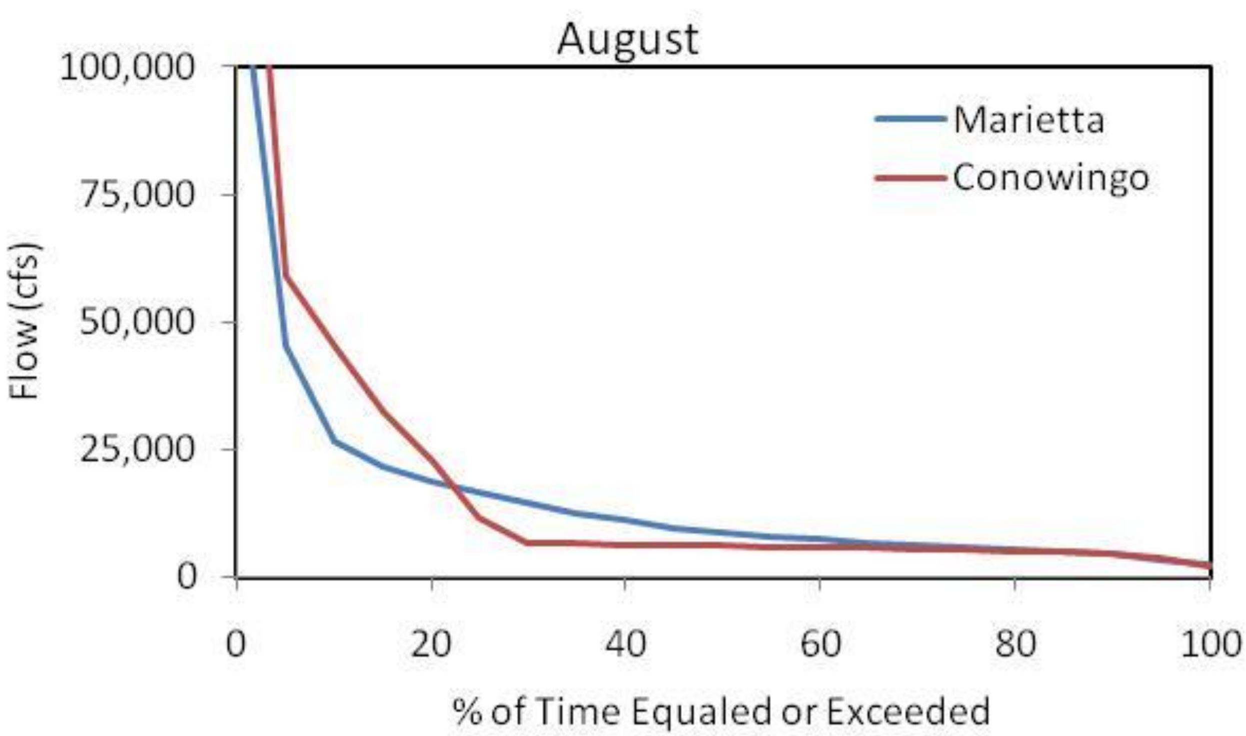

March
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo

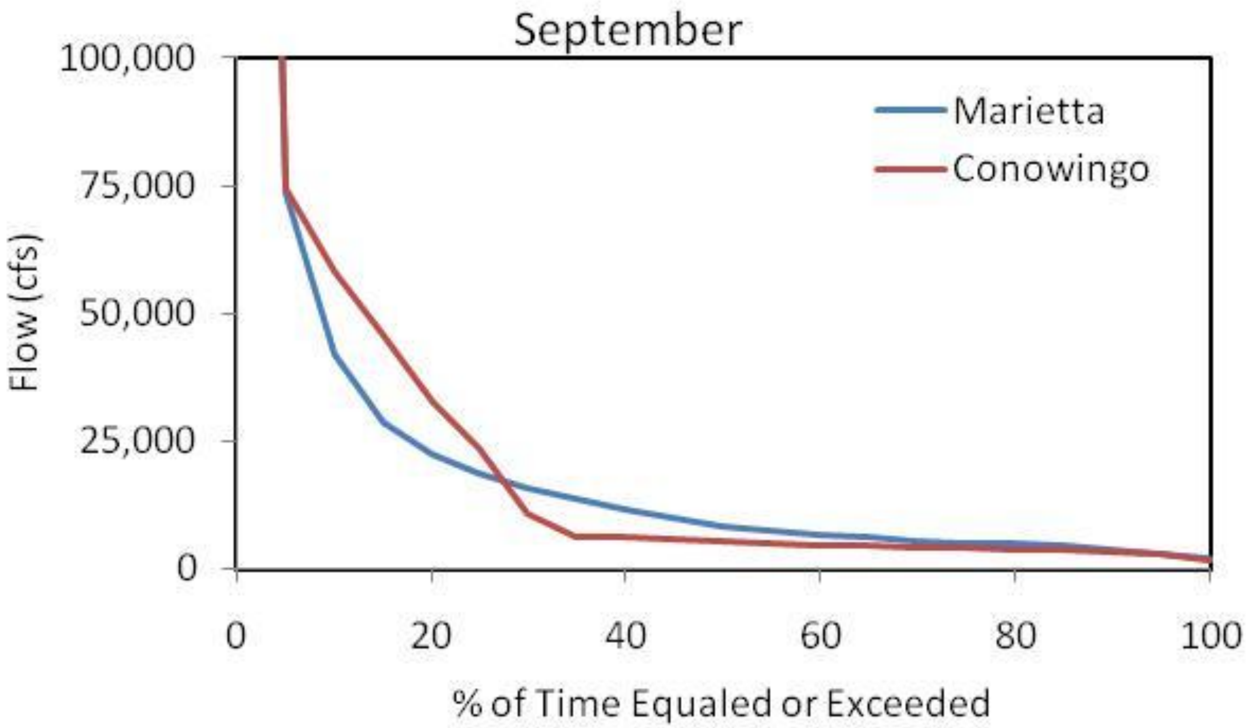

April
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo

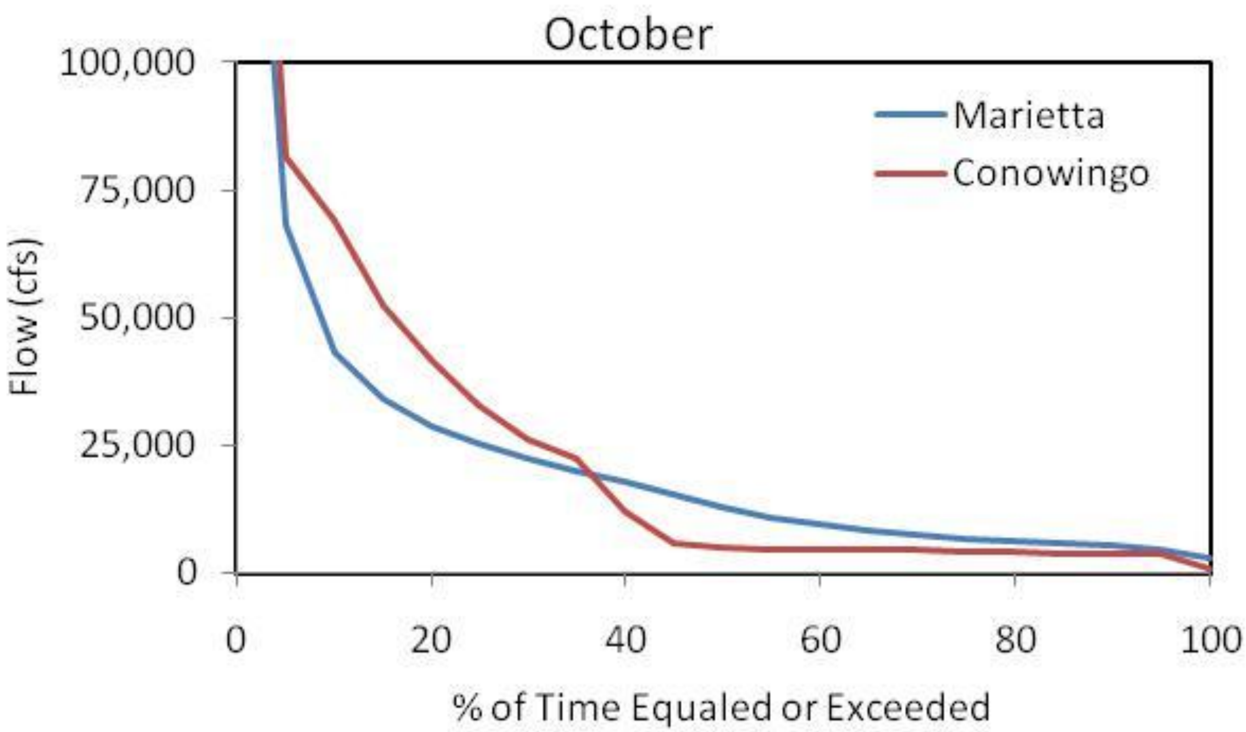

May
100,000
75,000
50,000
25,000
0
Flow (cfs)
Marietta
Conowingo
0
20
40
60
80
100
% of Time Equaled or Exceeded

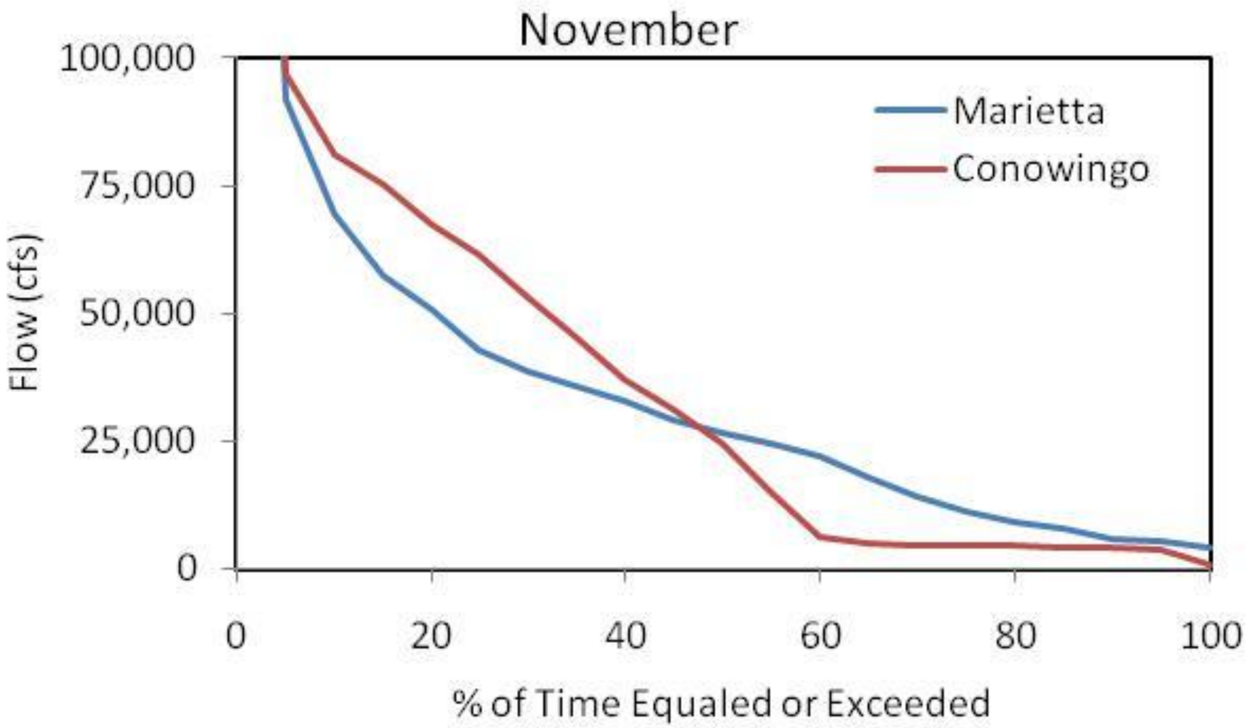

June
100,000
75,000
50,000
25,000
0
Flow (cfs)
Marietta
Conowingo
0
20
40
60
80
100
% of Time Equaled or Exceeded

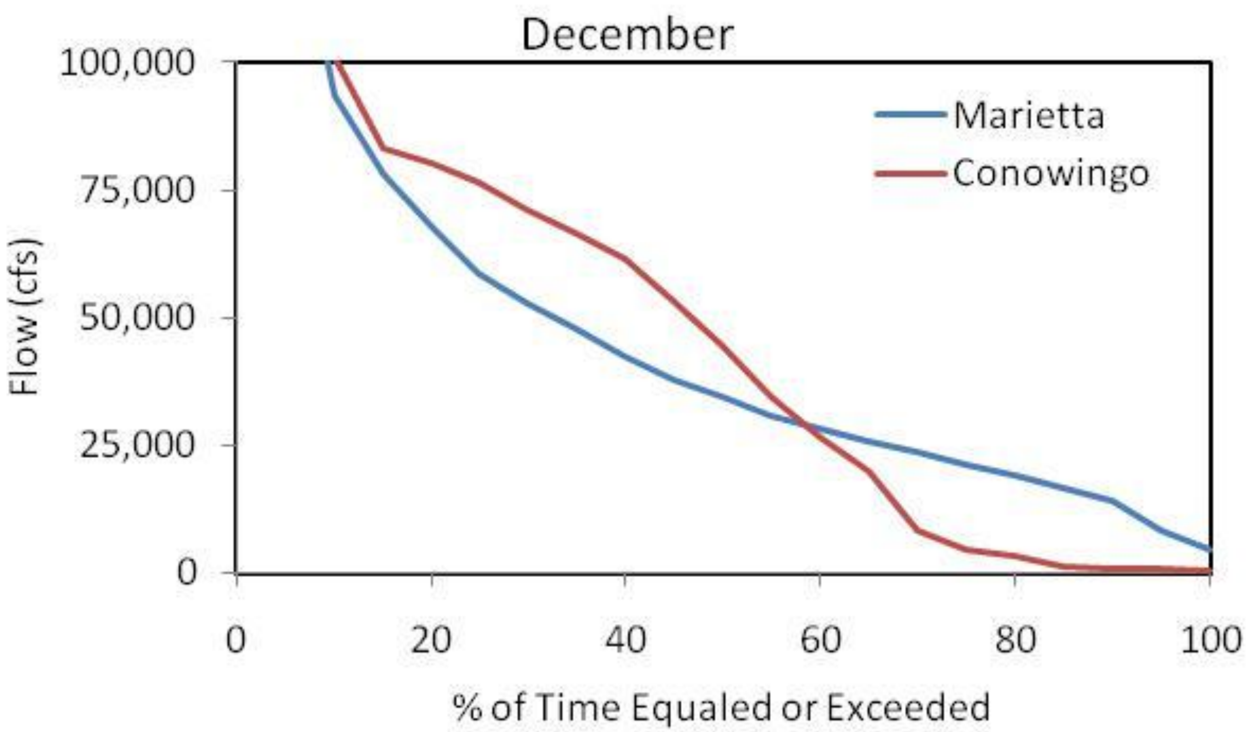

July
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo


August
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo

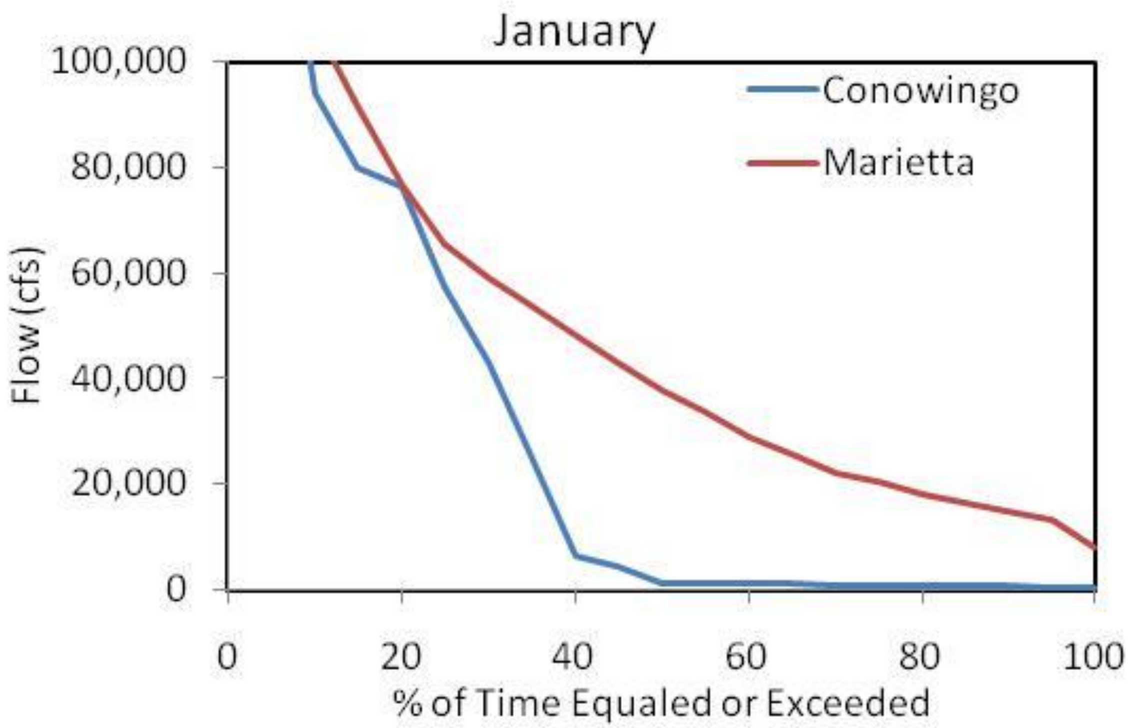

September
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo

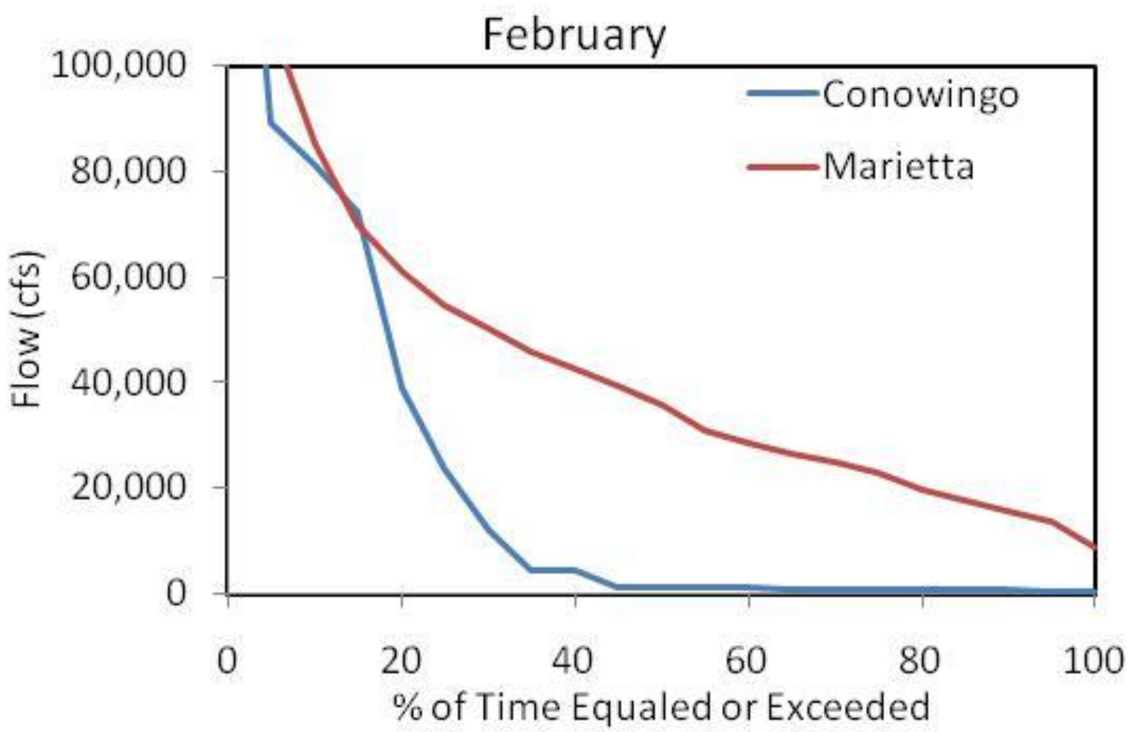

October
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo

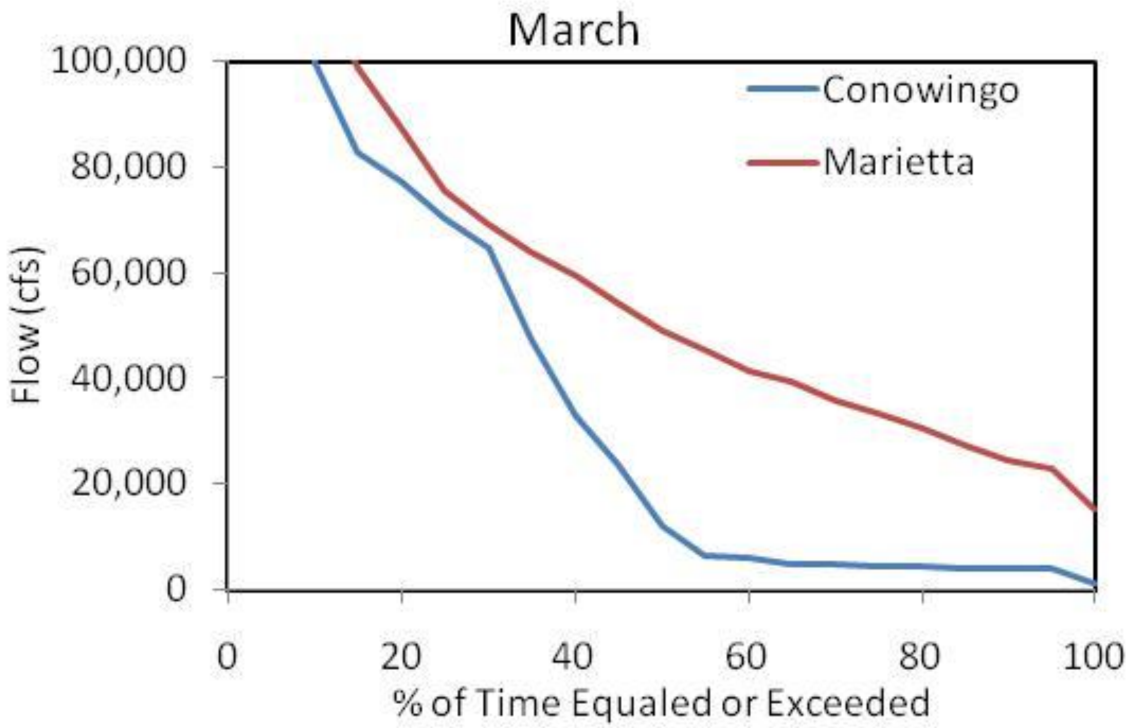

November
100,000
75,000
50,000
25,000
0
Flow (cfs)
Marietta
Conowingo
0
20
40
60
80
100
% of Time Equaled or Exceeded

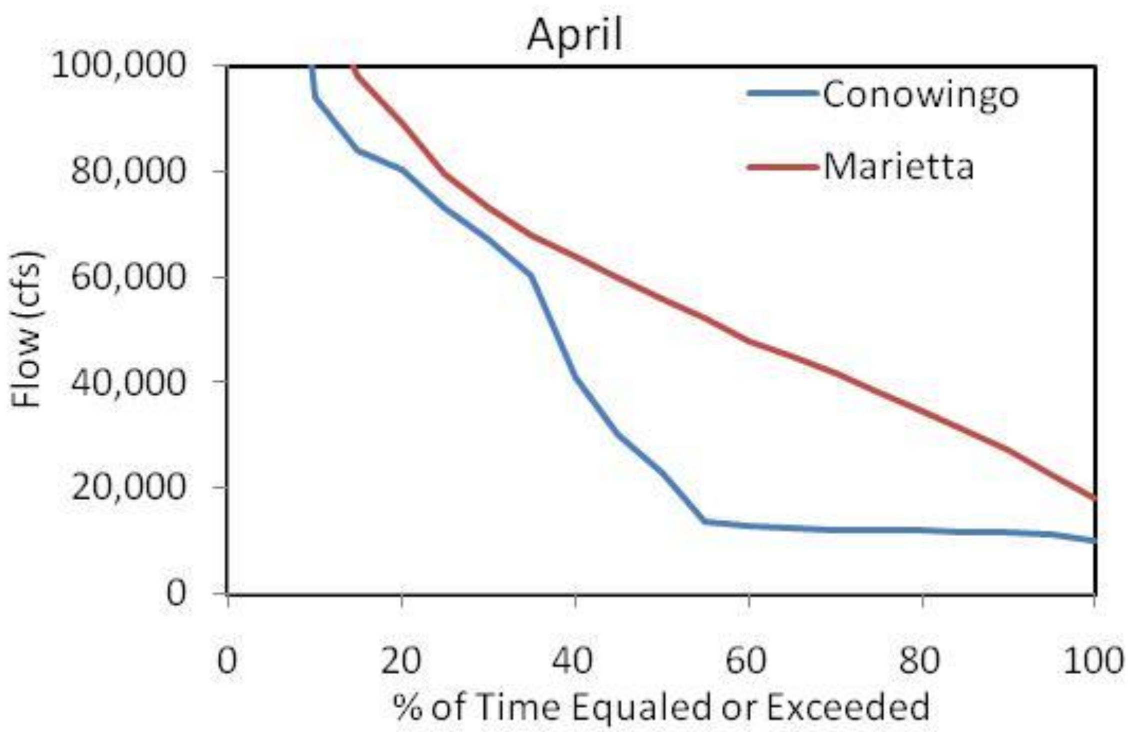

December
100,000
75,000
50,000
25,000
0
Flow (cfs)
Marietta
Conowingo
0
20
40
60
80
100
% of Time Equaled or Exceeded

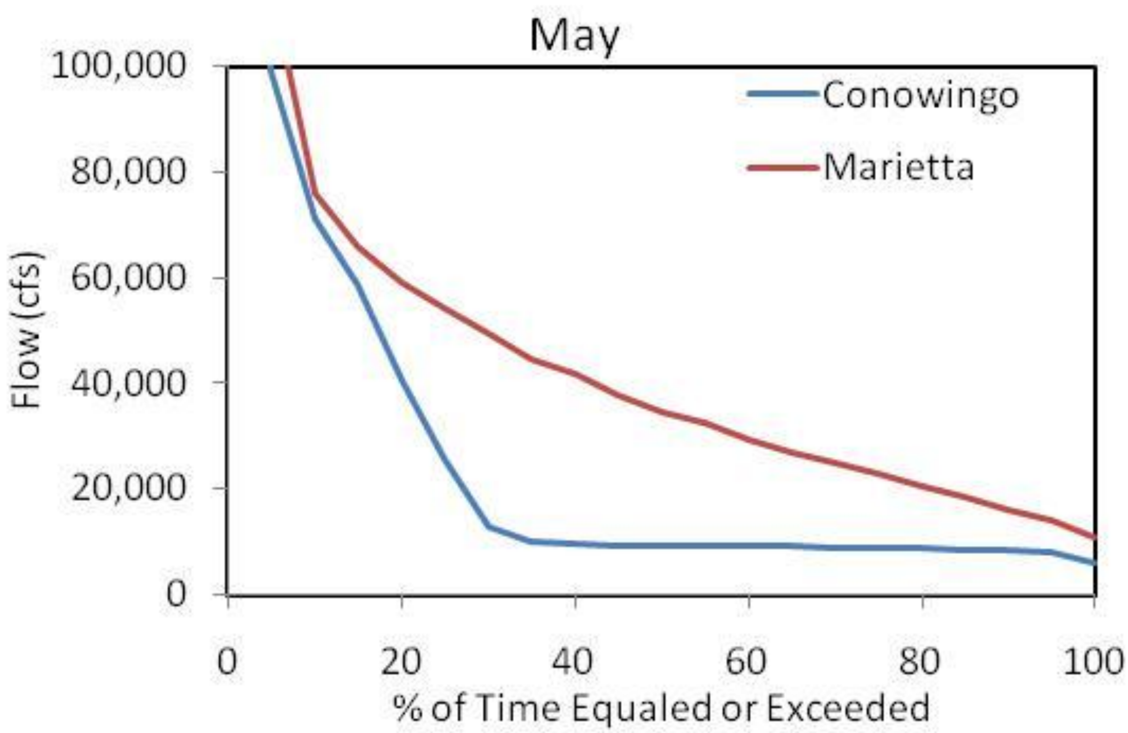
APPENDIX C-DAILY MINIMUM FLOW EXCEEDANCE PERCENTILES BY MONTH. DAILY MINIMUM FLOWS CALCULATED FROM SUB-DAILY (30-MIN) INSTANTANEOUS FLOW DATA (WY 1989-1990, 1992-1993, 1995-2009).

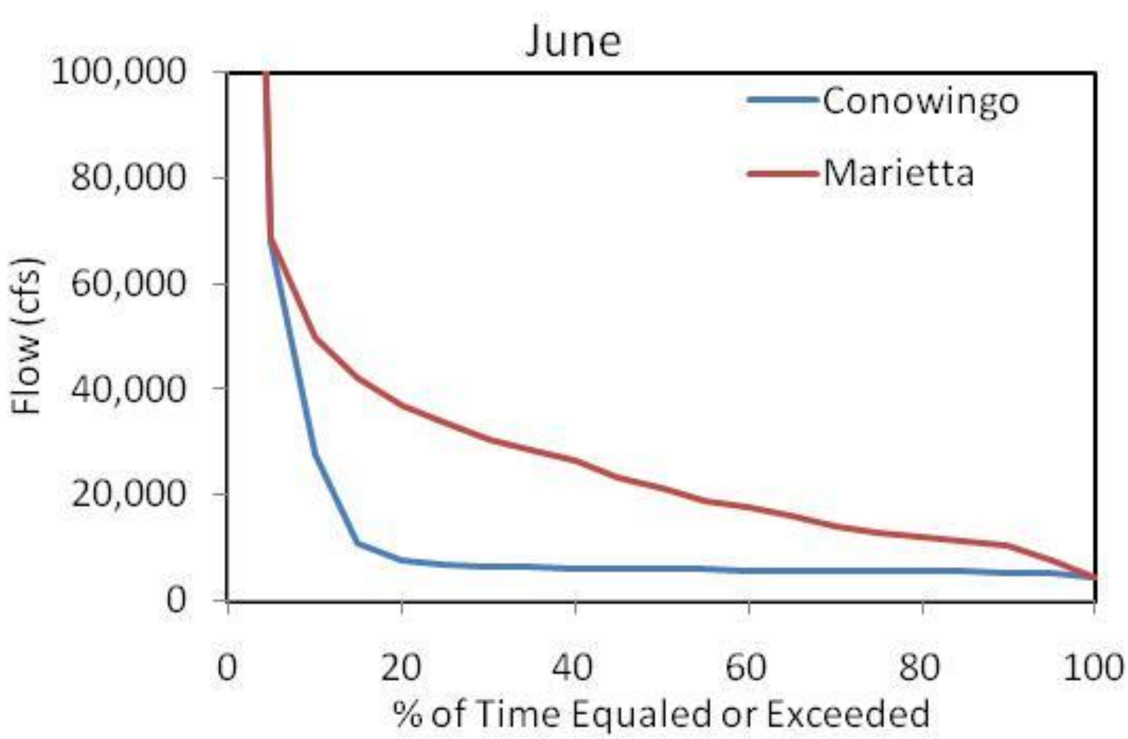

January
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded

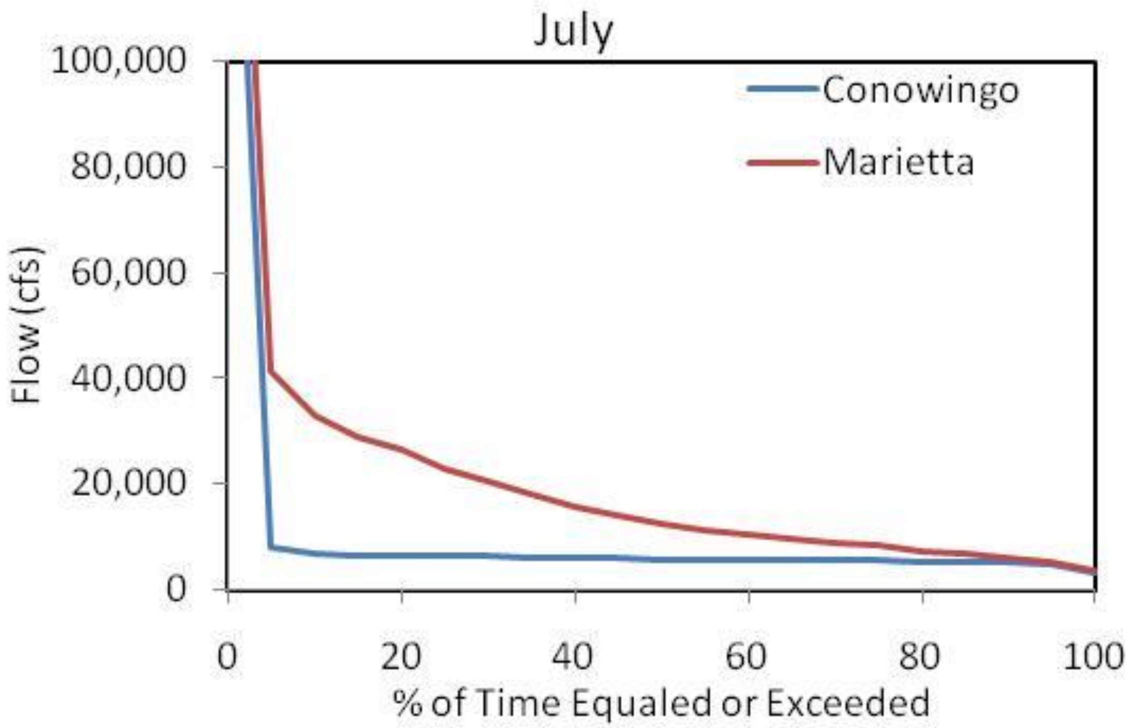

February
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded

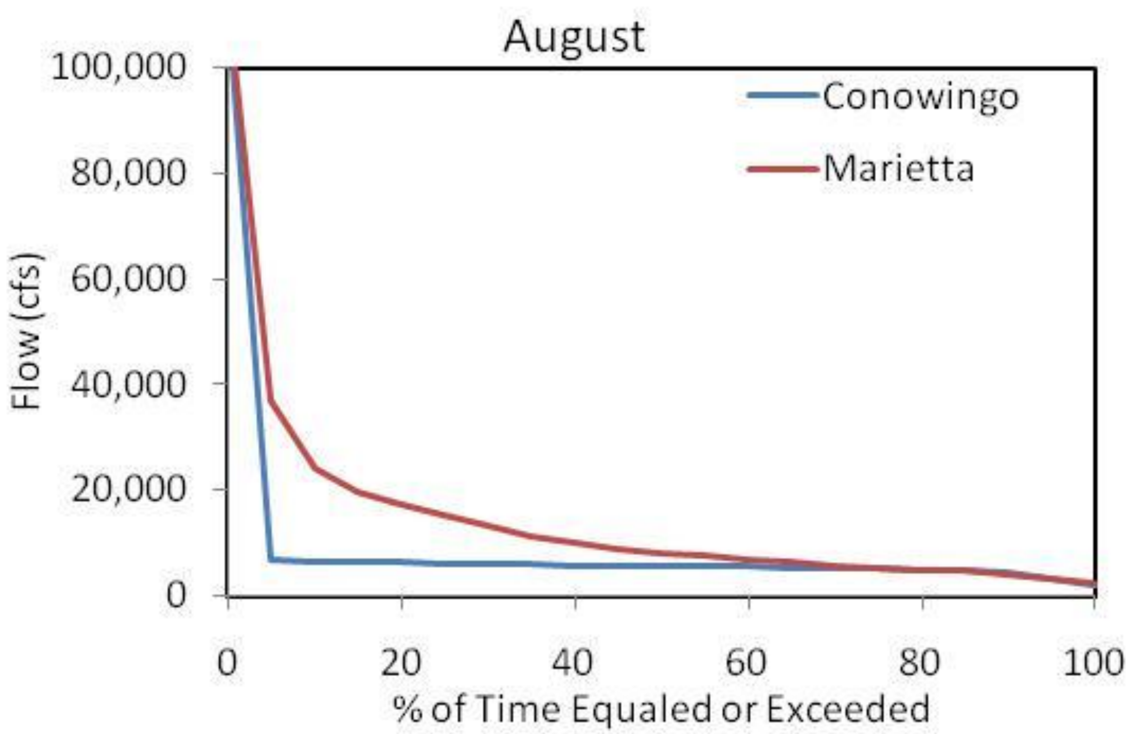

March
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded
Conowingo
Marietta

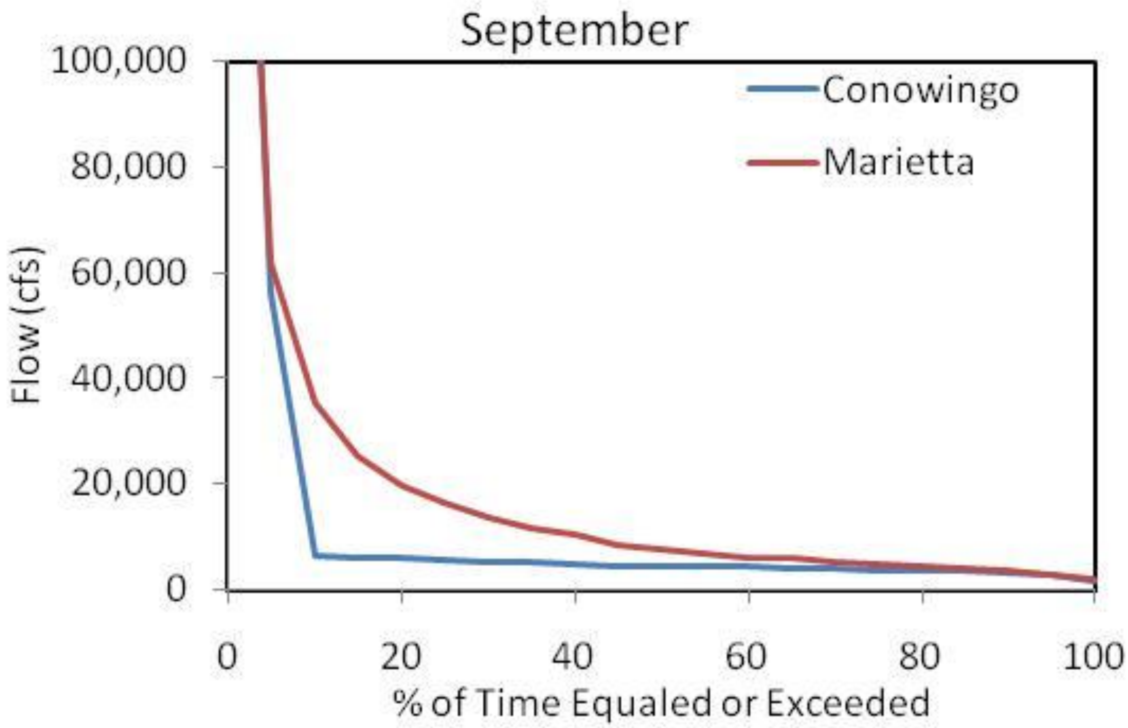

April
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded
Conowingo
Marietta

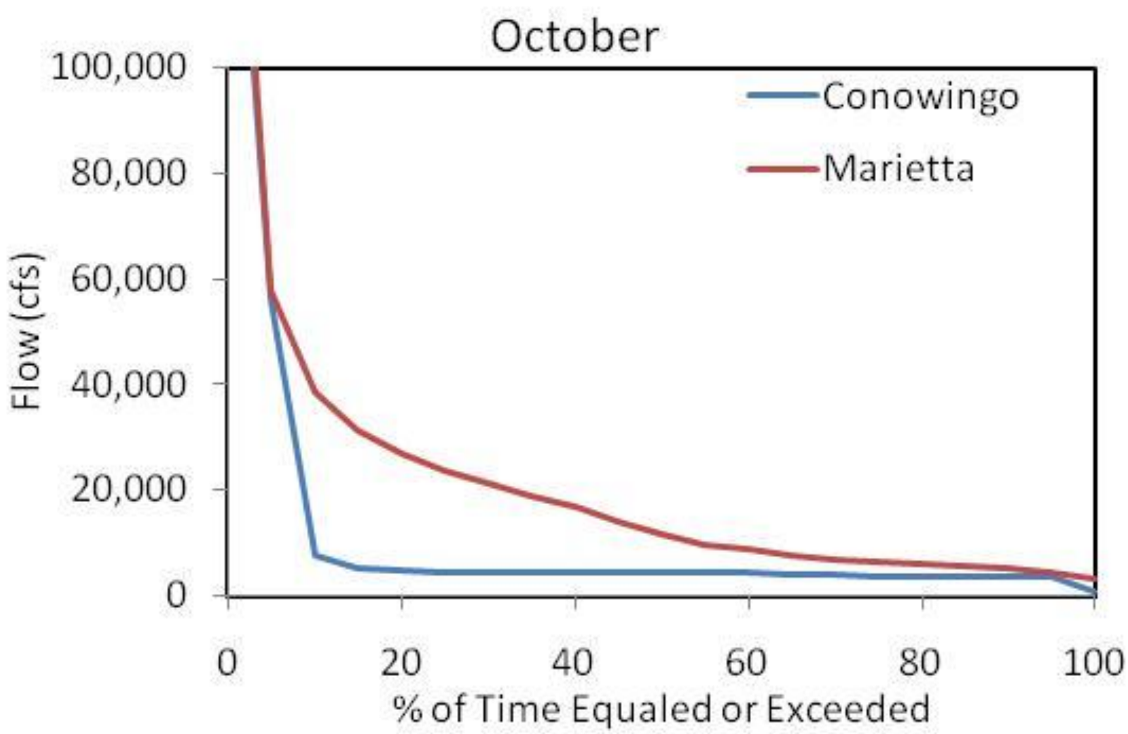

May
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded

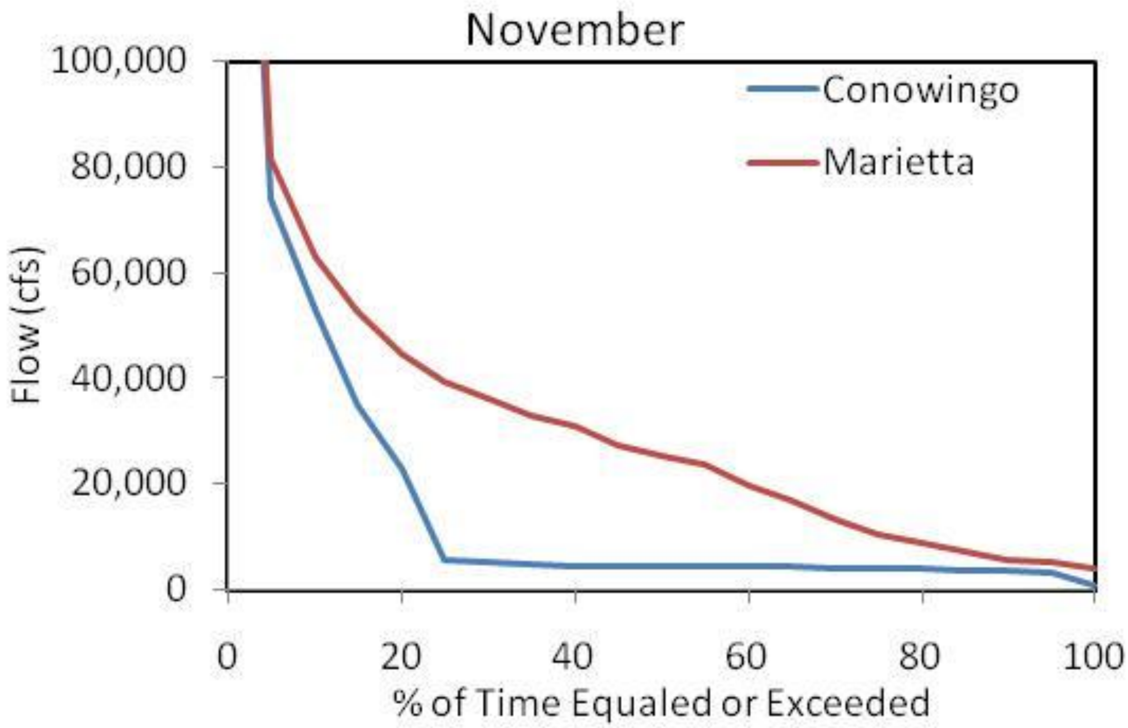

June
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded

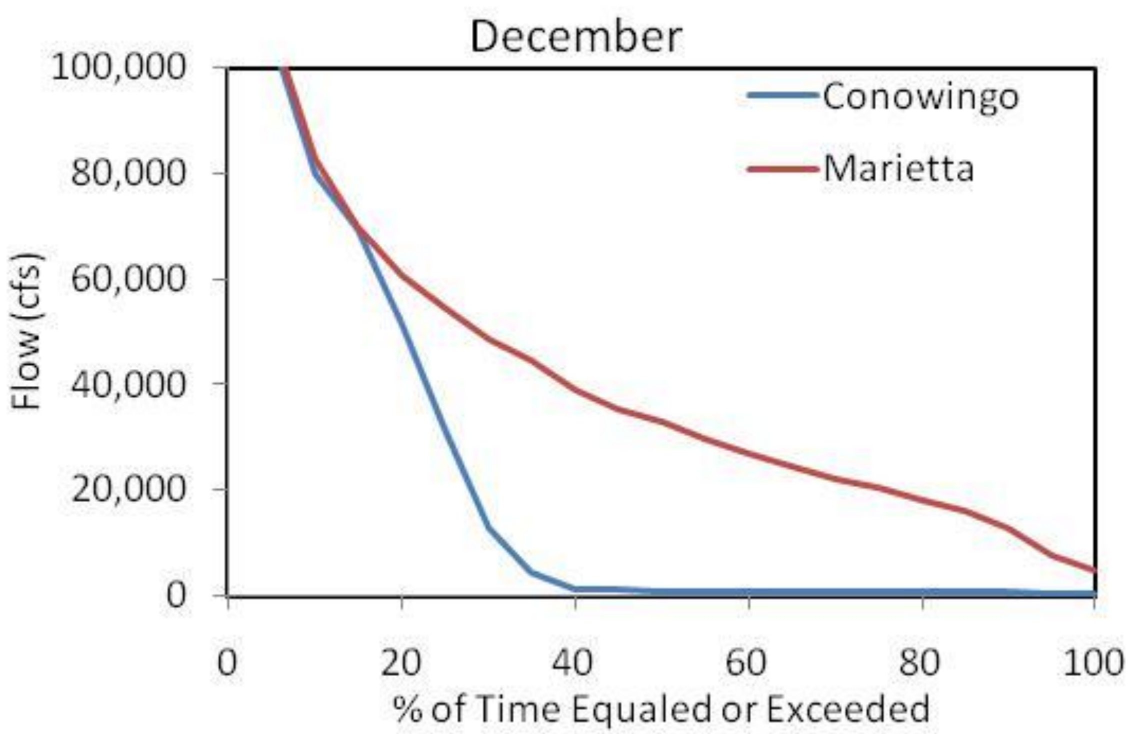

July
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded


August
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded

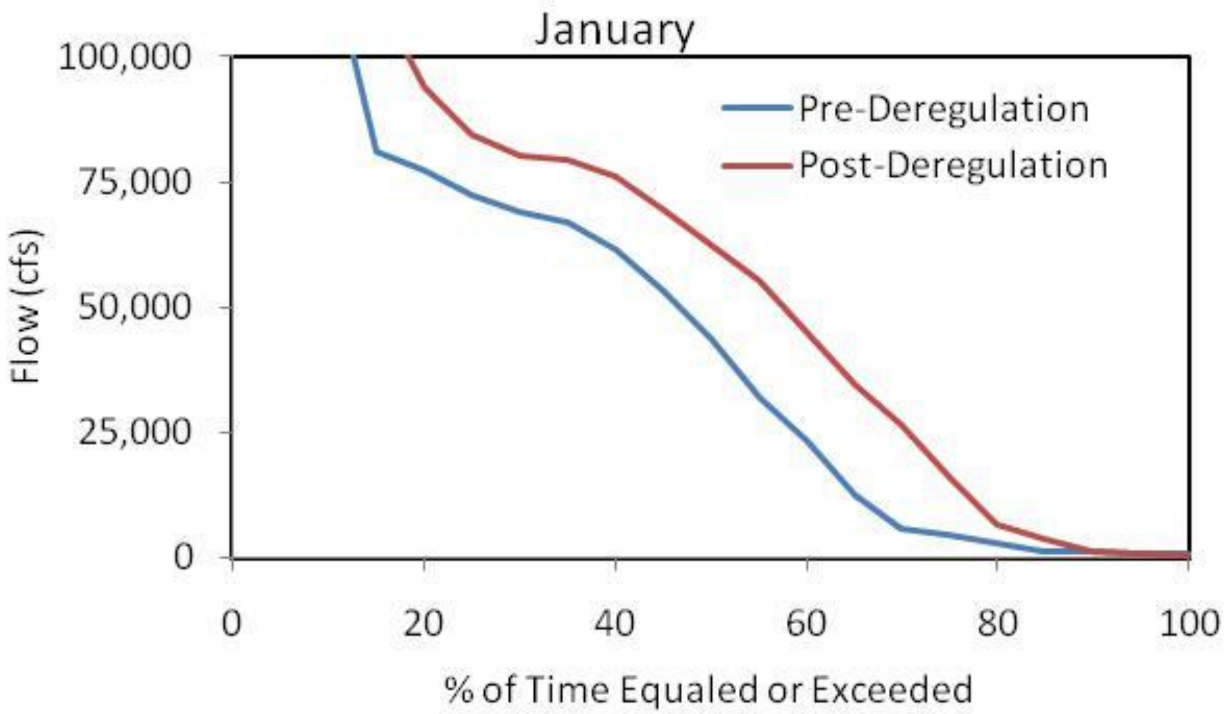

September
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

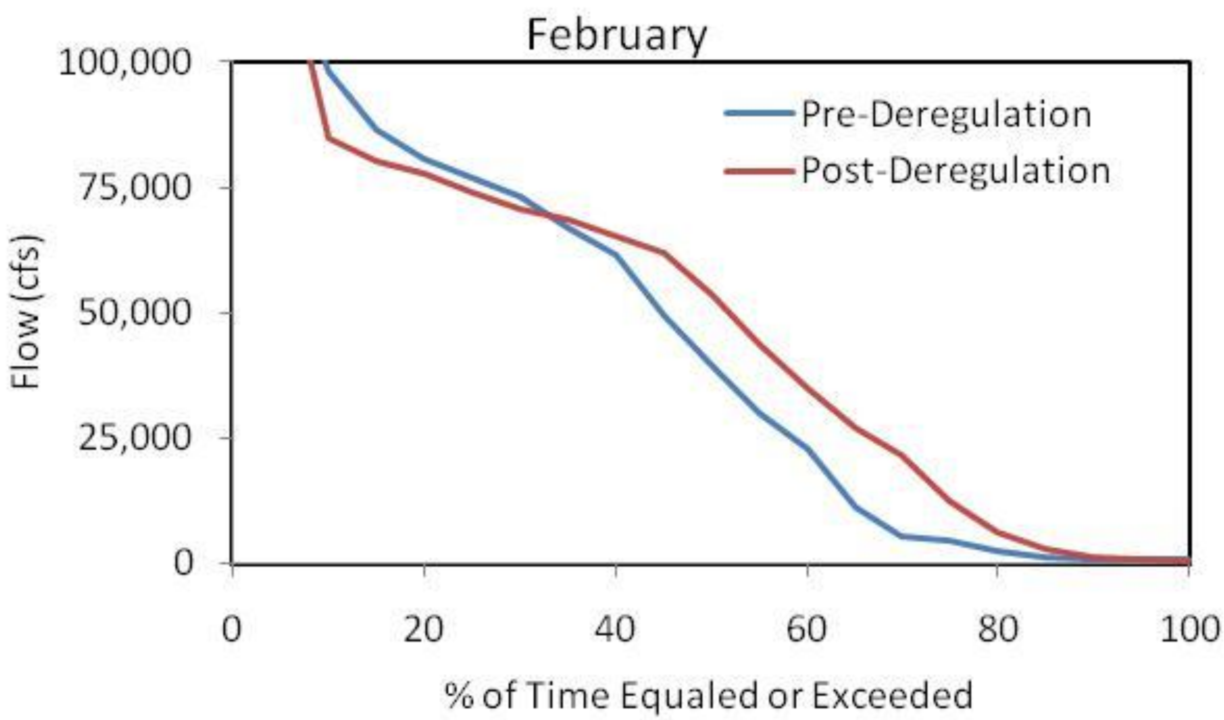

October
Conowingo
Marietta
Flow (cfs)
100,000
80,000
60,000
40,000
20,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

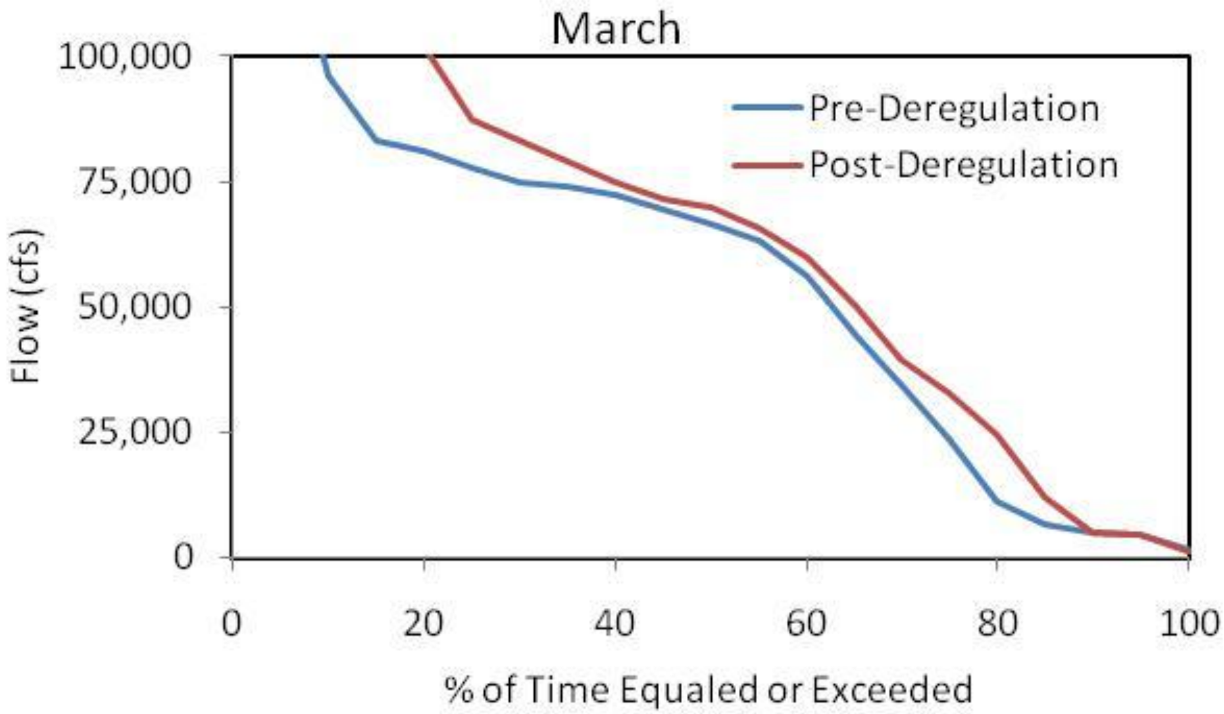

November
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded

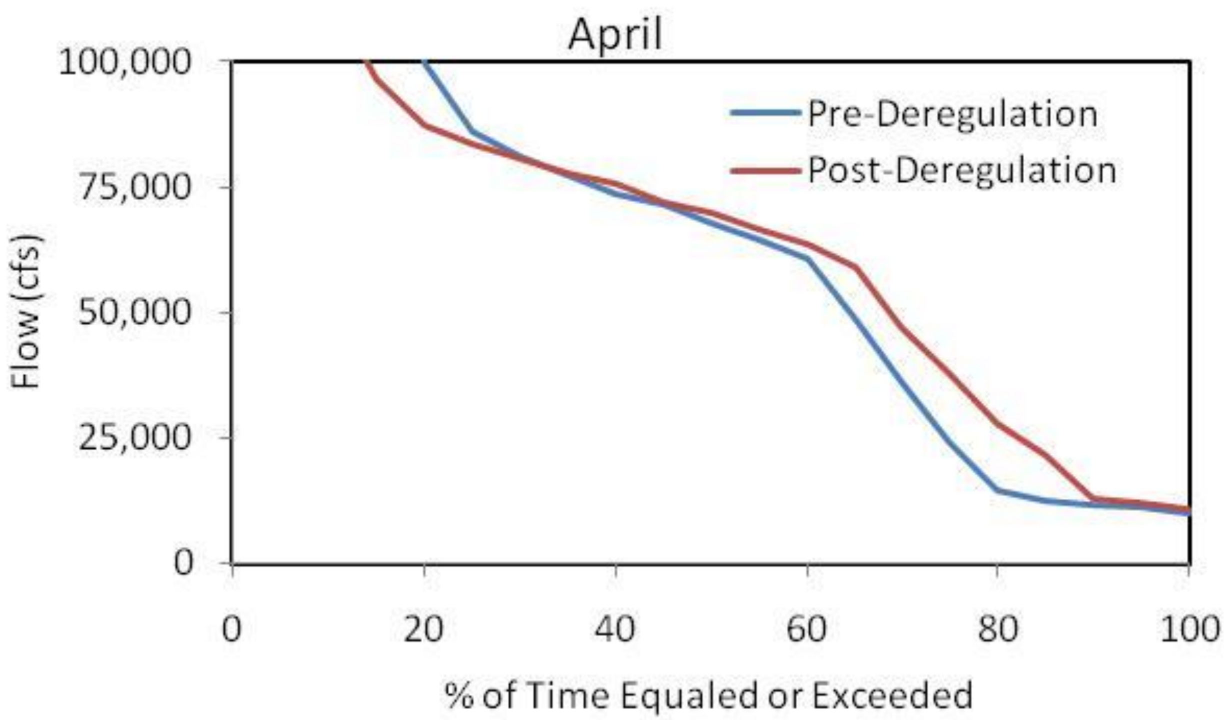

December
100,000
80,000
60,000
40,000
20,000
0
Flow (cfs)
Conowingo
Marietta
0
20
40
60
80
100
% of Time Equaled or Exceeded

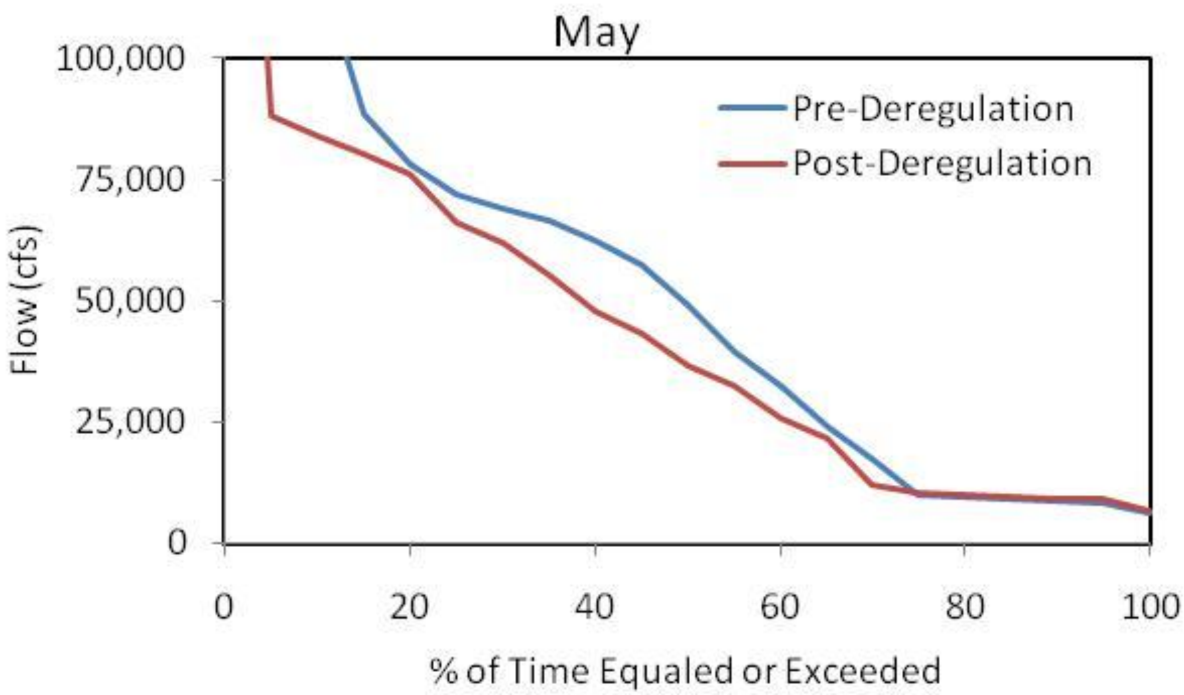
APPENDIX D-PRE (WY 1989-1990, 1992-1993, 1995-1997) AND POST (WY 1998-2009) DEREGULATION SUB-DAILY FLOW EXCEEDANCE CURVES.

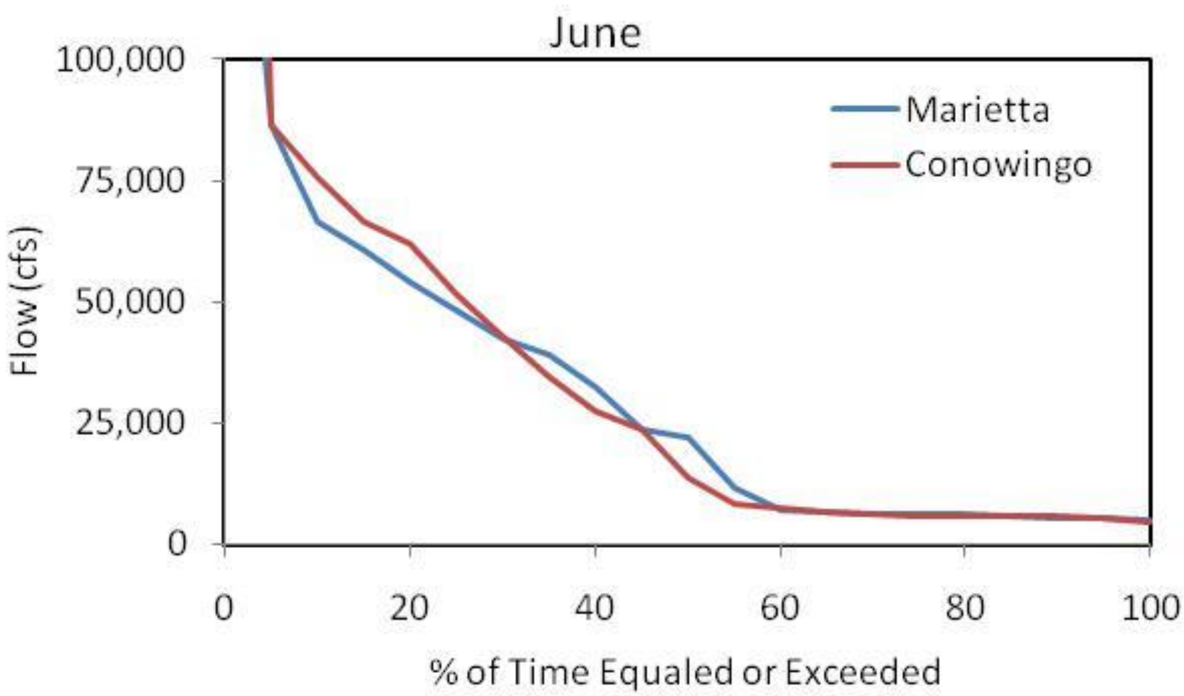

January
Pre-Deregulation
Post-Deregulation
Flow (cfs)
100,000
75,000
50,000
25,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

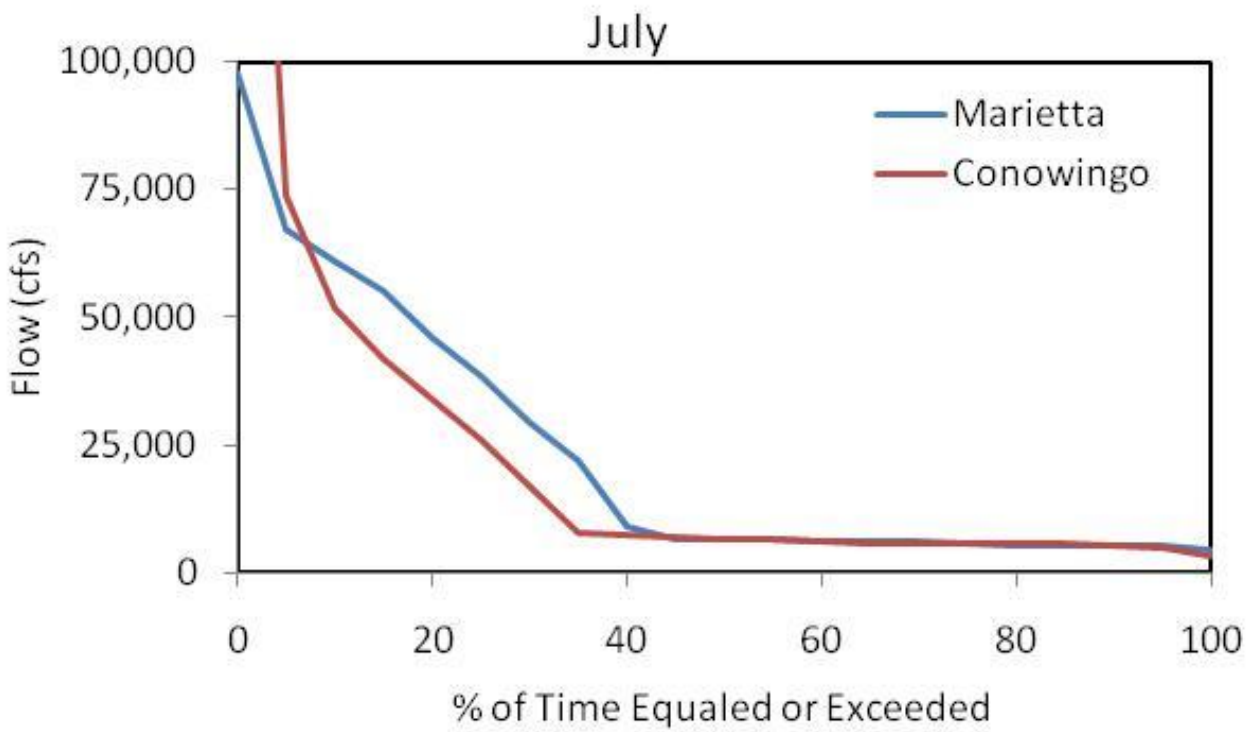

February
Pre-Deregulation
Post-Deregulation
Flow (cfs)
100,000
75,000
50,000
25,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

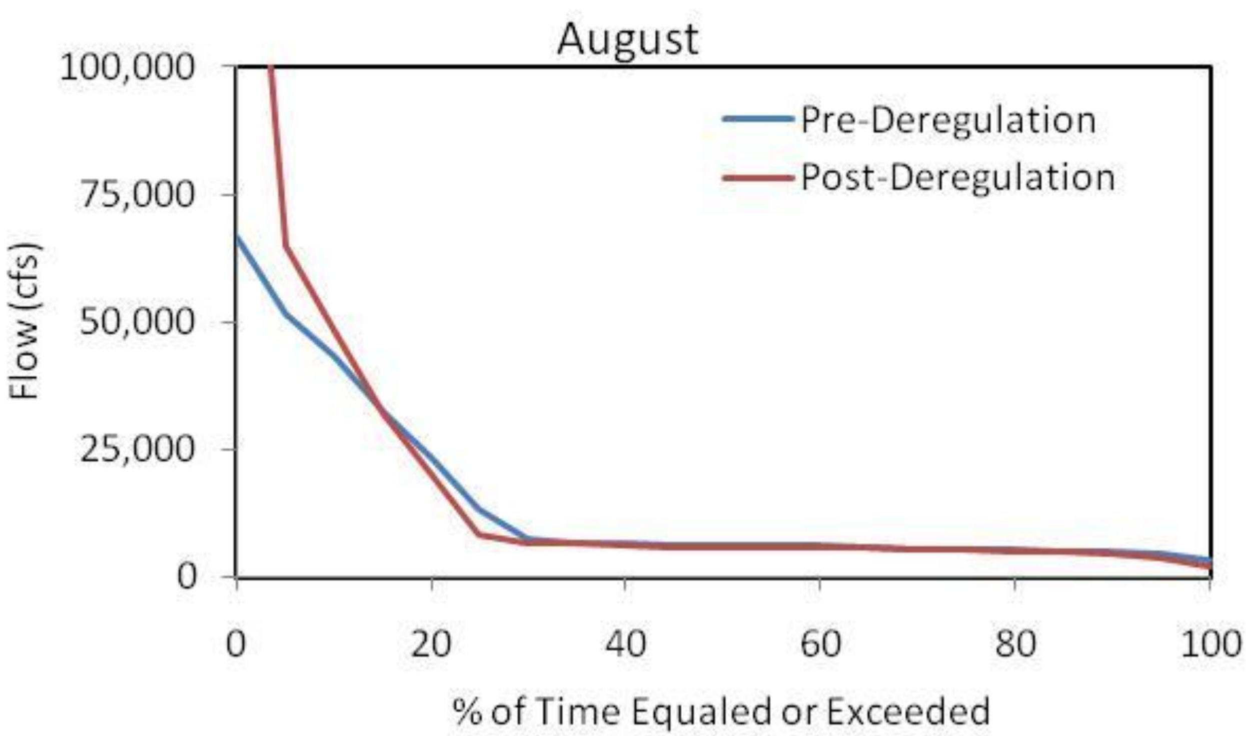

March
Pre-Deregulation
Post-Deregulation
Flow (cfs)
100,000
75,000
50,000
25,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

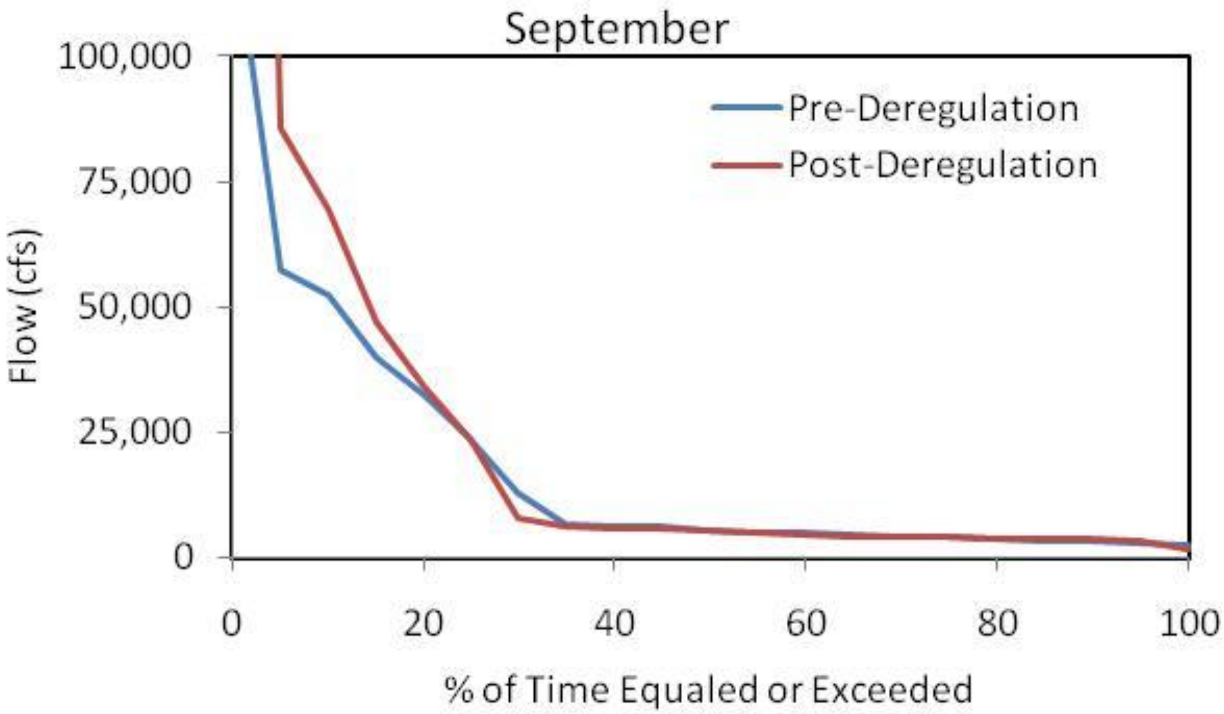

April
Pre-Deregulation
Post-Deregulation
Flow (cfs)
100,000
75,000
50,000
25,000
0
0
20
40
60
80
100
% of Time Equaled or Exceeded

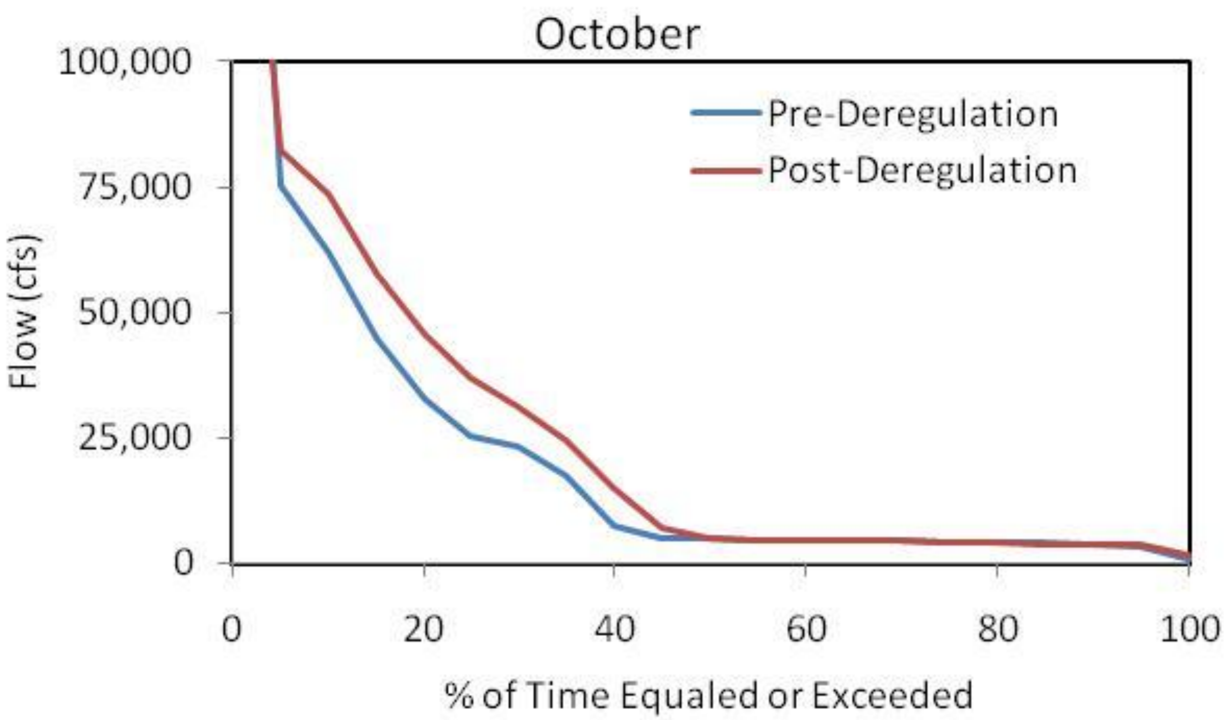

May
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Pre-Deregulation
Post-Deregulation

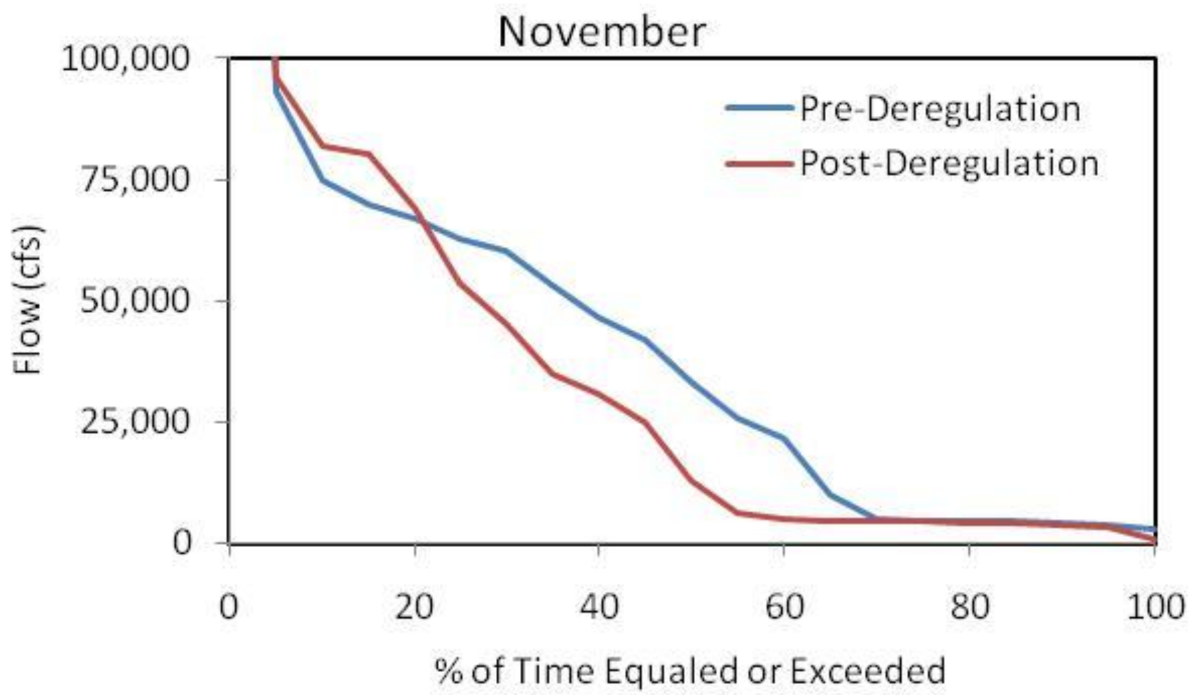

June
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo

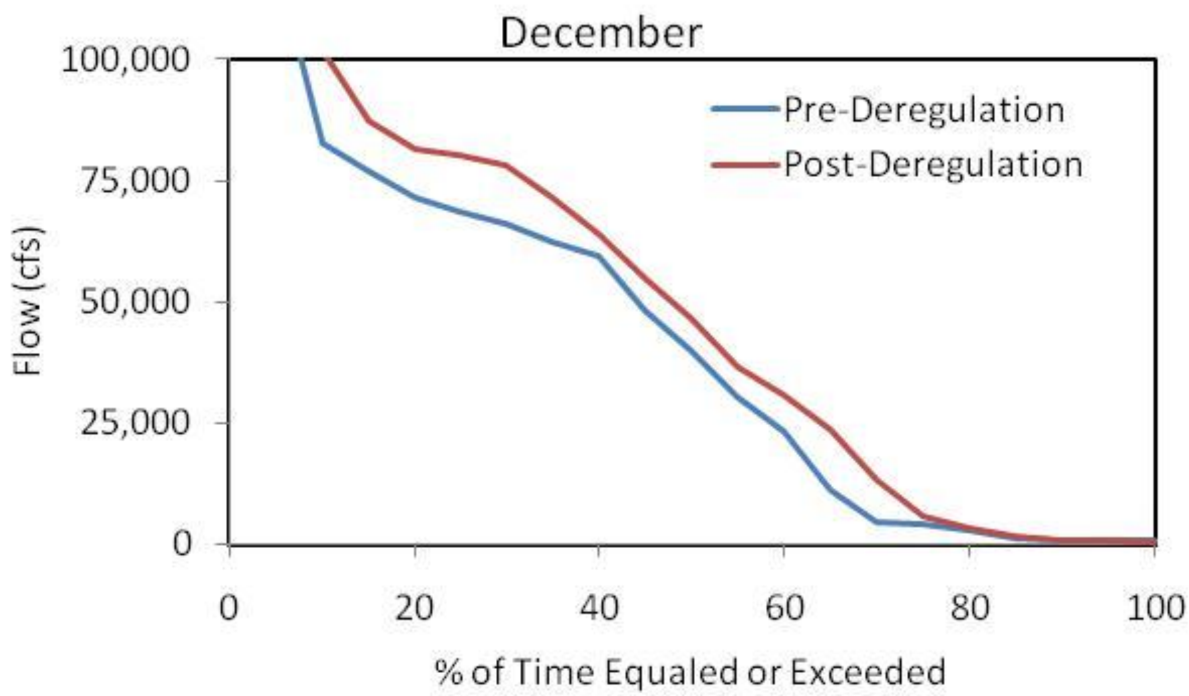

July
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Marietta
Conowingo


August
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Pre-Deregulation
Post-Deregulation


September
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Pre-Deregulation
Post-Deregulation


October
100,000
75,000
50,000
25,000
0
Flow (cfs)
0
20
40
60
80
100
% of Time Equaled or Exceeded
Pre-Deregulation
Post-Deregulation


November
100,000
75,000
50,000
25,000
0
Flow (cfs)
Pre-Deregulation
Post-Deregulation
0
20
40
60
80
100
% of Time Equaled or Exceeded


December
100,000
75,000
50,000
25,000
0
Flow (cfs)
Pre-Deregulation
Post-Deregulation
0
20
40
60
80
100
% of Time Equaled or Exceeded