AMERICAN SHAD PASSAGE STUDY: SUSQUEHANNA RIVER AMERICAN SHAD MODEL MODEL PRODUCTION RUNS

RSP 3.4

CONOWINGO HYDROELECTRIC PROJECT

FERC PROJECT NUMBER 405

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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). The current license for the Conowingo Project was issued on August 14, 1980 and expires on September 1, 2014. Exelon is applying for a new license using the FERC's Integrated Licensing Process (ILP). In June, 2011 Exelon distributed a revised study plan (RSP 3.4) for a study to model the effects of restoration measures on the Susquehanna River American shad population returning to Conowingo Dam (and upstream) to spawn.

During 2011, an annual step numeric model was developed in Microsoft Access software to simulate the American shad spawning population returning to Conowingo Dam. The model allows the user to alter variables to examine the population response to potential enhancement measures (Normandeau Associates and Gomez & Sullivan 2012).

Some key features of the model included:

- Annual projections of the American shad returning spawner population to Conowingo Dam and the upper Susquehanna River;
- Deterministic output or stochasticity elements to account for life history variability;
- Inclusion of the best available data from within the Susquehanna River Basin, including upstream fish passage counts and relative passage effectiveness, trap-and-transport passage, larval / juvenile stocking and survival, age distribution of virgin and repeat spawners, and sex ratio;
- Use of existing data for calibration of assumed model parameters so that modeled estimates of the spawner population returning to and passed at Conowingo Dam are fit to the observed catch;
- The ability to examine model sensitivity to various restoration measures;
- The ability to individually examine model sensitivity to alterations of adult upstream passage effectiveness and juvenile downstream passage survival rates at each mainstem project; and
- The resolution to assess cumulative effects of projects on shad restoration.

An initial study report (ISR) was filed on January 23, 2012, containing Exelon's 2011 study findings. The deadline for formal comments on the ISR including requested study plan modifications was April 23, 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.

In 2012, data compiled in the ISR and in further consultation with agencies and stakeholders were developed to provide baseline inputs that were used to calibrate the model to observed American shad returns to Conowingo Dam. Additionally, based on agency and stakeholder input, a matrix of simulations bracketing low and high range values for input variables was developed.

Model runs were done using a combination of baseline input values for variables that will not be directly affected by relicensing of Conowingo Dam and Muddy Run Pumped Storage Project and high and low bracketing input values for variables that may be directly affected by relicensing to assess the projected response of the population of

American shad spawning in the Susquehanna River upstream of York Haven Dam (and to some extent below York Haven). The results supported the conclusion that population growth cannot occur without provision of access to spawning habitat for a sufficient number of spawners, however the results were subject to inputs associated with high and low value models including variables that have not been demonstrated.

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LIST OF ABBREVIATIONS

Agencies

FERC	Federal Energy Regulatory Commission
MDE	Maryland Department of the Environment
MDNR-PPRP	Maryland Department of Natural Resources–Power Plant Research Program
PFBC	Pennsylvania Fish and Boat Commission

Units of Measure

MW	megawatt

Regulatory

ILP	Integrated Licensing Process
NOI	Notice of Intent
PAD	Pre-Application Document
PSP	Proposed Study Plan
RSP	Revised Study Plan

Miscellaneous

Exelon	Exelon Generating Company, LLC
MSD	Mean Squared Deviation
Project	Conowingo Hydroelectric Project
PM&E	Protection, mitigation, and enhancement
SASM	Susquehanna American Shad Model
SD	Standard Deviation

1.0 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. In its final study plan determination for the Project, issued February 4, 2010, FERC determined that the proposed American Shad (*Alosa sapidissima*) Passage Study (Study 3.4) was not required noting that "the information is either redundant with other studies or would not inform a decision on fish passage at the project".

In a letter filed with FERC on September 30, 2010, as the result of an agreement with Exelon, Maryland's Department of Natural Resources–Power Plant Research Program (MDNR-PPRP) and Department of the Environment (MDE) withdrew their request for a formal dispute resolution, filed with FERC February 24, 2010, regarding a number of studies. In the resolution of the disputed matters, MDNR-PRRP and MDE agreed that, "in conjunction with other resource agencies, they will, in good faith, actively participate in the development and assessment of Exelon's shad population model as set forth in section 3.4 of Exelon's revised study plan." Such participation assumed that MDNR-PPRP and MDE as well as other resource agencies, including Pennsylvania Fish and Boat Commission (PFBC) would have active involvement in the model development and implementation process, obtain regular progress updates from Exelon, and have the opportunity to comment and provide feedback throughout the implementation of the study.

In June, 2011 Exelon distributed a revised study plan (RSP 3.4) and on August 23, 2011 the study plan was presented and discussed with agencies and Stakeholders at a relicensing team meeting.

The objectives of the study were to:

- Review and compile existing information to provide input variables and ranges for modeling.
- Construct a mathematical simulation model (based on a previous model) of the Susquehanna River American shad population returning to Conowingo Dam.

An initial study report (ISR) was filed on January 23, 2012, containing Exelon's 2011 study findings. The deadline for formal comments on the ISR including requested study plan modifications was April 23, 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 ISR contained a description of an annual step numeric model (Susquehanna American Shad Model, SASM) developed as an application in Microsoft Access software to simulate the American shad spawning population returning to Conowingo Dam and to allow for the user to alter variables to examine the population response to potential enhancement measures (Normandeau Associates and Gomez & Sullivan 2012). In 2012, data compiled in the ISR and in further consultation with agencies and stakeholders were developed to provide baseline inputs that were used to calibrate the model to observed American shad returns to Conowingo Dam. Additionally, based on agency and stakeholder input, a matrix of simulations bracketing (low and high) a range of values for input variables was developed and each node in that matrix was run as a model simulation.

2.0 METHODS

2.1 Model Function

Model development and function are thoroughly described in the ISR (Normandeau Associates and Gomez and Sullivan 2012).

The SASM simulates adult American shad upstream passage and juvenile downstream passage survival proportions at each of five hydroelectric facilities along the lower Susquehanna River (Conowingo Dam, Muddy Run Pumped Storage Project - MRPSP, Holtwood Dam, Safe Harbor Dam, and York Haven Dam; Figure 2.1-1). The model has the ability to include annual stocking of hatchery-reared juveniles, upstream transport/stocking of adult American shad collected at Conowingo Dam, sex ratio, and age structures for virgin and repeat-spawning females. Additionally the model calculations can incorporate a proportion of the annual number of adults that are available but do not pass York Haven Dam, assumed to spawn in the river reach below York Haven Dam with a maximum cap. Stochastic variation components can be invoked to simulate annual variation in upstream passage success, juvenile downstream passage survival, and overall reproductive rate (future recruitment per spawner, termed net R). Stochasticity is simulated for net R by running a specified number of iterations, randomly drawing from a gamma distribution (bounded by 0), with peak frequency of occurrence around the specified value and the range of the randomly drawn values controlled by a distribution shape parameter. Stochasticity for upstream passage success and juvenile downstream passage survival is similar, randomly drawing an overall rate of passage for each iteration from a range of zero – 1 (beta distribution) with its peak around the specified value and range controlled by the distribution shape parameter. The starting year, length (in years) of a simulation, and starting population can be specified (Figure 2.1-2). The model outputs graphical and tabular projections of the numbers of fish returning to various points in the lower Susquehanna River system annually throughout the period specified.

2.2 Baseline Calibration

Baseline model runs were made using the best available information for key input parameters including: adult upstream passage effectiveness, juvenile downstream passage survival, trap-and-transport adult stocking numbers, hatchery reared juvenile stocking numbers, and population dynamics information (age frequency distribution of first spawning females, frequency and age distribution of repeat spawning females, and sex ratio). In the calibration procedure, those input variables were fixed and the primary 'tuning' element of the model, net R was adjusted to determine the best fit of the model to existing data for annual American shad adult returns to Conowingo Dam. Baseline calibration runs were done starting with 1980 for 32 years (through 2010) with a starting Conowingo passage number of zero. The SASM was run in deterministic mode; stochastic variability elements were not invoked so that one output was produced for each year simulated. The determination of best fit was made by comparison of mean squared deviation (MSD) of the projected American shad returns from the actual observed returns and a qualitative review of the results.

2.2.1 Input Values

Compilation of the best available information included data provided by stakeholders and multiple meetings and correspondences with interested stakeholders. A full description of the derivation of input values, summarized below, was provided in the ISR (Normandeau Associates and Gomez and Sullivan 2012).

- Upstream Passage Effectiveness:
  - York Haven = 10%;
  - Safe Harbor = 72%;
  - Holtwood = 33%;
  - Muddy Run = 96%;
  - Conowingo = 45%.
- Downstream Juvenile Passage Survival:
  - York Haven = 85%;
  - Safe Harbor = 97%;
  - Holtwood = 74%;
  - Muddy Run = 95%;
  - Conowingo = 93%.
- Sex ratio: 46% female.
- Age Frequency Distribution of First Spawning Females:
  - Age 4 = 16%;
  - Age 5 = 44%;
  - Age 6 = 31%;
  - Age 7 = 9%.
- Age Distribution and Frequency of Repeat Spawning Females (adjusted values for model function):
  - Age 5 = 38%;
  - Age 6 = 34%;
  - Age 7 = 19%.
- Larval / Juvenile Stocking: 6,700,000 / Year.
- Return Rate for Stocked Larvae / Juveniles 0.0044.
- Spawning Below York Haven: 15% with a maximum of 57,600 spawners.

- An Annual Input Override Table of empirical data for annual upstream passage effectiveness, adult trap & transport, juvenile stocking, and juvenile survival to return.

Preliminary assessment indicated that Conowingo passage effectiveness higher than 45% resulted in a better fit to the historic data, so 55%, 60%, and 65% were also assessed for calibration.

2.2.2 Documentation

For each calibration run the date, a sequential run number, and the output MSD along with the input value for net R and any alterations to input values noted above were recorded in a log. Input and output data were archived in individual, uniquely named files (MS Excel) for each run, and SASM generated output reports (PDF format) were archived for each run, and those file names were recorded in the log for reference.

2.3 Production Runs

This initial phase of production model runs was used to examine the response in projected pre-spawned adult American shad returning to Conowingo Dam to a range of plausible input values for biological and enhancement measures.

2.3.1 Input Values

A range (low and high) of input values for those variables that are not directly related to potential PM&E measures was determined in coordination with representatives of agencies and other stakeholders. Values were assigned for adult upstream passage effectiveness and juvenile downstream passage survival at Safe Harbor and Holtwood Dams, age frequency distribution of first spawning females, frequency and age distribution of repeat spawning females (adjusted to incorporate age-based fecundity), sex ratio, and the proportion of fish that fail to pass York Haven Dam but successfully spawn in the riverine reach below York Haven Dam. Note that upstream and downstream passage values for Safe Harbor and Holtwood Dams were fixed at one value and included in this section because they are either meeting restoration plan passage goals (Safe Harbor) or are expected to reach those goals due to license requirements (Holtwood). Net R was adjustable, but values of 6 and 12 were the range extremes used because 12 provided a relatively good fit of the model output to historic data, however in our judgment 12 was not a sustainable long-term reproductive rate; we selected 50% of that value as the lower value. Additionally, Agency and stakeholder representatives were queried for their input to determine appropriate bounds for variables that are directly related to potential PM&E measures. Those included adult upstream passage effectiveness and juvenile downstream passage survival at York Haven and Conowingo Dams and at Muddy Run Pumped Storage Project (Conowingo Dam passage – entrainment), annual juvenile American shad stocking, and annual trap & transport contributions.

2.3.1.1 Summary of Input Values for Production Runs

- Upstream Passage Effectiveness:
  York Haven: Low = 8%; High = 85%;

    Safe Harbor = 72%;
    Holtwood = 75%;
    Muddy Run: Low = 80%; High = 99%;
    Conowingo: Low = 30%; High = 85%;
    Overall: Low = 1%; High = 39%.

- Downstream Passage Survival:
    York Haven: Low = 75%; High = 95%;
    Safe Harbor = 97%;
    Holtwood = 95%;
    Muddy Run: Low = 85%; High = 100%;
    Conowingo: Low = 90%; High = 95%;
    Overall: Low = 53%; High = 83%.
- Age Frequency Distribution of First Spawning Females:
    Age 4: Low = 28%; High = 7%;
    Age 5: Low = 54%; High = 30%;
    Age 6: Low = 15%; High = 48%;
    Age 7: Low = 3%; High = 15%.
- Age Distribution and Frequency of Repeat Spawning Females (adjusted for age-based fecundity and model input):
    Age 5: Low = 16%; High = 57%;
    Age 6: Low = 15%; High = 45%;
    Age 7: Low = 7%;   High = 23%.
- Sex Ratio (% female): Low = 40%; High = 60%.
- Number of Adults Spawning Below York Haven Dam: Low = 0; High = 57,600.
- Annual Juvenile Stocking: Low = 2 million; High = 25 million.
- Annual Trap & Transport: Low = 0; High = 50,000.
- Net R: Low = 6; High = 12.

2.3.1.2 Population Projection Modeling

An initial examination of the sensitivity of the population of American shad spawners returning to Conowingo Dam used a series of model runs projecting the number of shad returning to Conowingo Dam out 50 years. Two baseline runs were made to encompass the high and low ranges for input variables that are not directly related to potential PM&E measures: age frequency distribution of first spawning females, frequency and age distribution of repeat spawning females, sex ratio, and the proportion of adults that fail to pass York Haven Dam but successfully spawn in the riverine reach below York Haven Dam. Those inputs were set to their defined high and low values for the two runs, respectively. Values for variables that are directly related to potential PM&E measures (adult upstream passage effectiveness and juvenile downstream passage survival at York Haven and Conowingo Dams and at Muddy Run Pumped Storage Project, annual juvenile American shad stocking, and annual trap & transport contributions) were set to the existing conditions as described in Section 2.2.1 (See Table 2.3-1). Next, a series of model runs was made altering PM&E variable inputs individually. The population response was modeled over time using either the high or low baseline model for all other variables along with the high or low level of the PM&E variable of interest, as described in Section 2.3.1.1 (Table 2.3-2, 2.3-3).

For those runs stochastic variability elements for fish passage and net R were invoked for 25 iterations and a variable shape parameter = 50. Simulations were run for 50 years beginning in 2015, which would be the first passage year under Conowingo Dam's new license. The start population was set to 120,000, which, with spawners distributed over the observed age frequency distribution, approximates the number of returners to Conowingo observed in recent years (~ 30,000).

2.3.2 Documentation

For each production run the date, a sequential run number, and the set of input variable values were recorded in a log along with several output statistics: mean, minimum 2 SD, and maximum 2 SD of the end point (e.g., year 2064) of all 25 iterations for both the estimated number of adults collected at Conowingo Dam and the estimated number of adults passing York Haven Dam. Input and output data were archived in individual, uniquely named files (MS Excel) for each run, and SASM generated output reports (PDF format) were archived for each run, and those file names were recorded in the log for reference.

3.0 RESULTS

3.1 Calibration Runs

The SASM provided a reasonably good fit to historic fish passage counts at Conowingo Dam using a net R of 6, but a better fit was achieved with a net R of 12 (Table 3.1-1, Figure 3.1-1). The model underestimated the peak American shad passage years in both of those runs. Additional calibration runs were done iteratively with net R set to 6 and 12, and Conowingo upstream passage rate at 55%, 60%, and 65%. The best fit was achieved with net R set to 12 and Conowingo passage effectiveness at 65% (Table 3.1-1, Figure 3.1-2).

3.2 Production Runs

In the baseline run 1 (low variable input values), upstream and downstream passage proportions were set to the observed levels (Holtwood was set to the expected levels based on license agreement), juvenile stocking was set to the overall mean value for annual stocking from 1980 – 2010. Population dynamics values, larval stocking, and net R, were set to the low values. Negligible American shad returns were achieved throughout the model run. The end-point returns to Conowingo Dam were somewhat lower than those observed in recent years (Table 2.3-1, Figure 3.2-1). In baseline run 2 (high), upstream and downstream passage proportions and juvenile stocking were set as in the first baseline run, but population dynamics values, larval stocking, and net R, were set to the high levels. In that case shad returns to Conowingo increased over about 20 years until reaching an asymptote at a higher level than is currently observed Table 2.3-1, Figure 3.2-2).

Similar to baseline run 1, production run 1-low, with a low juvenile stocking rate depicted a decline from approximate present returns to a low level. In that case, the return level was lower than in the baseline run because of a lower annual stocking rate (Figure 3.2-3). Similar to baseline run 2, production run 1-high, with a high juvenile stocking rate resulted in population growth for approximately 20 years until reaching an asymptote (Figure 3.2-4).

Production runs 2-low and 2-high yielded similar results. With no trap and transport of adults to spawning habitat, the population was projected to fall to a low level using the low model (Figure 3.2-5) and rise to an asymptote similar to that projected in baseline run 2 using the high model (Figure 3.2-6).

Production runs 3-low and high, using low and high juvenile downstream passage survival rates along with the low and high baseline inputs yielded results that were nearly identical to the two baseline runs (Figure 3.2-7, 3.2-8). Production runs 4-low, applying low upstream passage with the low model, resulted in a suppressed population similar to all other model runs with the low input set (Figure 3.2-9). Run 4-high, with high upstream passage, however, resulted in exponential population growth (Figure 3.2-10).

Additional production runs were made to more closely investigate the effect of high upstream passage by comparing the effect of altering passage at one facility rather than considering overall passage. Production runs 4.1, 4.2, and 4.3 used the high values for upstream passage at York Haven, Muddy Run, Conowingo, respectively, while setting upstream passage at the other two facilities in each run at their baseline level. Production run 4.1, high upstream passage at York haven, resulted in exponential population growth (Figure 3.2-11). Production run 4.2, high upstream passage at Muddy Run, was similar to baseline run 2 (Figure 3.2-12). Production run 4.3, high upstream passage at Conowingo had a similar result except that the American shad asymptote was at a slightly higher level (Figure 3.2-13).

4.0 DISCUSSION

The purpose for developing SASM was to provide a tool to evaluate scenarios that would provide the best value improvements in the American shad returns to Conowingo Dam. These results demonstrate that the SASM has the capability to be a useful decision-making support tool. This is, in part, because it is highly tailored for this system and because of the availability of important input data due to long running population restoration programs.

The model assumes that, except for recruitment contributions from stocked juveniles, all returning adults result from successful spawning upstream of York Haven Dam and limited spawning between Safe Harbor and York Haven in previous years. Model calibration used existing data for returning spawners counted from 1980 to 2010. While calibration adjustments of the major unknown inputs of net R and upstream passage proportion at Conowingo affect the magnitude of the model-generated spawner returns curve, the fact that the shape of the model output so well follows the shape of the observed Conowingo catch over that time-period indicates that this assumption is well founded. This further supports the conclusion that the rise and fall of annual shad returns to Conowingo over those years was primarily related to the level of adult and juvenile stocking effort during that time.

Results of the first baseline run indicated a low return rate with little variability and no population growth over time. This suggested that production would result primarily from the annual stocking of hatchery produced larvae. The slightly higher level of returns depicted over the first seven years of the simulation were an artifact of the start population value input into the model, which was calibrated to approximate the current actual returns. Adjusting the population dynamics variables down simply shifted the productivity of hatchery stocking down.

The return rate to Conowingo differed greatly between the two baseline runs. Baseline run 1 yielded endpoint returns that are similar, albeit lower, to recent observed returns at Conowingo. Baseline run 2 yielded much higher returns due to idealized conditions including a maximum spawning allowance below York Haven and a very high net R; both are conditions that have not been verified empirically. It is likely, however, that the low and high baseline models fully encompassed the real effects of those variables since they resulted in a liberal range of endpoints that bracketed the realm of observed returns to Conowingo. In both scenarios it was assumed that upstream and downstream passage values for Holtwood Dam will meet the goals of license requirements. Future production, runs should consider incremental improvements at Holtwood as well as those goals.

The results of production runs altering the juvenile stocking rate suggested that with increased stocking, the American shad population may be increased or decreased depending on the level of stocking, but the population growth would be limited. The growth observed with high juvenile stocking was driven by the increased juvenile stocking rate rather than the increased value for net R because a specific return rate, based on empirical observations, is applied to hatchery reared fish in the model rather than net R. Production runs altering between the low and high juvenile downstream passage survival rates along with the low and high baseline inputs yield results that were nearly identical to the two baseline runs, suggesting that altering downstream passage, given the low and high input sets, would do little to effect the population relative to other measures.

In production runs altering trap and transport stocking of adults to upstream of York Haven, the low level specified no transport, and was identical to the low baseline run. When trap and transport was high, however, population growth resulted. Though the magnitude resulted in part from the high input model, including net R, the endpoint was higher than for any other run except with high upstream passage rate. This demonstrated that transport of adults to spawning habitat would likely result in observable population growth.

When upstream passage rate was set to the low level (overall, lower than observed), results were similar to other runs with low input sets, however with high upstream passage exponential population growth occurred. This resulted from an exceptionally high total reproductive rate, in terms of eventual returning spawners produced per female (4.29). Subsequent model runs suggested that increasing the upstream fish passage at York Haven was the most important single adjustment and the only one that also resulted in exponential population growth. There were moderate effects of increasing the upstream fish passage proportion at Conowingo, and negligible effects of increasing the Muddy Run passage proportion. It is important to note that the endpoints in the overall high upstream passage run and the high upstream passage at York Haven were implausible. Those runs were made with the high input values for net R and for spawning below York Haven. Both are variables that have not been verified. In the model, population growth was unlimited and reproductive potential was not moderated by population size or density. In reality, carrying capacity, compensatory mechanisms, and perhaps other factors would moderate growth rate with population abundance and result in an asymptote at some level. In addition to high input variables for net

R and spawning below York Haven, the production runs for upstream passage placed no practical restrictions on the number of fish that can be passed at each facility. Similar to what was done for trap & transport, future production runs need to account for an upper limit on the numbers of fish that can be passed at each facility.

The SASM results demonstrate that the single most important factor in significantly increasing the Susquehanna River American shad population is allowing access of sufficient numbers of spawners to upriver spawning habitat. Given the best available information for existing conditions (see Section 2.2.1), the model projection indicates a relatively fixed population of returners to Conowingo Dam of around 20,000 passing Conowingo and only around 400 passing York Haven. The majority of returners would be products of hatchery rearing, and the similarity of the projected counts and those observed in recent years at both Conowingo and York Haven suggest that the Susquehanna American shad population has reached that state. If a catastrophic event occurred (e.g., hurricane similar to Agnes in 1972, hatchery failure) the Susquehanna River shad population could be set back further.

In the results reported here, the most productive runs in terms of growth resulted from high upstream passage and high trap and transport rates. Both are methods of providing access to spawning habitat. Note, however, that the results of trap and transport have been demonstrated whereas it is not known whether the high upstream passage model would be achieved. One or more bottlenecks that reduce the number of pre-spawned shad from reaching the upstream spawning areas would affect population growth. This differs from other river systems, (e.g., Connecticut, Santee) where there is sufficient spawning habitat between dams to maintain self-sustaining populations, whereas the reservoirs between the lower four Susquehanna River dams provide poor or limited spawning habitat and therefore negligible recruitment to the population.

The results presented included sets of variable inputs that were intended to bracket the real levels for variables that would not be directly altered by PM&E measures. These results demonstrate that the SASM can be used to evaluate the response in the number of shad returning to Conowingo and York Haven due to various protection, mitigation, and enhancement measures. To develop PM&E measures, the intent is to use this tool, along with other analyses, to consider a narrower set of input variable values to: (a) evaluate which measure(s) provide the best value (i.e., improvement to the Susquehanna shad population per dollar spent), and (b) illustrate how some measures implemented at Exelon’s facilities may be directly linked to the degree of effectiveness of measures at other projects. Ultimately, the goal is to improve the American shad population through efficient and cost-effective measures.

TABLE 2.3.1: SUSQUEHANNA RIVER AMERICAN SHAD MODEL. LOW AND HIGH BASELINE MODEL RUNS FOR EXAMINATION OF THE PROJECTED RESPONSE OF THE SUSQUEHANNA RIVER AMERICAN SHAD POPULATION RETURNING TO CONOWINGO DAM TO POTENTIAL PROTECTION, MITIGATION, AND ENHANCEMENT MEASURES

	Non-PM&E Variable Inputs							**PM&E Variable Inputs**					
Baseline Run No.	**Net R**	**Age Freq., virgin (%, age 4,5,6,7)**	**Age Dist., repeat (%, age 5, 6, 7)**	**Adults Spawning Below YH (N max)**	**Sex Ratio (% Female)**	**Upstream Passage, Safe Harbor, Holtwood (%)**	**Downstream Passage Survival, Safe Harbor, Holtwood (%)**	**Upstream Passage YH, MR, C (%)**	**Downstream Passage Survival, YH, MR, C (%)**	**Trap & Transport (N max)**	**Juvenile Stocking (N)**	**End Point Returns, Conowingo**	**End Point Returns, York Haven**
1. Low	**6**	**28, 54, 15, 3**	**16, 15, 7**	**0**	**40**	**72, 75**	**97, 95**	**10, 96, 45**	**85, 95, 93**	**0**	**6,700,000**	**15,891**	**810**
2. High	**12**	**7, 30, 48, 15**	**57, 45, 23**	**100% to 57,600**	**60**	**72, 75**	**97, 95**	**10, 96, 45**	**85, 95, 93**	**0**	**6,700,000**	**223,234**	**11,496**

TABLE 2.3.2: SUSQUEHANNA RIVER AMERICAN SHAD MODEL. PRODUCTION RUNS FOR EXAMINATION OF THE PROJECTED RESPONSE OF THE AMERICAN SHAD POPULATION RETURNING TO CONOWINGO DAM TO POTENTIAL PROTECTION, MITIGATION, AND ENHANCEMENT MEASURES

	Non-PM&E Variable Inputs							PM&E Variable Inputs				Output		
Production Run No.	Net R	Age Freq., virgin (%, age 4,5,6,7)	Age Dist., repeat (%, age 5, 6, 7)	Adults Spawning Below YH (N max)	Sex Ratio (% Female)	Upstream Passage, Safe Harbor, Holtwood (%)	Downstream Passage Survival, Safe Harbor, Holtwood (%)	Upstream Passage YH, MR, C (%)	Downstream Passage Survival, YH, MR, C (%)	Trap & Transport (N max)	Juvenile Stocking (N)	End Point Returns, Conowingo	End Point Returns, York Haven	Change in Returners (%)[1]
1 low (juv. stocking)	6	28, 54, 15, 3	16, 15, 7	0	40	72, 75	97, 95	10, 96 ,45	85, 95, 93	0	2,000,000[2]	4,771	250	-84%
1 high (juv. stocking)	12	7, 30, 48, 15	57, 45, 23	100% to 57,600	60	72, 75	97, 95	10, 96 ,45	85, 95, 93	0	25,000,000	299,531	16,148	898%
2 low (T&T)	6	28, 54, 15, 3	16, 15, 7	0	40	72, 75	97, 95	10, 96 ,45	85, 95, 93	0[3]	6,700,000	15,949	822	-47%
2 high (T&T)	12	7, 30, 48, 15	57, 45, 23	100% to 57,600	60	72, 75	97, 95	10, 96 ,45	85, 95, 93	50,000	6,700,000	401,695	18,886[4]	1239%
3 low (downstream passage)	6	28, 54, 15, 3	16, 15, 7	0	40	72, 75	97, 95	10, 96 ,45	75, 85 ,90	0	6,700,000	15,773	814	-47%
3 high (downstream passage)	12	7, 30, 48, 15	57, 45, 23	100% to 57,600	60	72, 75	97, 95	10, 96 ,45	95, 100 ,95	0	6,700,000	282,889	15,190	843%
4 low (upstream passage)	6	28, 54, 15, 3	16, 15, 7	0	40	72, 75	97, 95	8, 80, 30	85, 95, 93	0	6,700,000	10,477	378	-65%
4 high (upstream passage)	12	7, 30, 48, 15	57, 45, 23	100% to 57,600	60	72, 75	97, 95	85, 99, 85	85, 95, 93	0	6,700,000	189,689,054	83,958,439	632197%

---

[1] % change from recent return counts at Conowingo Dam, ~30,000 / year.
[2] Highlighted cells indicate specific input altered for a model run.
[3] This run is the same as baseline – low.
[4] Including spawners transported from Conowingo to above York Haven the modeled number of spawners above York Haven is 68,886

TABLE 2.3-3: SUSQUEHANNA RIVER AMERICAN SHAD MODEL. PRODUCTION RUNS FOR EXAMINATION OF THE PROJECTED RESPONSE OF THE AMERICAN SHAD POPULATION RETURNING TO CONOWINGO DAM TO POTENTIAL PROTECTION, MITIGATION, AND ENHANCEMENT MEASURES WITH HIGH BASELINE VARIABLE INPUTS AND HIGH UPSTREAM PASSAGE AT SPECIFIC FACILITIES.

	Non-PM&E Variable Inputs							**PM&E Variable Inputs**				**Output**		
Production Run No.	**Net R**	**Age Freq., virgin (%, age 4,5,6,7)**	**Age Dist., repeat (%, age 5, 6, 7)**	**Adults Spawning Below YH (N max)**	**Sex Ratio (% Female)**	**Upstream Passage, Safe Harbor, Holtwood (%)**	**Downstream Passage Survival, Safe Harbor, Holtwood (%)**	**Upstream Passage YH, MR, C (%)**	**Downstream Passage Survival, YH, MR, C (%)**	**Trap & Transport (N max)**	**Juvenile Stocking (N)**	**End Point Returns, Conowingo**	**End Point Returns, York Haven**	**Change in Returners (%)[5]**
4 high (upstream passage)	**12**	**7, 30, 48, 15**	**57, 45, 23**	**100% to 57,600**	**60**	**72, 75**	**97, 95**	**85, 99, 85[6]**	**85, 95, 93**	**0**	**6,700,000**	**189,689,054**	**83,958,439**	**632197%**
4 high (YH upstream passage)	**12**	**7, 30, 48, 15**	**57, 45, 23**	**100% to 57,600**	**60**	**72, 75**	**97, 95**	**85, 96 ,45**	**85, 95, 93**	**0**	**6,700,000**	**1,615,510**	**702,942**	**5285%**
4 high (Muddy Run bypass / passage)	**12**	**7, 30, 48, 15**	**57, 45, 23**	**100% to 57,600**	**60**	**72, 75**	**97, 95**	**10, 99, 45**	**85, 95, 93**	**0**	**6,700,000**	**230,077**	**12,660**	**667%**
4 high (Conowingo upstream	**12**	**7, 30, 48, 15**	**57, 45, 23**	**100% to 57,600**	**60**	**72, 75**	**97, 95**	**10, 96, 85**	**85, 95, 93**	**0**	**6,700,000**	**538,574**	**29,808**	**1695%**

---

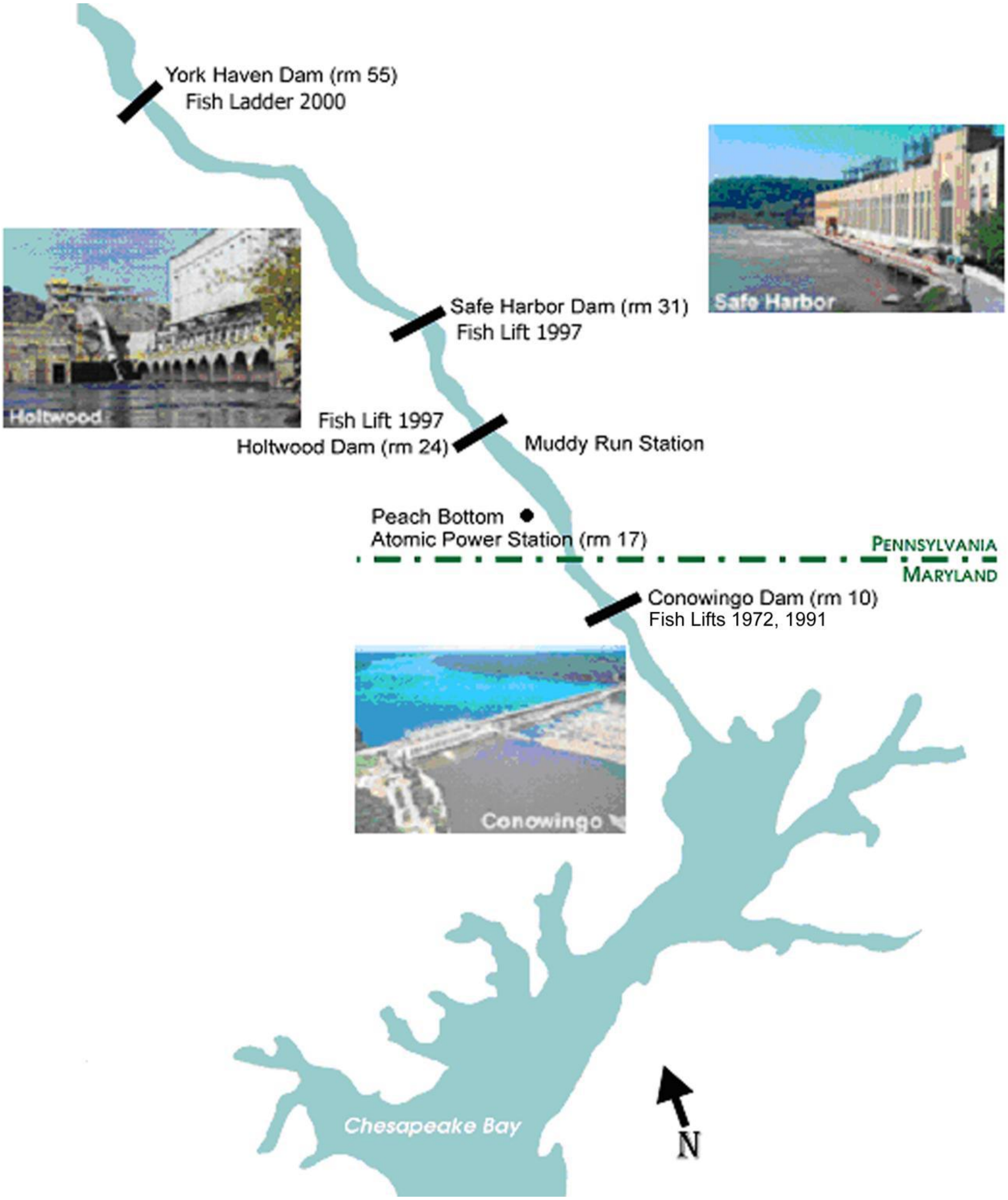
[5] % change from recent return counts at Conowingo Dam, ~30,000 / year.

[6] Highlighted cells indicate specific input altered for a model run.

TABLE 3.1-1: SUSQUEHANNA RIVER AMERICAN SHAD MODEL. RESULTS OF CALIBRATION RUNS WITH SSECIFIC INPUTS FOR NET R AND CONOWINGO PASSAGE EFFECTIVENESS. RESULT IS MEASURED AS THE MEAN SQUARED DEVIATION (MSD) OF PROJECTED ANNUAL AMERICAN SHAD RETURNS TO CONOWNIGO DAM FROM THE ACTUAL RETURNS.

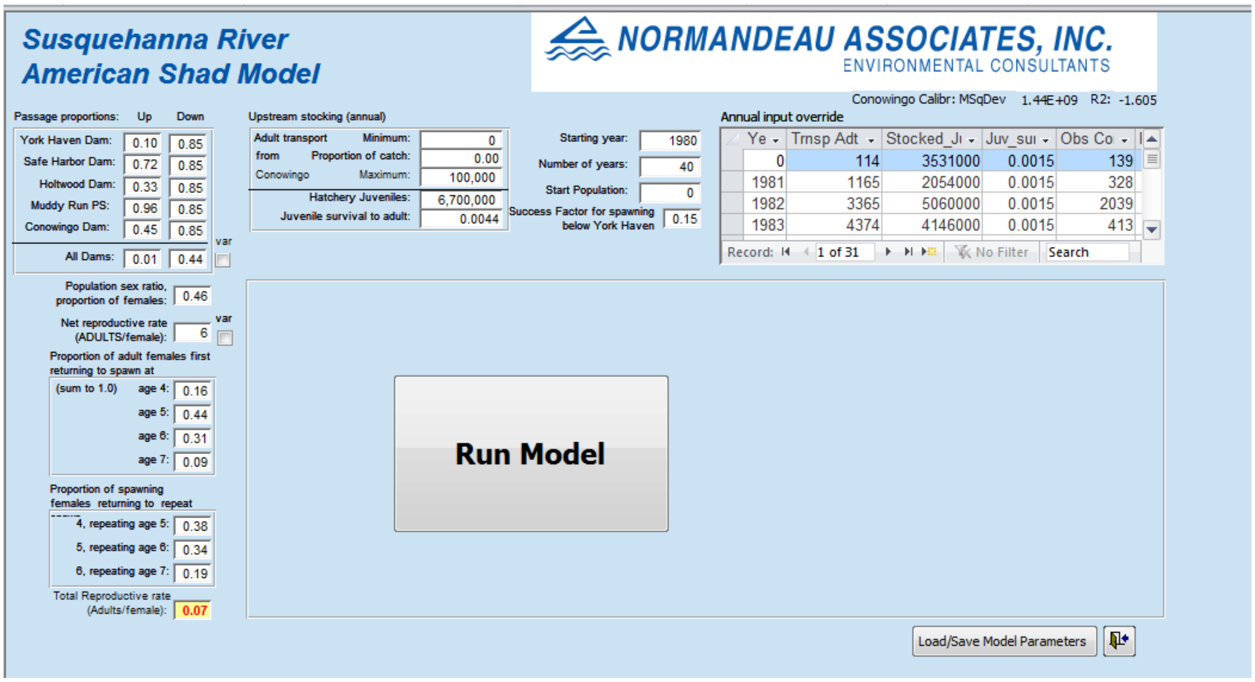
Date	Run No.	Net R	Conowingo Passage	MSD
4/12/2012	1	6	0.45	1.37E+09
4/12/2012	2	12	0.45	7.18E+08
4/12/2012	3	6	0.55	9.51E+08
4/12/2012	4	12	0.55	3.91E+08
4/12/2012	5	6	0.65	6.30E+08
4/12/2012	6	12	0.65	2.61E+08
4/12/2012	7	6	0.60	7.78E+08
4/12/2012	8	12	0.60	3.01E+08

FIGURE 2.1-1: HYDROELECTRIC PROJECTS AND FISH PASSAGE FACILITIES OF THE



LOWER SUSQUEHANNA RIVER

FIGURE 2.1-2: SUSQUEHANNA RIVER AMERICAN SHAD POPULATION MODEL DASHBOARD



Passage proportions:

	Up	Down
York Haven Dam:	0.10	0.85
Safe Harbor Dam:	0.72	0.85
Holtwood Dam:	0.33	0.85
Muddy Run PS:	0.96	0.85
Conowingo Dam:	0.45	0.85
All Dams:	0.01	0.44

var ☐

Population sex ratio, proportion of females: 0.46

Net reproductive rate (ADULTS/female): 6 var ☐

Proportion of adult females first returning to spawn at (sum to 1.0)

age 4: 0.16
age 5: 0.44
age 6: 0.31
age 7: 0.09

Proportion of spawning females returning to repeat

4, repeating age 5: 0.38
5, repeating age 6: 0.34
6, repeating age 7: 0.19

Total Reproductive rate (Adults/female): 0.07

Upstream stocking (annual)

Adult transport from Conowingo
Minimum: 0
Proportion of catch: 0.00
Maximum: 100,000

Hatchery Juveniles: 6,700,000
Juvenile survival to adult: 0.0044

Starting year: 1980
Number of years: 40
Start Population: 0
Success Factor for spawning below York Haven 0.15

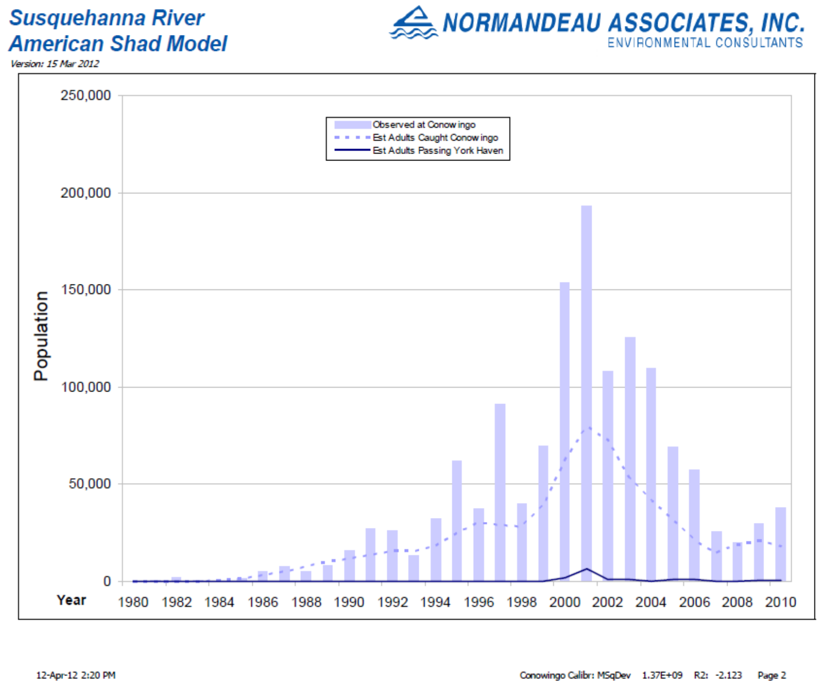
Conowingo Calibr: MSqDev 1.44E+09 R2: -1.605

Annual input override

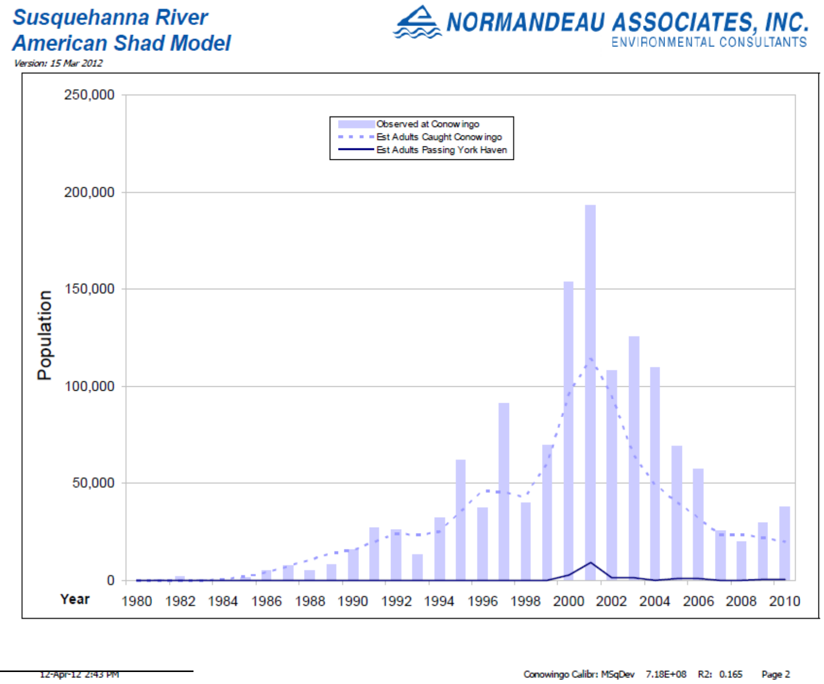
Ye	Trnsp Adt	Stocked_Ju	Juv_sur	Obs Co
0	114	3531000	0.0015	139
1981	1165	2054000	0.0015	328
1982	3365	5060000	0.0015	2039
1983	4374	4146000	0.0015	413

FIGURE 3.1-1: SUSQUEHANNA RIVER AMERICAN SHAD MODEL. A. CALIBRATION RUN #1, NET R = 6, B. CALIBRATION RUN #2, NET R = 12[7]

A.



B.



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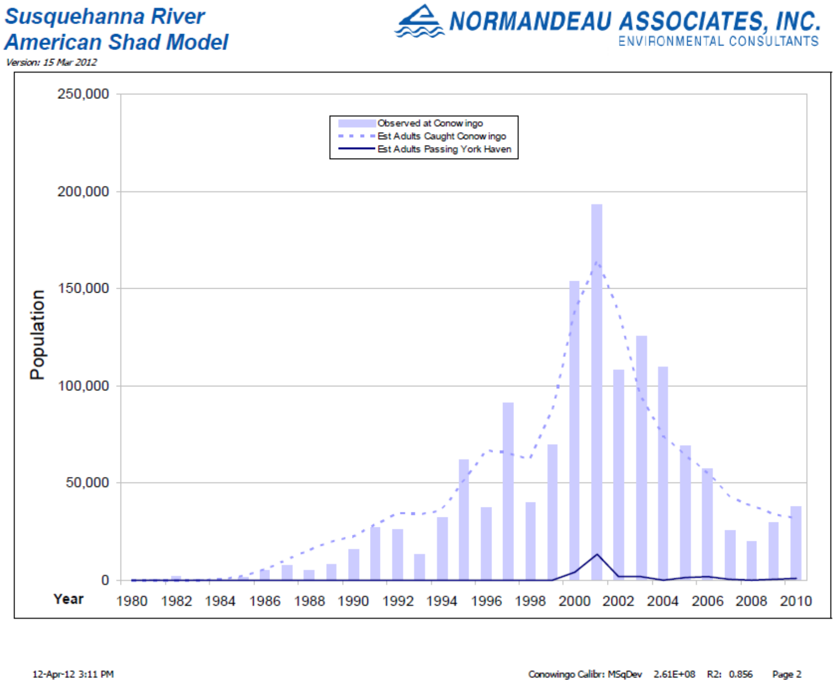
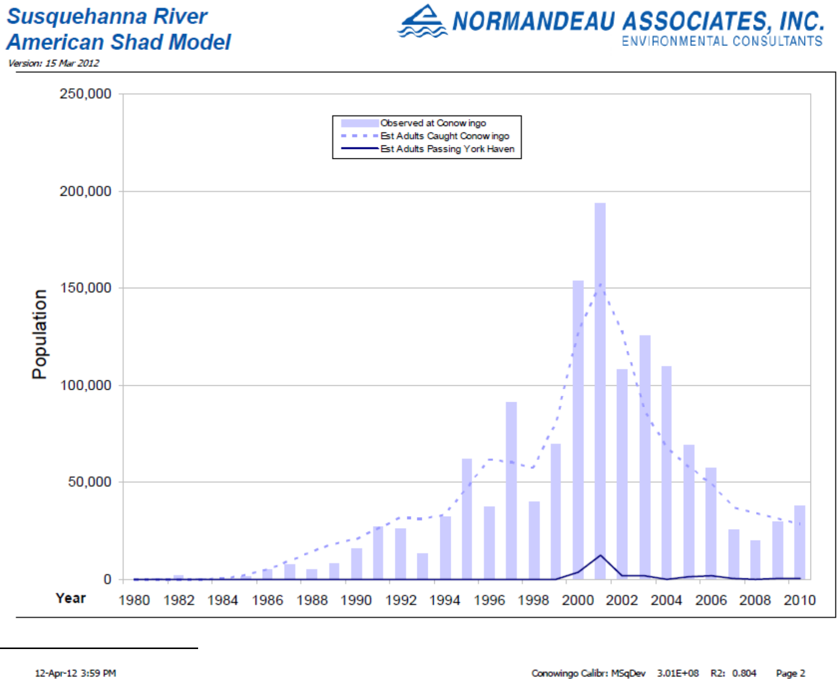
[7] A. mean squared deviation of predicted from observed values = 1.37E+9; B. mean squared deviation = 7.18E+8

FIGURE 3.1-2: SUSQUEHANNA RIVER AMERICAN SHAD MODEL. A. CALIBRATION RUN #6, NET R = 12, CONOWINGO PASSAGE EFFECTIVENESS = 65%, B. CALIBRATION RUN #8, NET R = 12, CONOWINGO PASSAGE EFFECTIVENESS = 0.60[8]

A.



B.



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[8] A. mean squared deviation of predicted from observed values = 2.61E+8; B. mean squared deviation = 3.01E+8

FIGURE 3.2-1: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, BASELINE RUN 1, WITH LOW VARIABLE INPUT SET.

See Table 1 for variable input values.

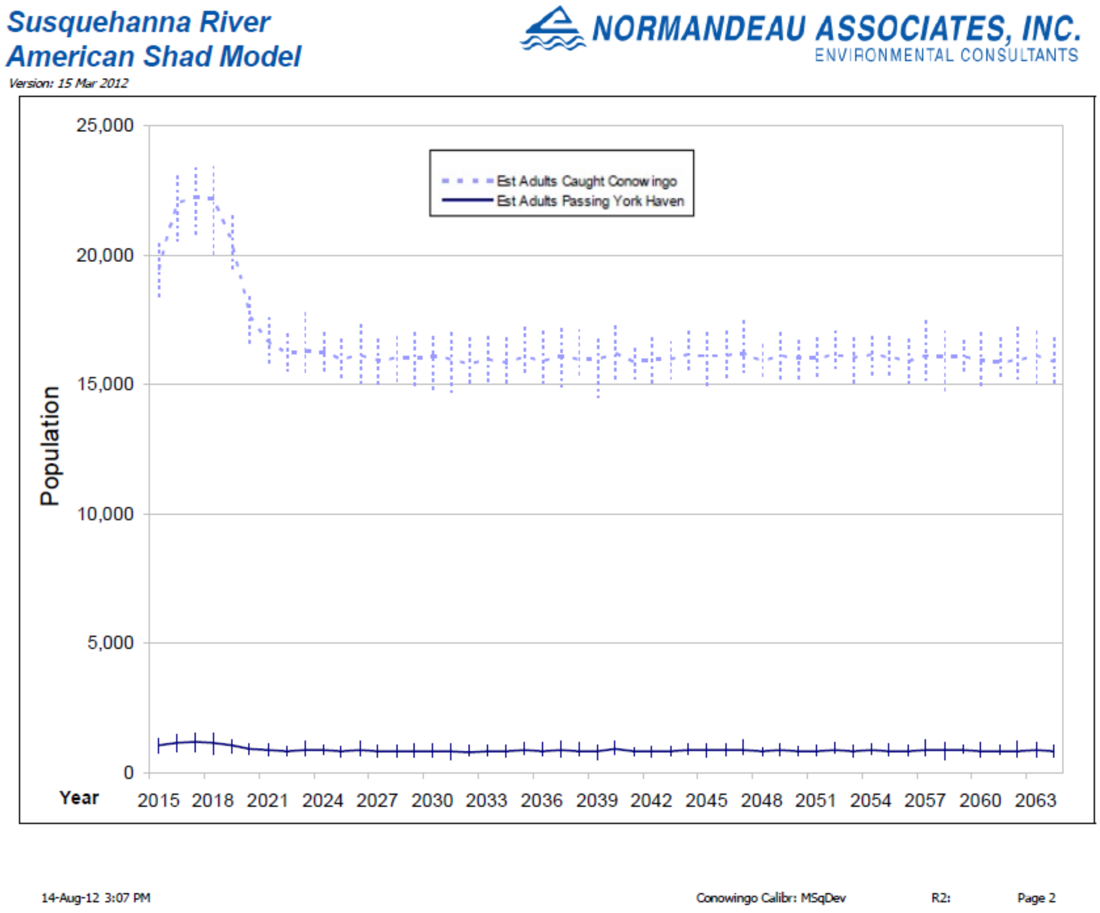


FIGURE 3.2-2: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, BASELINE RUN 2, WITH HIGH VARIABLE INPUT SET.

See Table 1 for variable input values.

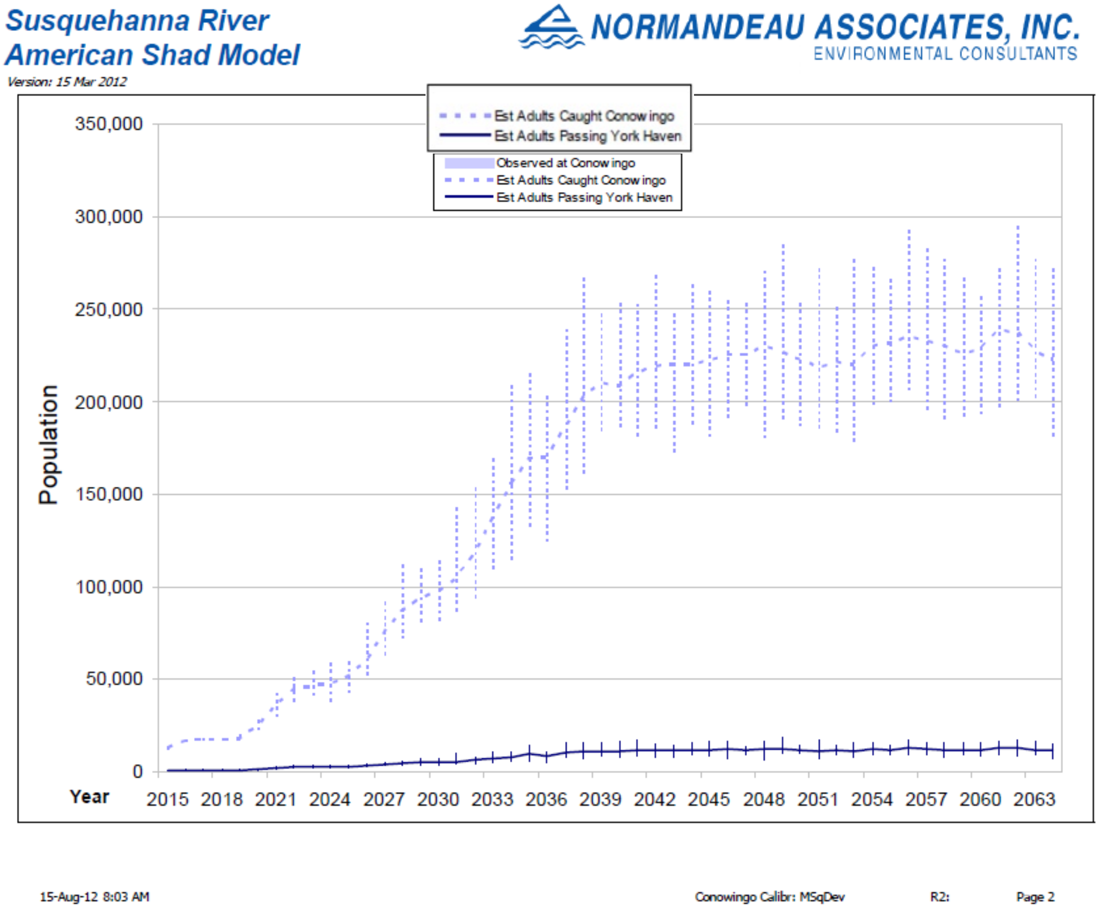


FIGURE 3.2-3: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 1-LOW: WITH LOW INPUT VARIABLE SET AND LOW JUVENILE STOCKING.

See Table 2 for variable input values

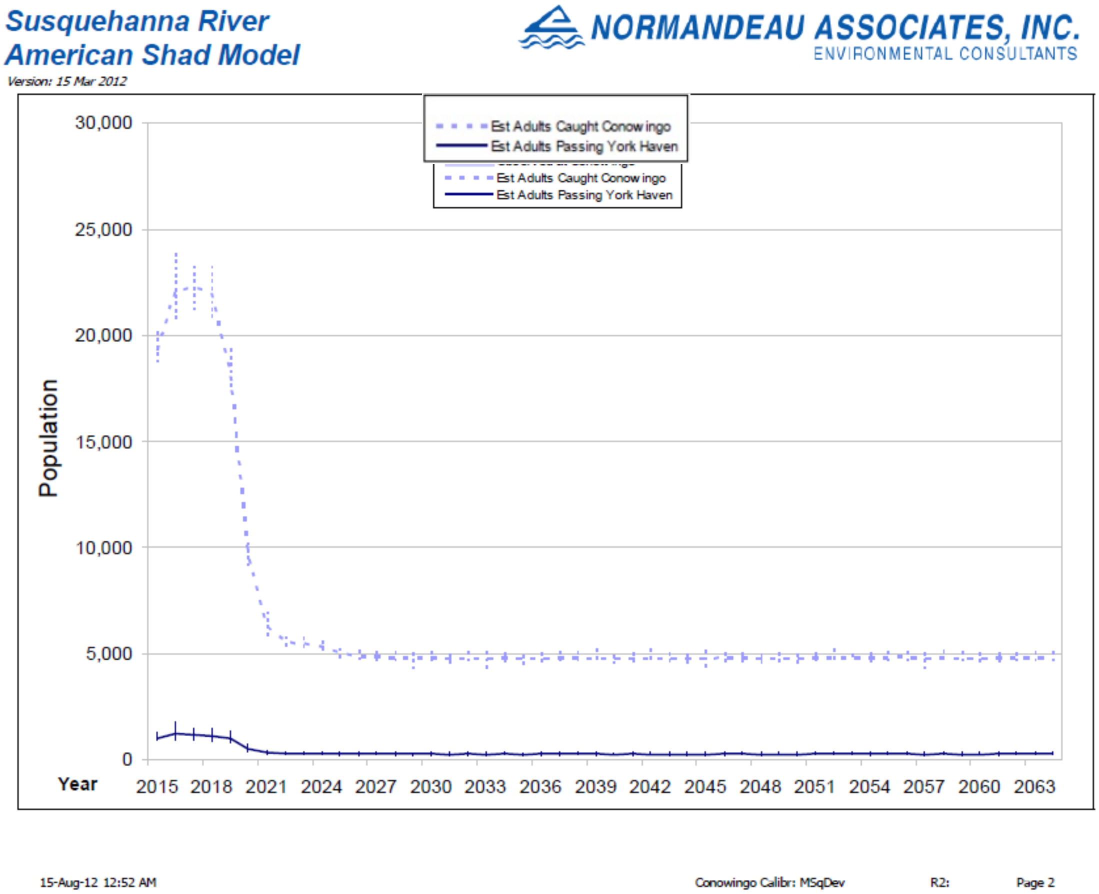


FIGURE 3.2-4: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 1-HIGH: WITH HIGH INPUT VARIABLE SET AND HIGH JUVENILE STOCKING.

See Table 2 for variable input values.

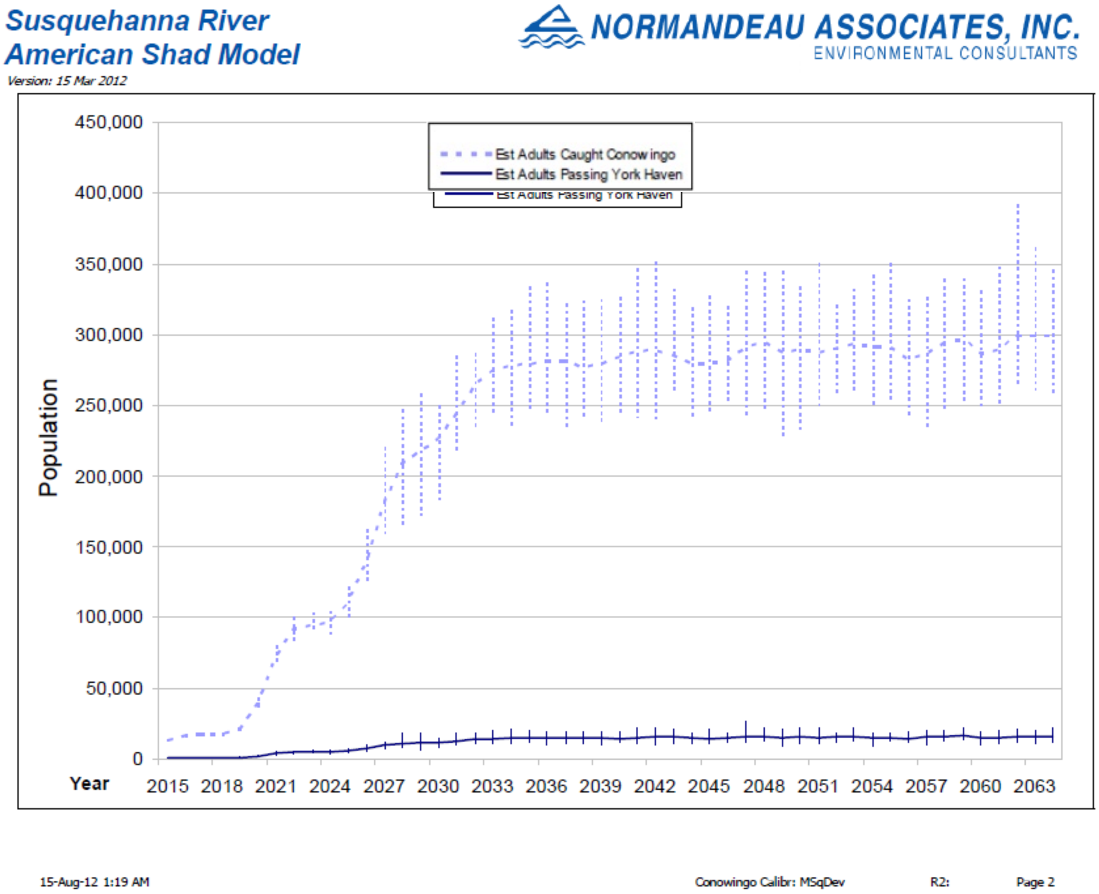


FIGURE 3.2-5: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 2-LOW: WITH LOW INPUT VARIABLE SET AND LOW (0) ADULT STOCKING (TRAP AND TRANSPORT).

See Table 2 for variable input values.

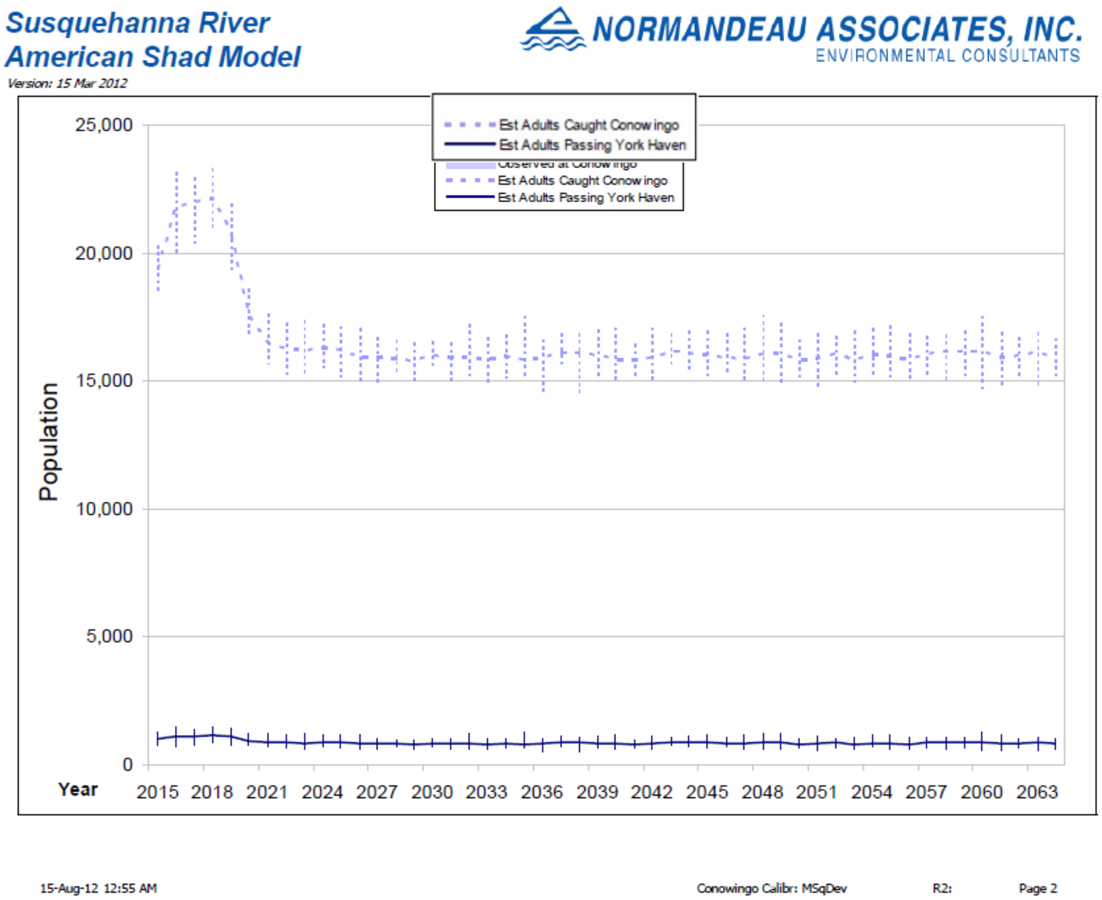
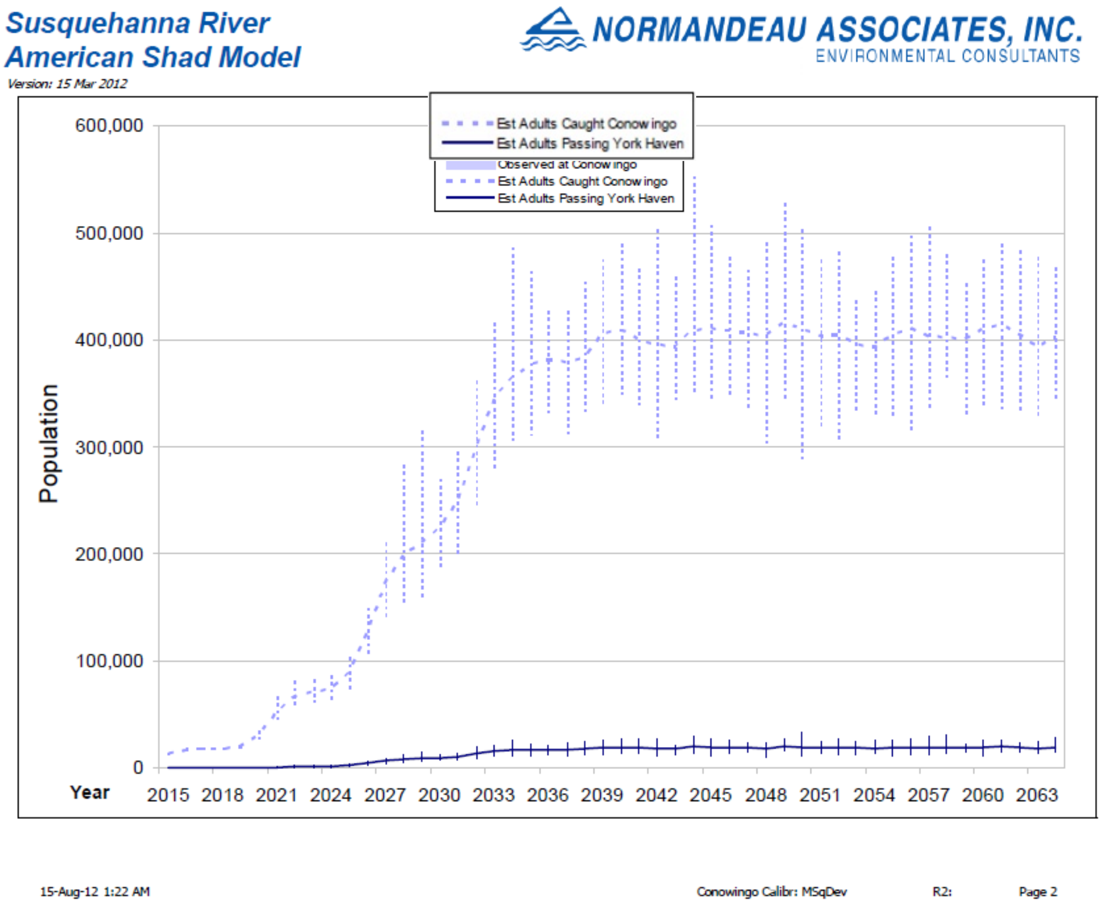


FIGURE 3.2-6: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 2-HIGH: WITH HIGH INPUT VARIABLE SET AND HIGH ADULT STOCKING (TRAP AND TRANSPORT)[9].

See Table 2 for variable input values.



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[9] Data plotted for estimated adults passing York Haven is for volitional passage only. Inclusion of spawners transported from Conowingo to above York Haven resulted in an modeled endpoint of 68,886 spawners above York Haven

FIGURE 3.2-7: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 3-LOW: WITH LOW INPUT VARIABLE SET AND LOW DOWNSTREAM PASSAGE.

See Table 2 for variable input values.

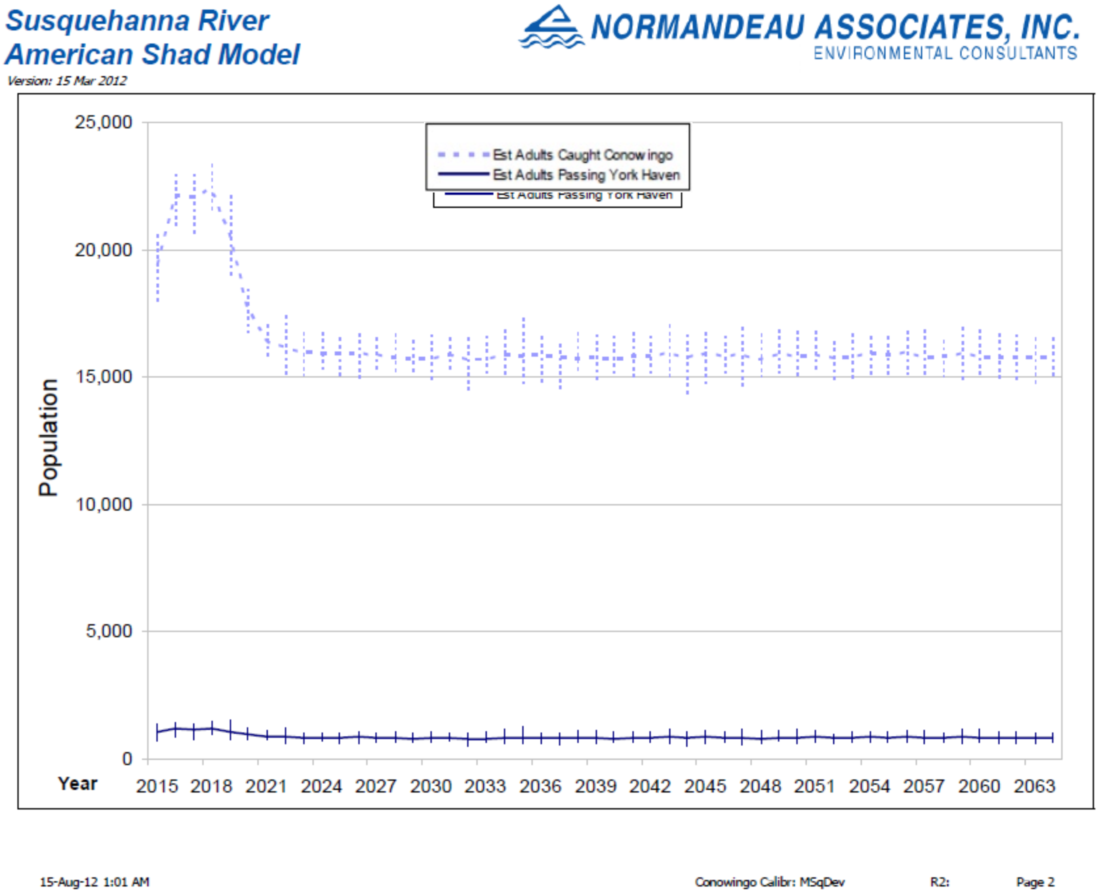


FIGURE 3.2-8: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 3-HIGH: WITH HIGH INPUT VARIABLE SET AND HIGH DOWNSTREAM PASSAGE.

See Table 2 for variable input values.

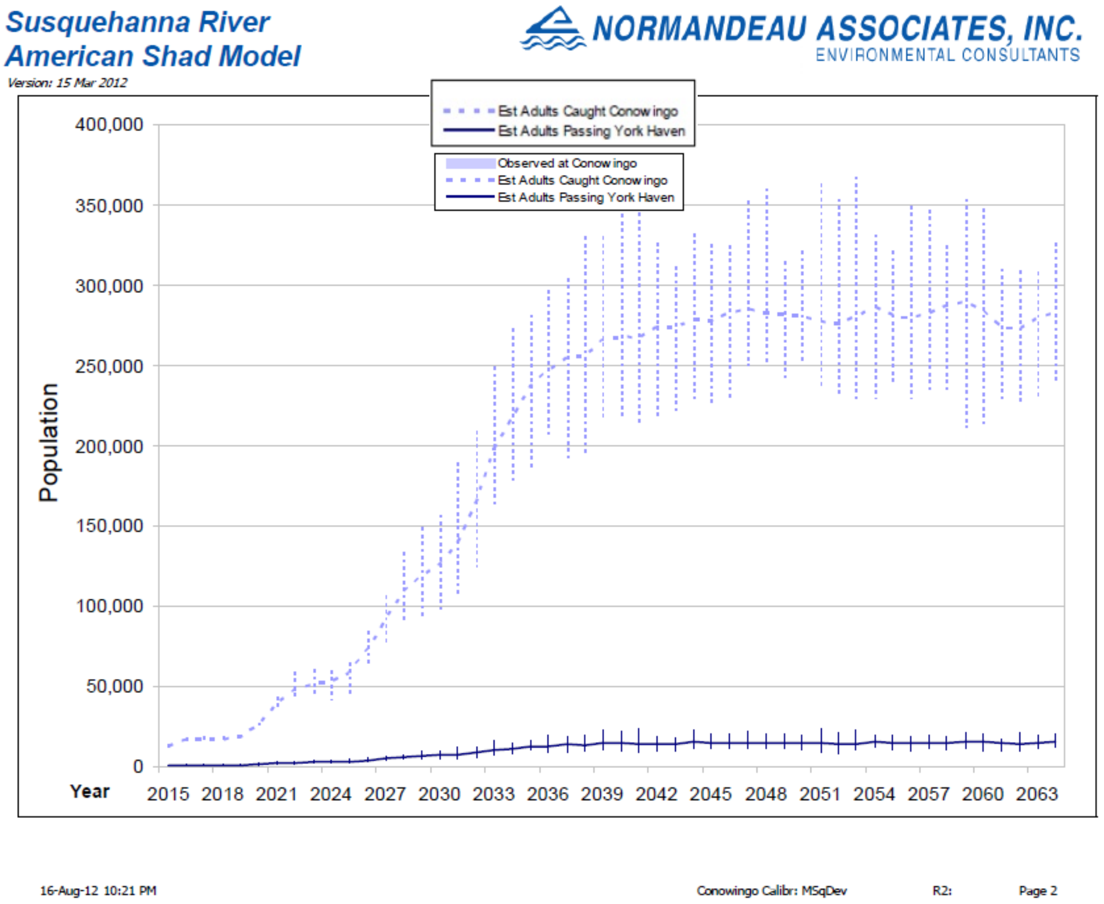


FIGURE 3.2-9: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 4-LOW: WITH LOW INPUT VARIABLE SET AND LOW UPSTREAM PASSAGE.

See Table 2 for variable input values

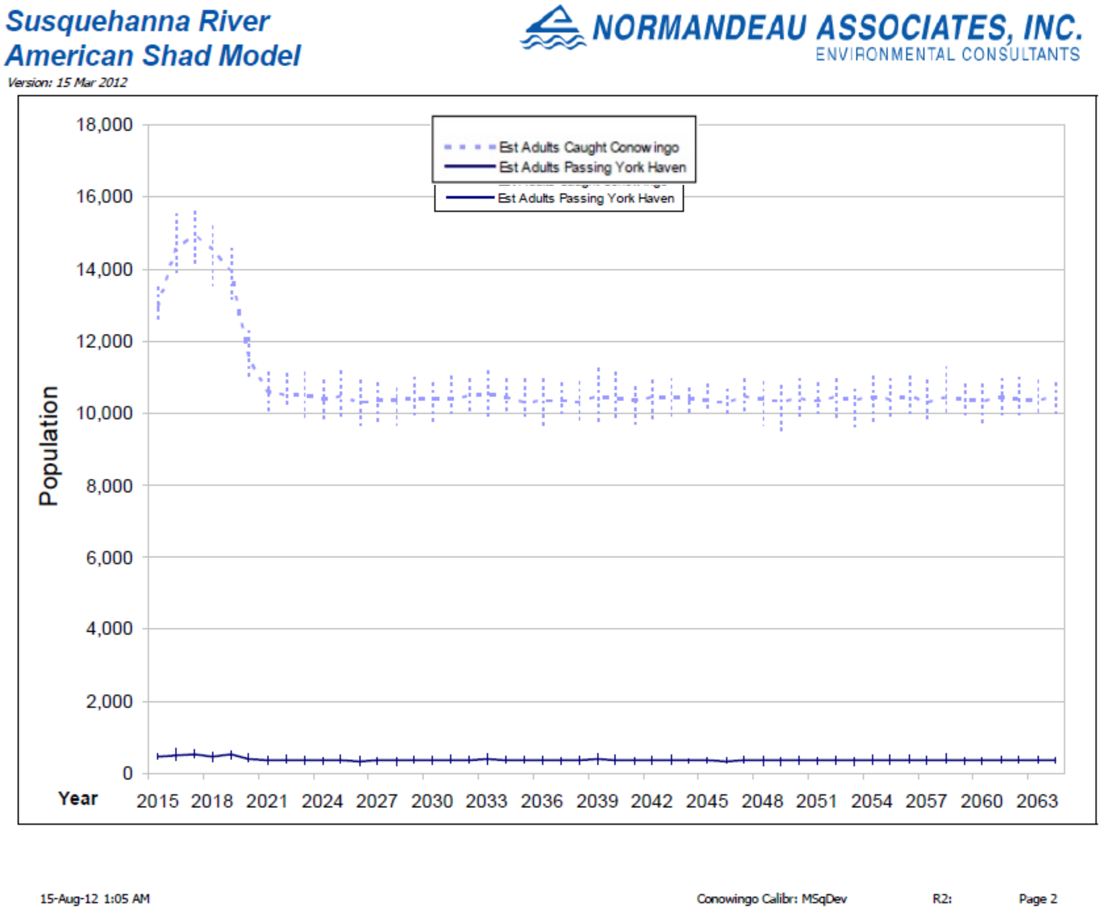


FIGURE 3.2-10: A. SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 4-HIGH: WITH HIGH INPUT VARIABLE SET AND HIGH UPSTREAM PASSAGE. B. OUTPUT LOG 10 TRANSFORMED TO ILLUSTRATE POPULATION GROWTH IN THE FIRST HAVE OF THE RUN PERIOD. See Table 2 for variable input values. Panel B shows results plotted on log scale.

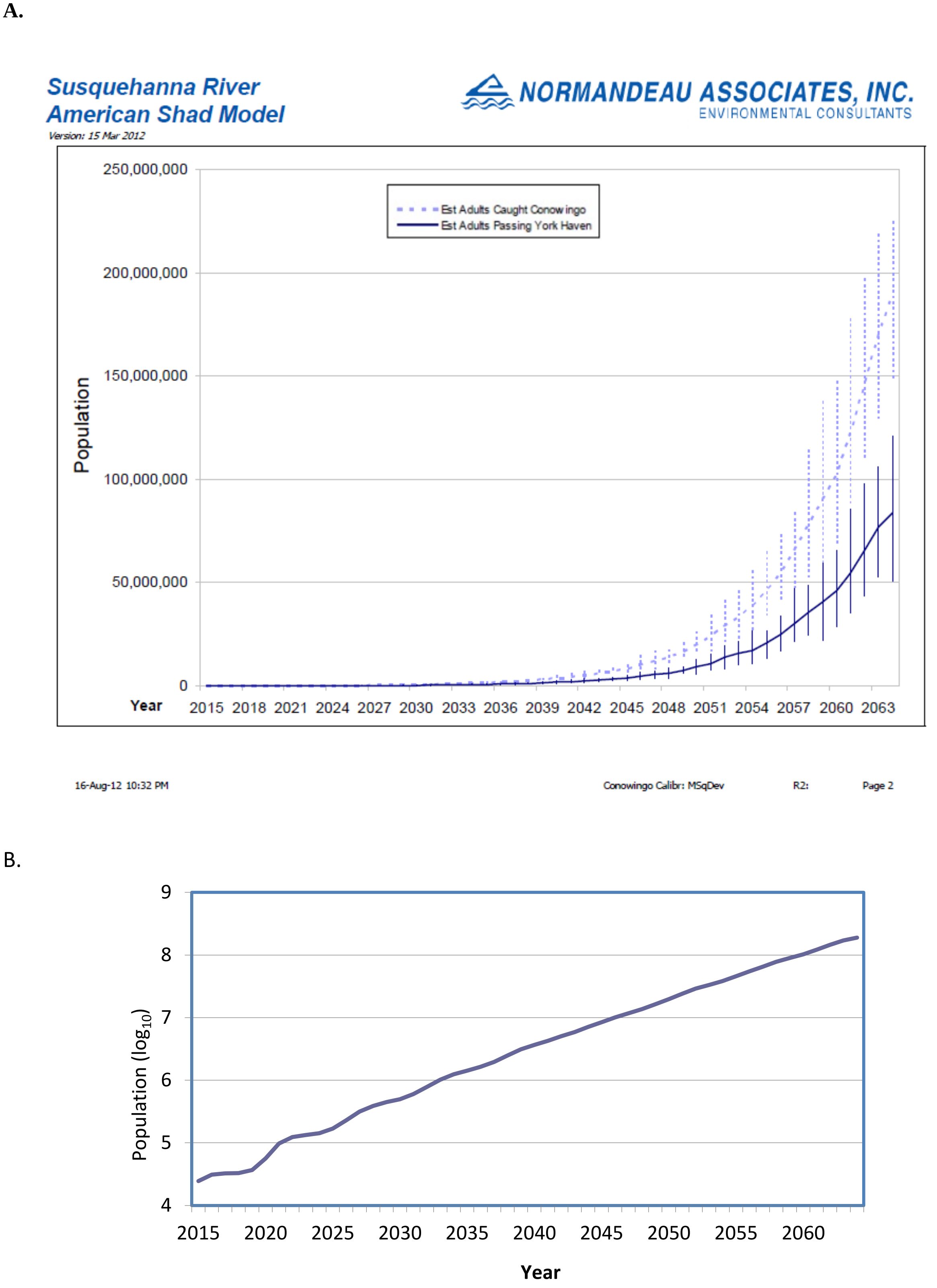
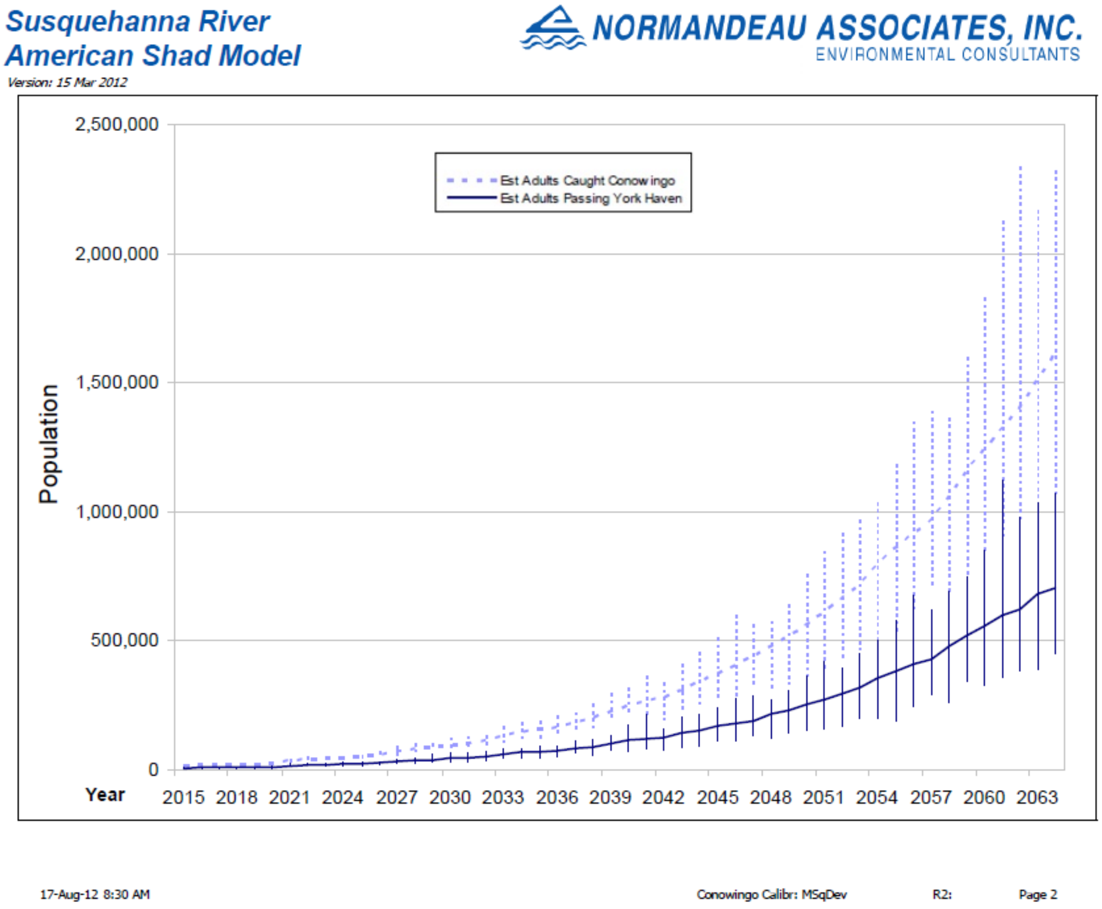


FIGURE 3.2-11: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 4.1-HIGH: WITH HIGH INPUT VARIABLE SET AND HIGH UPSTREAM PASSAGE AT YORK HAVEN.

See Table 3 for variable input values.



Susquehanna River
American Shad Model
Version: 15 Mar 2012

NORMANDEAU ASSOCIATES, INC.
ENVIRONMENTAL CONSULTANTS

17-Aug-12 8:30 AM Conowingo Calibr: MSqDev R2: Page 2

FIGURE 3.2-12: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 4.2-HIGH: WITH HIGH INPUT VARIABLE SET AND HIGH UPSTREAM PASSAGE BYPASS OF MUDDY RUN.
See Table 3 for variable input values.

Susquehanna River
American Shad Model
Version: 15 Mar 2012

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ENVIRONMENTAL CONSULTANTS

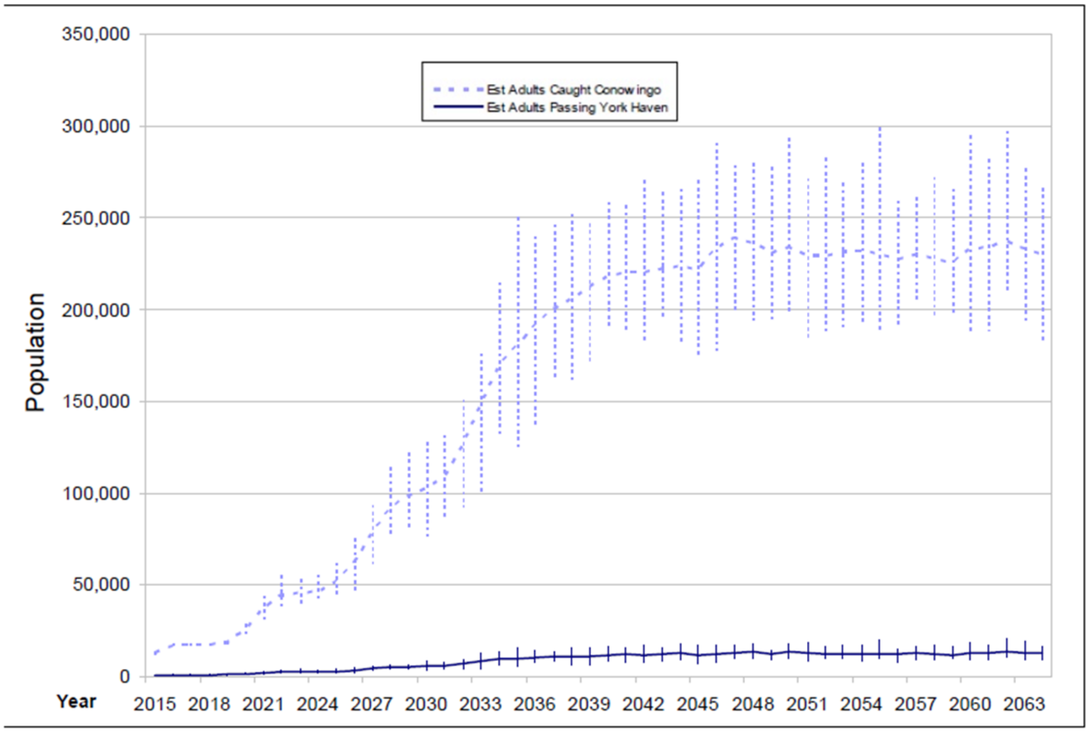

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FIGURE 3.2-13: SUSQUEHANNA RIVER AMERICAN SHAD MODEL, PRODUCTION RUN 4.3-HIGH: WITH HIGH INPUT VARIABLE SET AND HIGH UPSTREAM PASSAGE AT CONOWINGO.

See Table 3 for variable input values.

Susquehanna River
American Shad Model
Version: 15 Mar 2012

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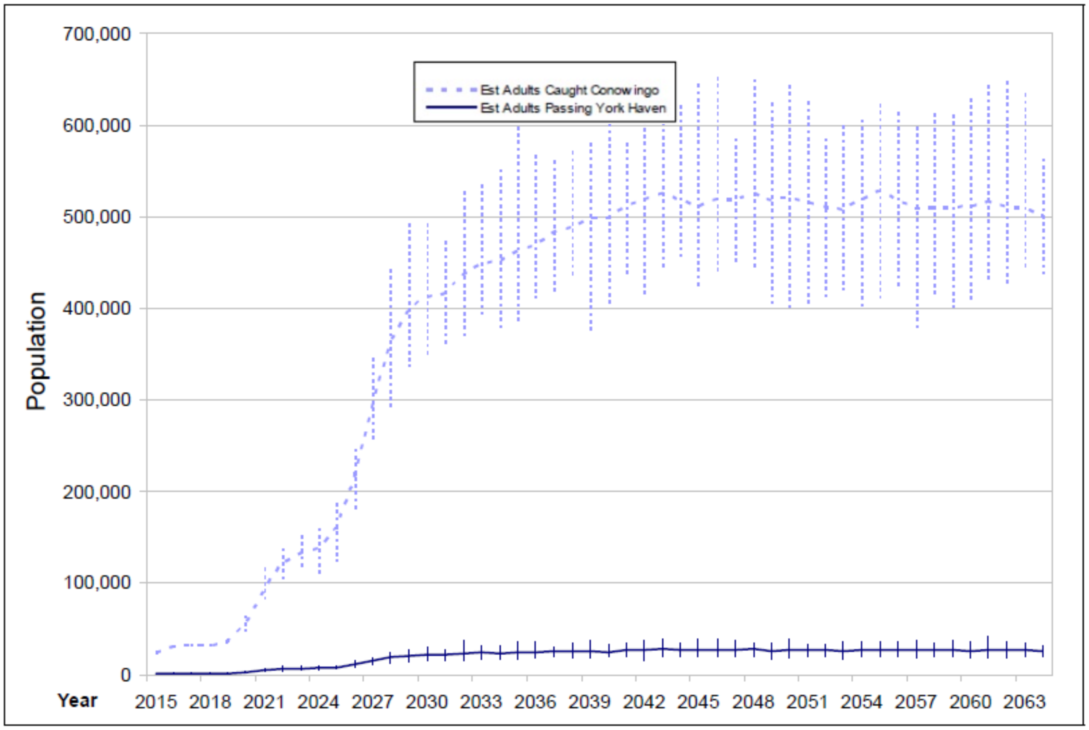

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FINAL STUDY REPORT
AMERICAN SHAD PASSAGE STUDY:
SUSQUEHANNA RIVER AMERICAN SHAD MODEL
MODEL DEVELOPMENT

RSP 3.4

CONOWINGO HYDROELECTRIC PROJECT

FERC PROJECT NUMBER 405

Prepared for:

Exelon

Prepared by:

Normandeau Associates, Inc.

Gomez and Sullivan Engineers, P.C.

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. Exelon is applying for a new license using the FERC's Integrated Licensing Process (ILP). In June, 2011 Exelon distributed a revised study plan (RSP 3.4) for a study to model the effects of restoration measures on the Susquehanna River American shad population returning to Conowingo Dam (and upstream) to spawn.

During 2011, the modeling study proceeded: existing Susquehanna River American shad data were compiled and reviewed; some potential limitations to American shad recovery that were not addressed in the modeling effort were reviewed; and an annual step numeric model was developed and refined. Potential limitations that were discussed included predation, bycatch (particularly in offshore fisheries), competition with other aquatic species for food resources, and climate change impacts.

An annual step numeric calculation model was developed in Microsoft Access software to simulate the American shad spawning population returning to Conowingo Dam and to allow for the user to alter variables to examine the population response to potential enhancement measures.

Some key features of the model include:

- Annual projections of the American shad returning spawner population to Conowingo Dam and the upper Susquehanna River.
- Deterministic output or stochasticity elements to account for life history variability
- The best available data, much of it from within the Susquehanna River Basin, including fish passage counts and relative passage effectiveness, trap-and-transport passage, larval / juvenile stocking and survival, age distribution of virgin and repeat spawners, and sex ratio**.**
- Existing data for "calibration" of assumed model parameters so that modeled estimates of the spawner population returning to and passed at Conowingo Dam are fit to the observed catch.
- The ability to examine model sensitivity to various restoration measures.
- The ability to individually examine model sensitivity to alterations of upstream and downstream passage rates at each mainstem project.
- The resolution to assess cumulative effects of projects on shad restoration.

An initial study report (ISR) was filed on January 23, 2012, containing Exelon's 2011 study findings. The deadline for formal comments on the ISR including requested study plan modifications was April 23, 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.

Data compiled in the review and in consultation with agencies and stakeholders were developed to provide baseline inputs to the model. Baseline data inputs were used to calibrate the model to observed American shad returns to Conowingo Dam. Based on agency and stakeholder input, a series of simulations were run using the model to investigate the projected effects of potential restoration measures that are feasible at the Conowingo and/or Muddy Run Projects. The output of those simulations are detailed in a separate report.

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LIST OF ABBREVIATIONS

Agencies

ASMFC	Atlantic States Marine Fish Commission
FERC	Federal Energy Regulatory Commission
MDE	Maryland Department of Environment
MDNR-PPRP	Maryland Department of Natural Resources – Power Plant Research Program
NMFS	National Marine Fisheries Service
PFBC	Pennsylvania Fish and Boat Commission
SRAFRC	Susquehanna River Anadromous Fish Restoration Committee (now Cooperative)
SRBC	Susquehanna River Basin Commission

Units of Measure

mm	millimeter
MW	megawatt

Miscellaneous

EFL	East Fish Lift
ILP	Integrated Licensing Process
MRPSP	Muddy Run Pumped Storage Project
Net R	Net Reproductive Rate
NOI	Notice of Intent
RSP	Revised Study Plan
PAD	Pre-Application Document
PSP	Proposed Study Plan
SASM	Susquehanna River American Shad Modeling
SD	Standard Deviation
Total R	Total Reproductive Rate
TL	Total Length
WFL	West Fish Lift

1.0 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. In its final study plan determination for the Project, issued February 4, 2010, FERC determined that the proposed American Shad (*Alosa sapidissima*) Passage Study (Study 3.4) was not required noting that "the information is either redundant with other studies or would not inform a decision on fish passage at the project".

In a letter filed with FERC on September 30, 2010, as the result of an agreement with Exelon, Maryland's Department of Natural Resources–Power Plant Research Program (MDNR-PPRP) and Department of the Environment (MDE) withdrew their request for a formal dispute resolution, filed with FERC February 24, 2010, regarding a number of studies. In the resolution of the disputed matters, MDNR-PRRP and MDE agreed that, "in conjunction with other resource agencies, they will, in good faith, actively participate in the development and assessment of Exelon's shad population model as set forth in section 3.4 of Exelon's revised study plan." Such participation assumed that MDNR-PPRP and MDE as well as other resource agencies, including Pennsylvania Fish and Boat Commission (PFBC) would have active involvement in the model development and implementation process, obtain regular progress updates from Exelon, and have the opportunity to comment and provide feedback throughout the implementation of the study.

In June, 2011 Exelon distributed a revised study plan (RSP 3.4) and on August 23, 2011 the study plan was presented and discussed with agencies and Stakeholders at a relicensing team meeting.

The objectives of the study were to:

- Review and compile existing information to provide input variables and ranges for modeling.
- Construct a mathematical simulation model (based on a previous model) of the Susquehanna River American shad population returning to Conowingo Dam.

An initial study report (ISR) was filed on January 23, 2012, containing Exelon's 2011 study findings. The deadline for formal comments on the ISR including requested study plan modifications was April 23, 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.

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2.0 BACKGROUND

In 1979, the Susquehanna River Anadromous Fish Restoration Committee (SRAFRC) adopted a Strategic Plan for the Restoration of Migratory Fishes to the Susquehanna River. In 2010, the plan was revised and expanded (Plan, SRAFRC 2010) to include five objectives each with a series of tasks defined as steps to achieving the overarching goal. One of the objectives was to enhance migratory fish spawning stock biomass and maximize juvenile recruitment through natural and/or artificial means. Some of the tasks identified to meet that objective included:

- Restore access to historic habitats for juvenile and adult migratory fish.
- Implement upstream passage performance measures including passage of at least 75% of adult American shad passed at the next downstream facility, or at least 85% of the adult American shad reaching project tailwaters.
- Implement downstream passage performance measures for adult alosines including at least 80% survival at each facility.
- Implement juvenile downstream passage performance measures of 95% survival of juvenile alosines at each facility.
- Enhance migratory fish spawning stock biomass and maximize juvenile recruitment.
- Stock 10 million or more hatchery-reared American shad larvae annually.
- Consider trap-and-transport stocking of adult American shad from Conowingo Dam fish lift(s) to above York Haven Dam while upstream fish passage is being improved at the Conowingo, Holtwood, and/or York Haven hydroelectric projects.

3.0 REVIEW OF EXISTING INFORMATION

Existing data were reviewed and compiled to provide baseline values for various input variables for the Susquehanna River American Shad Model (SASM). Additionally, a qualitative assessment of factors (listed below) that may affect the Susquehanna River American shad population and the population range-wide, but that will not be addressed in the population model, was included.

3.1 **Susquehanna River Shad Data**

Settlement agreements played a significant role in installation of fishways at the four dams between 1972 and 2000 (Figure 2.0-1). Exelon (then Philadelphia Electric) entered into the first agreement in 1970 resulting in the installation of the West Fish Lift at Conowingo Dam (WFL) in 1972 (initially to operate for only five years). Between 1972 and 1996, the WFL acted as a trap-and-transport facility to facilitate upstream migration of shad. The second agreement in 1988 resulted in installation of the East Fish Lift (EFL) in 1991. The EFL provided a trap-and-transport system between 1991 and 1996. Both fish lifts were used for trap-and-transport until the Holtwood and Safe Harbor projects were equipped with fish lifts. Volitional passage at Conowingo Dam via the EFL began in 1997, allowing passage of American shad and other species into Conowingo Pond. The EFL has the capacity to pass 750,000 American shad into Conowingo Pond, and it can be increased in capacity by installing a second hopper. The Conowingo fish lifts and the fishways at upstream projects have provided reasonably accurate American shad counts, as reported in annual reports of the SRAFRC (Normandeau Associates 2010, SRAFRC 2010). Annual upstream passage counts were used to calculate apparent passage effectiveness. Passage effectiveness at Holtwood, Safe Harbor, and York Haven Dams is defined as the ratio of the number of fish counted at a fish passage facility to the number counted at the passage facility of the downstream dam (Table 3.1-1). Data available for the estimation of passage effectiveness at Conowingo Dam are limited, however. A radio-telemetry study was conducted during the 2010 spawning migration season to provide those estimates (Normandeau Associates and Gomez and Sullivan Engineers 2011, SP 3.5). The study was scheduled to be continued in 2011, but exceptionally high river discharge resulted in a postponement until 2012.

Trap-and-transport stocking of spawning adult American shad was a significant measure used to implement the restoration program in the Susquehanna River prior to completion of fish passage facilities at all four lower river dams. Transfer of out-of-basin (e.g., Hudson and Connecticut rivers) American shad was conducted from 1980 through 1987, and an upstream trap-and-transport program for Susquehanna River fish was initiated in 1982 when American shad were first collected from the Conowingo WFL in sufficient numbers to justify the program. Beginning in 1991 when the EFL became operational, both lifts were used to trap fish for upstream transport until 1997 when passage from the EFL into Conowingo Pond was volitional (SRAFRC 2010). The trap-and-transport program was terminated after the 2000 season when the York Haven Dam fishway (and therefore upstream passage at all four dams) was completed. A total of 258,175 fish was transported from 1980 - 2000 (annual range 114 – 56,370, Table 3.1-2).

Stocking of fertilized eggs, fry, and fingerlings from out-of-basin rivers (e.g., Hudson, Delaware, Columbia, James, Pamunkey) and fry from Susquehanna River stock has been ongoing since 1976 with more than 212 million stocked (range 0.663 million – 13.530 million, annual mean = 6.07 million, SD = 3.67, SRAFRC 2010, Table 3.1-2). Prior to stocking at 18 days old, the ototliths of fry were marked by immersion in oxytetracycline, and subsequently estimates of the rate of return of stocked fry to Conowingo Dam as spawning adults were calculated (Sadzinski and Hendricks 2007) with mean annual rate of return from 1986 – 2002 of 0.0044 (range 0.0006 - 0.0147, Table 3.1-2).

Data for losses of adult pre-spawned American shad are limited. The annual proportions that failed to pass, that is the remaining percentage from the passage effectiveness estimates, for Holtwood, Safe Harbor, and (to a lesser, as yet unquantified, level) York Haven Dams can be considered lost to the spawning population because of lack of suitable habitat between the dams. Additionally, the rate of entrainment of immigrating adult American shad by the Muddy Run Project was estimated from radio telemetry study results to be 5.1% in 2001 (Normandeau Associates 2001a) and 3.6% in 2008 (Normandeau Associates and Gomez and Sullivan Engineers 2009). Therefore the estimated rate of migration past Muddy Run is approximately 96%. Downstream passage survival estimates were determined for emigrating post-spawned adult American shad at Safe Harbor Dam through one Kaplan unit and one mixed flow unit. The pooled 48-hour survival estimate was 86% (Normandeau Associates 1998).

Reliable downstream passage survival rates for juvenile American shad have been estimated as 93% at Conowingo Dam (RMC 1994). Similarly, in 2011, a survival rate for juvenile American shad passing through an aerated Francis unit turbine at Conowingo Dam was estimated at 89.9% with 90% confidence intervals of ≤ ± 5.5%, 90% of the time (α = 0.10, Normandeau Associates and Gomez & Sullivan Engineers 2012a). Downstream passage survival rates for juvenile American shad have also been estimated at 67-80% for Holtwood Dam (RMC 1992), 97% for Safe Harbor Dam (RMC 1991, Heisey et al. 1992) and 77-93% for York Haven Dam (Normandeau Associates 2001b). In 2011, juvenile American shad entrainment at MRPSS was examined using radio telemetry techniques. The calculated study entrainment rate inclusive of all telemetered shad that passed MRPSS during all operating conditions (pumping, generating, and idle mode) was 9.4 %. A pumping entrainment rate of 22.6% was estimated for telemetered shad that encountered the zone of influence at the MRPSS during pumping mode only. The estimate of population entrainment rates that could actually be vulnerable to entrainment at MRPSS during peak emigration times (1700-2200 hrs), ranges from 2.9% to 6.6%. The population entrainment rate is likely more representative of typical fall juvenile shad emigration based on emigration behavior and operations of MRPSS (Normandeau Associates and Gomez and Sullivan Engineers 2012b).

Age frequency distribution, repeat spawner frequency, and sex ratio data from Conowingo fish lift samples are available (M. Hendricks, PFBC, unpublished data, Sadzinski and Hendricks 2007, Jarzynski and Sadzinski 2009) and are discussed in Section 4.

3.2 **Other Factors That May Affect the Susquehanna River American Shad Stock**

There are many factors that may affect the Susquehanna River American shad population that are not explicitly addressed in the model. These are factors that may be conceptual (relationships are poorly defined, data inadequate to incorporate their effects as model elements) or processes that largely occur outside of the Susquehanna River system.

3.2.1 Predation

American shad are prey for many species. In the ocean, American shad are likely preyed upon by many species of fish, marine mammals, and seabirds (Greene et al. 2009). Inshore, it has been suggested that striped bass (*Morone saxatilis*) predation may limit the American shad population. In the Connecticut River, Savoy and Crecco (2004) related reduced alosine abundance to increased striped bass abundance, and Crecco et al. (2007) reported that adult striped bass preyed on small mature American shad in the Connecticut River. Later, Davis et al. (2011) estimated that striped bass consumed almost 100,000 American shad (95% CI = 3,541 – 159,688) between Hartford, Connecticut and the Massachusetts/Connecticut border in May 2008. Although only a relatively small portion of the striped bass population (4%) was found to be feeding heavily on American shad, they were the most prevalent diet item in ≥ 900 mm total length (TL) striped bass. In other systems, however, no such relationship has been determined. Studies including extensive analysis of striped bass gut contents concluded that predation by striped bass was not an issue regarding American shad abundance in the Hudson River (ASMFC 2007a). Off of the Virginia and North Carolina coasts, alosine species were minor contributors to the diet of striped bass (Overton et al. 2008), and American shad were not included in the stomach contents of striped bass during a Chesapeake Bay study completed from 1998 to 2001 (Overton et al. 2009).

Species other than striped bass prey on American shad in river and estuarine systems as well. Erkan (2002) noted that the double-crested cormorant (*Phalacrocorax auritus*) often feed on American shad staging near fishway entrances in Rhode Island. Ross and Johnson (1997) modeled predation rates on fish by cormorants in eastern Lake Ontario at an estimated number of fish consumed ranging from 37 to 128 million annually. Though American shad did not reside in that system, the related alosine fish, alewife (*Alosa pseudoharengus*), was the principal species consumed.

Non-native piscivorous fishes in the Susquehanna River including smallmouth bass (M*icropterus dolomieui*), walleye (*Sander vitreum*), and flathead catfish (*Pylodictis olivaris*) have the potential to impact American shad abundances. Brown et al. (2005) noted that flathead catfish reproduction has been documented in the Susquehanna, Potomac, and Delaware River systems and suggested that the species could jeopardize efforts to restore American shad. Kwak et al. (2004, cited in Brown et al. 2005) demonstrated that flathead catfish actively feed on juvenile and adult American shad, and Bauman and Kwak (2011) analyzed the diet of flathead catfish in the Cape Fear River Basin, North Carolina where they found that feeding was opportunistic on prevalent prey. Although American shad did not occur in their study area, the clupeid gizzard shad (*Dorosoma cepedianum*) was the second most prevalent food item by weight.

American shad eggs and larvae are preyed upon by American eels (*Anguilla rostrata*) and striped bass (*Morone saxatilis*, Walburg and Nichols 1967). American shad larvae that were stocked in the Susquehanna River at high rates may have resulted in increased predator aggregation at the release site, but despite consumption of up to 900 American shad larvae by individual predators, mortality of larvae at the stocking site was usually less than 2%; a value that the authors considered to be insignificant (Johnson and Ringler 1998).

3.2.2 Bycatch

Bycatch in commercial fisheries is a threat of significant concern for American shad populations. Significant bycatch primarily occurs in coastal ocean trawl fisheries for Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*) and squids (Miller 2010). In Amendment 3 to the fishery management plan for shad and river herrings, ASMFC (2010) identified concerns over quantifying and effectively managing the bycatch mortality, both in state waters as well as in federal jurisdiction waters (U.S. Exclusive Economic Zone) by cooperation with the National Marine Fisheries Service (NMFS) and the regional Fishery Management Councils as a restoration tool. In Chesapeake Bay, bycatch can occur in the commercial striped bass fishery in Virginia and in pound net fisheries bay-wide with unknown effects on survival or migration (Tuckey 2009).

3.2.3 Competition

Competition with other aquatic species for food resources could impact American shad abundances. For example, gizzard shad populations increased dramatically in the mid-20th century as broad based ecological changes provided a potential increase in suitable habitats (Miller 1960). Gizzard shad thrive in warm, shallow bodies of water that have a soft mud bottom, high turbidity, and relatively few predators. Competition with gizzard shad for the same food sources in the Susquehanna River may constitute another factor that has delayed the recovery of American shad stocks (Klauda 1991). Gizzard shad in early life stages consume zooplankton, often to the detriment of other young fishes (Normandeau Associates 1994). Conowingo Dam WFL data indicate that a fish assemblage consisting of white perch (*Morone americanus*), blueback herring (*Alosa aestivalis*), channel catfish (*Ictalurus punctatus*), gizzard shad and other species in the 1970's has become increasingly dominated by gizzard shad over time. Additionally, it has been noted that at times the overabundance of gizzard shad appears to impede the ability for American shad to enter and utilize the Conowingo fish lifts effectively (SRAFRC 2010). Larval striped bass may also be competitors to larval American shad for prey resources. Though the presence of larval striped bass is limited in the upper Chesapeake Bay and lower Susquehanna River (Normandeau Associates 2011), many studies have noted that American shad and striped bass prey upon similar species during early life stages and may compete for food resources (Bilkovic 2000).

Another potential source of competition for food resources is the invasive zebra mussel (*Dreissena polymorpha*), which was confirmed in the lower Susquehanna River in 2010 and upstream of Conowingo Dam in November 2008 (MDNR 2010). Strayer et al. (2004) found that rapid and pervasive declines in phytoplankton linked to invasion of the Hudson River by zebra mussels was associated with some declines in abundance, decreases in the growth rate of young-of-the-year, as well as spatial shifts in habitat use of American shad.

3.2.4 Climate change

Climate change is another factor that has been identified as potentially impacting early life stage and adult abundance of American shad. ASMFC (2010) stated that as climate changes occur, habitat modification is expected. Those changes could result in: fluctuations in large-scale distribution patterns; temperature changes that could negatively impact spawning and egg and larval survival; reduction in suitable habitat due to reduced dissolved oxygen concentrations; and rising sea level could result in flooding of spawning and rearing habitats. To date, these effects are largely hypothetical and their magnitude is unknown.

4.0 SUSQUEHANNA RIVER AMERICAN SHAD MODEL (SASM)

4.1 **Introduction**

A mathematical simulation model of the Susquehanna River American shad population was constructed to provide a tool to evaluate the effects of existing and potential restoration measures on the Susquehanna River shad population and prioritize improvements based on their likelihood of resulting in an increase in the population and the relative magnitude of that increase. Interpretation of population simulations selected with careful consideration will aid in determination of measures that provide the most beneficial effects while avoiding potentially ineffective measures.

Past efforts have been made to model the upper Susquehanna River spawning population of American shad (Mathur and Bason 1987; Brush et al. 1988, Dumont and Foote 1993), but they did not have the benefit of incorporating a long time series of baseline data including passage data from fishways, stocking records, and population characteristics. Those data are now available and can be used for validating the model, resulting in less speculative predictions. Also, in those earlier efforts, the stock-recruit or reproductive rate was fixed over time for a given simulation. Environmental variability may greatly influence the stock-recruit relationship (Crecco and Savoy 1984; Crecco et al. 1986; Crecco and Savoy 1987; Lorda and Crecco 1987), thus it may not be appropriate to select a fixed annual value for important effects of environmental parameters on recruitment.

Key features of the model include:

- Annual projections of American shad returning spawner population to Conowingo Dam and the upper Susquehanna River.
- Deterministic output or stochasticity elements to account for life history variability.
- The best available data, much of it from within the Susquehanna River Basin, including fish passage counts and relative passage effectiveness, trap-and-transport passage, larval / juvenile stocking and survival, age distribution of virgin and repeat spawners, and sex ratio.
- Existing data for "calibration" of assumed model parameters so that modeled estimates of the spawner population returning to and passed at Conowingo Dam are fit to the observed catch.
- The ability to examine model sensitivity to various restoration measures.
- The ability to individually examine model sensitivity to alterations of upstream and downstream passage rates at each mainstem project.
- The resolution to assess cumulative effects of projects on shad restoration.

4.2 **Methods**

4.2.1 Model Development

An annual step numeric calculation model was developed in Microsoft Access software to simulate the American shad spawning population returning to Conowingo Dam and to allow the user to alter certain variables to examine the population response to potential enhancement measures. The model incorporates an age structure for virgin and repeat-spawning females. Upstream and downstream passage proportions are modeled at each of five hydroelectric facilities along the lower Susquehanna River (Conowingo Dam, Muddy Run Pumped Storage Project - MRPSP, Holtwood Dam, Safe Harbor Dam, and York Haven Dam; Figure 2.0.1). The model also allows for annual stocking of hatchery juvenile shad and for upstream transport/stocking of adult American shad collected at Conowingo Dam. An optional stochastic variation component can simulate annual variations in upstream passage success and reproductive rate. All model variables can be specified by the user, and some can be specified at the annual detail level (to allow for short-term restoration measure strategies or observed historical values for specific years). The starting "year" and length of simulation can be specified, as can a "starting population". The model output is a graph and table of annual predicted numbers of fish returning to various points in the lower Susquehanna River system.

The model platform (Figure 4.2-1) functions as a user 'dashboard' with inputs for:

- Upstream adult passage effectiveness at each of five hydroelectric facilities along the lower Susquehanna River. The complement of an estimated entrainment rate at MRPSP was considered to be a passage rate for that facility.
    - The proportion of the population successfully passed above York Haven Dam is automatically calculated from the user inputs for passage effectiveness.
- Downstream juvenile passage effectiveness at each facility.
    - The proportion of juveniles passed to below Conowingo Dam is automatically calculated from the user input values for downstream passage effectiveness.
- Proportion of females in the spawner population.
- Net reproductive rate (Net R) defined as the number of progeny of a female that will survive to eventually return to Conowingo Dam as a spawner.
- Age distribution of first spawning females, age distribution of repeat spawning females (represented proportional to the total number of females – first and repeat spawning).
- Trap-and-transport option including minimum, maximum, and proportion of Conowingo fish lift catch transported to upstream of York Haven Dam.
- Annual hatchery reared stocking contribution.
- Estimated survival of juveniles to return as adult spawners.
- Success factor for spawning below York Haven Dam, defined as the proportion of the population that passed Safe Harbor but did not pass York Haven that may successfully reproduce.

The total reproductive rate (Total R), defined as the proportion of Net R that are passed above York Haven Dam, is automatically calculated from the input variables. Additionally, the start year, number of years to simulate, and starting population are user defined. An annual input override table is included to incorporate existing annual data for adult trap-and-transport stocking numbers (1980 - 2000), annual hatchery stocking contributions (1980 – 2010), juvenile survival to return as spawning adult values (1986 – 2002), and observed passage for each of the four dams (1980 – most recent observation).

The model can be used deterministically, where one output value is produced for each year specified as a result of the suite of input variables, or in an iterative simulation to produce a predicted outcome range by invoking built-in stochastic variability estimators. Those are included for overall fish passage effectiveness and for Net R and allow for user specified number of trials per simulation. Each trial will randomly select a value for the variable for which the variability estimator has been selected from a defined distribution, resulting in a quasi-Monte Carlo simulation.

After each simulation run, the model outputs results in both graphical and tabular format (Figure 4.2-2) and the dashboard includes a feature to export data in spreadsheet format or to output a full report format that includes input variables and data as well as annual output in graphical and tabular form. Additionally, any annual step can be examined, including input, intermediate calculations, and output at each geographical point of reference (Figure 4.2-3).

4.2.2 **Some Model Attributes and Assumptions**Calculations are done at an annual step.

- Age structure and spawning numbers apply to females only; the model assumes that sufficient males will be available for successful reproduction.
- Recruitment of future adult fish from the current spawning population is based on a single net reproductive rate (future returning adults per spawning female).
- All adults returning to Conowingo Dam are intent on upstream migration to spawn above York Haven Dam.
- No spawning will occur between Conowingo Dam and Safe Harbor Dam.
- Limited spawning and reproduction may occur between Safe Harbor Dam and York Haven Dam in a 13-mile section of riverine habitat downstream of York Haven Dam (see Section 4.4.1).

  All adult females reaching the river above York Haven Dam will spawn successfully.

4.2.3 Preliminary Sensitivity Analysis

Initial sensitivity analyses of several input parameters to the SASM were conducted by holding the values of all but one parameter constant and noting the effect on model predictions by varying the one parameter over a range of values. The model was run starting with 10,000 adults at year 2020 (beyond all entered annual override values) for 30 years; the predicted number of adult fish returning to Conowingo Dam in year 2049 was used as the model output index. In this configuration, the model essentially produces an exponential growth estimate. For the examined parameters, either a power function or an exponential function provided a reasonably good fit to the 30-year result endpoint against the input values of the parameter. The exponential coefficient of the fitted function can be used to compare the model sensitivity among the various parameters.

Net R, Net upstream, and Net downstream passage rates

These input parameters are all related, in that net (all facility) upstream and downstream passage rates are applied in the model as attenuating factors on Net R. Sensitivity runs for each parameter were performed using a variety of set values for the other two. While the absolute range of results varied, depending on the combination of input parameters, the sensitivity response to changing values of each parameter was very similar, and quite high, for all three (Figures 4.2-4, 5, 6).

Repeat Spawning Proportions

This analysis was conducted at two values of Net R (8.0 and 12.0) with net upstream and downstream passage rates set at 0.5 and 0.8, respectively. The parameter “proportion of age 4 spawners returning at age 5” was tested at levels varying from 0.12 to 0.45. For each run, this value was divided by three for the “age 5 returning at age 6” proportion, and then further reduced by half for “age 6 returning at age 7” (e.g., 0.45, 0.15, 0.075). While increasing the proportions of repeat spawners did also increase the 30-year results endpoint, the increases were much less dramatic than with the Net R parameters. The sensitivity estimates were similar at the two levels of Net R (Figure 4.2-7).

Proportion Spawning Below York Haven

This analysis was conducted at two different levels of Net R (8.0 and 12.0), a net downstream passage rate of 0.8, and two different levels of upstream passage: 0.52 (representing 0.85 passage at four dams) and 0.31 (representing 0.85 passage at the first three dams, and 0.50 passage at York Haven). An exponential function provided a better fit than a power function for this analysis. In this case, the model did not show a strong sensitivity to variation in the proportion spawning below York Haven when passage at York Haven was high; however, lowering the York Haven passage rate did substantially increase sensitivity to the York Haven spawning proportion. Sensitivities were similar at both tested values of Net R (Figure 4.2-8).

4.3 **Baseline Data**

Baseline data were synthesized to derive initial model inputs from which to calibrate the model for key input parameters including: upstream and downstream passage effectiveness, spawning stock (trap-and-transport stocking) and hatchery reared early life stage (fry and fingerling) stocking, and population dynamics information.

4.3.1 Upstream Passage Effectiveness

Upstream passage effectiveness was derived for each of the five hydroelectric facilities along the lower Susquehanna River; the four dams have fish passage facilities in place, and the pumped storage project is a potential diversion to migrating fish. Annual American shad passage counts were compiled for the period of volitional passage, 1997 – 2010 (Normandeau Associates 2010, SRAFRC 2010, Table 3.1-1, Figure 4.3-1). Upstream passage effectiveness for Holtwood, Safe Harbor, and York Haven Dams was defined as the proportion of fish passing each dam that had passed the next downstream, and the overall means for each project were used for baseline values. For MRPSP, a baseline value of 96% was derived from radio telemetry studies that demonstrated entrainment of 5.1% and 3.6% of immigrating adult American shad (passage = 94.9% and 96.4%) in 2001 and 2008 (Normandeau Associates 2001a, Normandeau Associates and Gomez and Sullivan Engineers 2009), respectively. Passage effectiveness at Conowingo Dam was estimated as 45% by radio-telemetry studies conducted during the 2010 spawning migration season (see RSP 3.5). That study was limited (and is planned to be repeated in 2012) and the passage rate may be an underestimate; however, it will be used as a baseline value for model calibration.

Baseline values for upstream fish passage effectiveness:

- York Haven = 10%
- Safe Harbor = 72%
- Holtwood = 33%
- Muddy Run = 96%
- Conowingo = 45%

4.3.2 Downstream Juvenile Passage Survival

Downstream passage survival rates have been examined for juvenile American shad using Hi-Z Turb ‘N Tag methods at each dam (see Section 3.1), resulting in survival estimates ranging from 67 - 97%.

- York Haven = 77-93%, median = 85%
- Safe Harbor = 97%
- Holtwood = 67-80%, median = 74%
- Muddy Run = 93.4-97.1%
- Conowingo = 93%

4.3.3 Population Dynamics

First Spawning Proportions

The baseline age frequency distribution values for first spawning female American shad was derived through a collaborative process with Stakeholders and was based on empirical age frequency distributions for fish collected in the Susquehanna River, Conowingo WFL and the Lehigh River (unpublished data, M. Hendricks, PFBC, Figure 4.3-2):

- age 4 = 16%
- age 5 = 44%
- age 6 = 31%
- age 7 = 9%

Repeat Spawning Proportions

Empirical data including the distribution of repeat spawning female American shad by age group were available in Sadzinski and Hendricks (2007) for 2000 – 2005, and were adapted for the model by calculating the percentage of repeat spawners and condensing to three age groups (age 5, 6, 7) for a total of 24% repeat spawners. The observations (age distribution and spawning check analysis from fish scales) provided annual proportions of the total returning population that were repeat spawners. However, those proportions include fish returning as repeat spawners and the fish returning for the first time. In the model the annual proportions of repeat spawners are effectively an output value (result). The input for model calculations is the proportion of fish at age X (4, 5, 6) from returns in year Y that will return again in year Y+1 at age X+1 (ages 5, 6, and 7). Unlike the age frequency distribution of first spawners, those values do not sum to 100% since not all spawners will survive to return. While we have no way to directly observe the proportion, we can use the model to estimate input values that will generate annual results approximating the frequency of repeat spawners estimated from the empirical data. The observed data were first input into the model and then increased proportionally in iterative simulations until the output was equivalent to empirical observations. The baseline input frequency distribution of repeat spawning female American shad (Figure 4.3-2) required adjustment by a factor of 3.75:

- age5 = 10%, adjusted = 37.50%;
- age 6 = 9%, adjusted = 33.75%;
- age 7 = 5%, adjusted = 18.75%.

Sex Ratio

The baseline input value for sex ratio of spawners returning to Conowingo Dam was derived from the empirical data as well. The ratio has varied over time; Sadzinski and Hendricks (2007) reported a range of 30-60% females sampled from the Conowingo WFL from 1993-2005. The mean annual proportion of females for that period will be used for the baseline value:

- Female proportion of spawners = 46%

4.3.4 Brood Stock and Early Life Stocking

The number of adult spawners released to the Susquehanna River was compiled, including out-of-basin transfers (1980-1987), trap-and-transport operations from the Conowingo fish lifts (1982-2000), and fry and fingerling stocking data (1976-2010) (Table 3.1-2, SRAFRC 2010). Numbers of adult spawners transported will only be included as empirical annual data for baseline model calibration; the default value for all other years will be 0.

The overall mean number of hatchery-reared fish released from 1976 through 2010 is 6.06 million (SD = 3.62). However, hatchery production and stocking increased significantly after the first few years of the program; from 1980 – 2010 the mean was 6.7 million, and that number will be used for the baseline value. Additionally, annual estimates of survival of stocked larvae returning to Conowingo Dam as spawners were obtained from annual SRBC reports for 1986-2002, yielding a mean survival to return rate of 0.0044.

- Number of larvae stocked = 6,700,000
- Rate of return for stocked larvae = 0.0044

4.4 **Model Application**

As of December 2011, coordination with Stakeholders was ongoing to develop appropriate ranges for input values and requested ‘production simulations’ (to be completed during 2012).

4.4.1 Input Value Ranges

During October – December, 2011 a series of meetings and teleconferences with Exelon and Stakeholders regarding the determination of fixed values or range extremes for certain model inputs was conducted. The intent of that process was to develop input values based on the best available information that would bracket the expected range of input values for variables that will not be examined as potential restoration measures in this study. The input ranges could then be applied to develop a matrix of desired simulation runs based on evaluation of a desired restoration measure. The input variables that were assigned prior to developing ‘production simulation runs’ included age frequency distribution of first spawning females, frequency and age distribution of repeat spawning females, sex ratio of returning adults, and the proportion of fish that pass Safe Harbor Dam but fail to pass York Haven Dam and subsequently spawn successfully below York Haven. Specific input values or ranges (high and low) developed through that process are presented below. These model inputs will be set for all production runs to the specified value or range of values.

Upstream Passage Effectiveness at Safe Harbor and Holtwood Dams

The input values for upstream passage effectiveness (measured as the mean annual proportion of fish that passed the next downstream project) will be fixed for these two projects. The default value for Safe Harbor will be the long-term mean passage (1997 – 2010), and for Holtwood will be the target passage goal stipulated in the Holtwood License Amendment Order and Pennsylvania 401 Water Quality Certification (October 30, 2009):

- Safe Harbor = 72%
- Holtwood = 75%

Juvenile Downstream Passage Effectiveness / Survival at Safe Harbor and Holtwood Dams

Downstream passage survival will be fixed for these two projects. The default values for Safe Harbor will be the estimated short-term turbine passage survival estimates for Kaplan and mixed flow units (Heisey et al. 1992), and for Holtwood will be the target passage goal stipulated in the Holtwood License Amendment Order and Pennsylvania 401 Water Quality Certification (October 30, 2009):

- Safe Harbor = 97%
- Holtwood = 95%

Age Frequency Distribution of First Spawning Females

High and low range inputs for age frequency distribution were adapted from empirical annual frequency distributions for American shad females sampled from the Susquehanna River at Conowingo Dam from 1995 - 2011 and from the Lehigh River from 1999 – 2010 (see Section 4.3.3). The low and high range distributions were derived by D. Pugh (American Rivers) and agreed upon by representatives of the agencies and Stakeholders via email correspondence. The annual age frequency distribution data for Susquehanna and Lehigh Rivers were filtered to eliminate any annual distribution where the number of samples was <50. Derivation of the age frequency distribution ranges included calculation of descriptive statistics for each age-group among all sample years and, where necessary (e.g., SD larger than the mean proportional contribution of a specific age class) selected from the observed distribution. For the low-range distribution, the proportional contribution for age 4 was the mean % at age + 1.5 SD; at age 6 was the mean %– 1 SD; age 7 was selected from the empirical distribution and age 5 was the remainder (total = 100%). This method allowed for selection of a reasonable distribution that was weighted toward the younger (age 4 and 5) age classes. For the high-range distribution, the proportional contribution of age 4 and 5 was the mean % at age – 1 SD; age 7 was selected from the empirical distribution and age 6 was the remainder. This produced a reasonable distribution that was weighted toward the older (age 6 and 7) age classes. Low and High range distributions (%) for first spawning female American shad are presented in Table 4.4-1.

Frequency and Age Distribution of Repeat Spawning Females

Based on the observed mean frequency of repeat spawners (24%, see Section 4.3.3), the low and high ranges, 10 and 30%, were selected to bracket that value, and then adjusted to account for increased fecundity with age or size of spawners. It is important to explain that empirical observations (age distribution and spawning check analysis from fish scales) provide annual proportions of the returning population that are repeat spawners. However, those proportions depend not only on the number of fish returning as repeat spawners, but also the number of fish returning for the first time. In the model representation, those proportions are an annual output (result) not a model input. The input for model calculations is the proportion of fish at age X (4, 5, 6) from returns in year Y that will return again in year Y+1 at age X+1 (ages 5, 6, and 7). While we have no way to directly observe this proportion, we can use the model to estimate input values that will generate annual results approximating the expected or desired range (see Table 4.4-2 for detail).

To determine appropriate inputs, the low and high range values were first adjusted to incorporate age-based fecundity estimates and then the model was used to estimate the appropriate inputs that would be required to yield those outcomes. To determine the age-based fecundity adjusted values, the age-frequency distribution of repeat spawners (24% ,see Section 4.3.3) was adjusted up or down to derive the low (10%) and high (30%) total frequency distributions. For the low range, the proportions were adjusted by a factor of 0.42 (10% / 24% = 0.42), and for the high range, the proportions were adjusted by a factor of 1.25 (30% / 24% = 1.25) resulting in:

Low = 10%: adjusted frequency distribution =

- age-5 = 4%
- age-6 = 4%
- age-7 = 2%

High = 30%: adjusted frequency distribution =

- age-5 = 13%
- age-6 =11%
- age-7 = 6%

To incorporate age-based fecundity, age increment adjustment factors were calculated from the age-specific fecundity data for the York River, VA of Hattala et al. (*in* ASMFC 2007a). The age-based fecundity adjustment was then applied to yield an equivalent proportion of female spawners that would be required to produce the increased fecundity (Table 4.4-3).

- age-4 to age-5, fecundity increased from 360,980 to 452,682 = 25% (multiply by 1.25)
- age-5 to age-6, fecundity increased from 452,682 to 524,888 = 16% (multiply by 1.16)
- age-6 to age-7, fecundity increased from 524,888 to 581,546 = 11% (multiply by 1.11)

Finally, the model was used to estimate the inputs necessary to result in the desired low and high range proportions of repeat spawners. In that exercise, all input values except for % repeat spawners (age-5, 6, 7) were held constant[1]. Output values for the proportion of repeat spawners were averaged for years 8-30 and input values were iteratively adjusted proportionally until a solution approximating the adjusted age frequency distribution was reached. The resultant adjustment for both the low and high range was a factor of 3.25. Therefore the inputs necessary to achieve the desired annual frequency of repeat spawners were:

Low range frequency distribution adjusted for age-based fecundity =

- Age 5: 4% x 1.25 x 3.25 = 16%
- Age 6: 4% x 1.16 x 3.25 = 15%
- Age 7: 2% x 1.11 x 3.25 = 7%

High range frequency distribution adjusted for age-based fecundity =

- Age 5: 13% x 1.25 x 3.25 = 57%
- Age 6: 11% x 1.16 x 3.25 = 45%
- Age 7: 6% x 1.11 x 3.25 = 23%

Sex Ratio

---

[1] upstream passage values were set to: YH=0.10, SH=0.72, H=0.33, MR=0.85, and C=0.80; downstream passage was set to 0.85 for all projects; Net R was set at 6; proportion female was set to 50%, stocked larvae was set to 6.7 million/yr; % spawning success below YH was set to 0.15, and age frequency of first spawning females was set to (age 4, 5, 6, 7) 0.15, 0.45, 0.31, 0.09. A start population of 10,000 was used and simulations were run from 2020 for 30 years.

From 2001-2011 the mean proportion of female American shad sampled from the Conowingo fish lifts was 55%, but previously the proportion was lower (1993 - 2005, mean % female = 46%). Per agency recommendation, two input values that bound the observed mean values of the percent of females identified from fish lift samples will be used:

- Low: 40% female
- High: 60% female

Proportion Spawning Below York Haven Dam

Potential spawning habitat below York Haven is not perceived to be equivalent in quality of that above York Haven. The model platform will be designed to include both a percentage and a maximum number for adult female American shad that do not pass York Haven Dam but are allowed to spawn. The low range value will be 0 and the high range value will be set as the approximated carrying capacity calculated by St. Pierre (1979) to set a target restoration goal for the river reach from Columbia, PA to York Haven Dam at 96,000 spawners x the high range value for sex ratio (60% female):

- Low = 0 females spawning below York Haven.
- High = 57,600 females spawning below York Haven.

Net Reproductive Rate

Net R, the number of eventual adult returners to Conowingo Dam produced per female spawner, acts as a model ‘tuning’ variable since it incorporates all unknown losses. The best fit of model simulation output to existing data will require adjustment of Net R depending on other input values for other variables; however, by consensus of best professional opinion, it was determined that low and high range values of 6 and 12 would serve as check-points. For a simulation run (using a specific set of inputs), a model fitting exercise will be used to determine the most appropriate value for Net R, but that value will be bounded by the stated range:

- Low = 6
- High = 12

5.0 2012 – CONTINUED STUDY

5.1 Calibration Runs and Production Simulations

In December, 2011 a questionnaire was distributed to Stakeholders asking them to document their desired production runs by listing the value (or low and high range) and a justification for those values for the input variables: annual hatchery reared juvenile stocking number; annual adult trap-and-transport stocking number; upstream passage effectiveness and downstream passage effectiveness / survival at York Haven, Muddy Run (escapement), and Conowingo. The purpose of that questionnaire was to provide a method to manage and collate requested simulation runs in order to prevent duplicated effort and to control the number of simulations. Once those requests are received, the ranges of input values described in Section 4.4.1 will be paired with the ranges of requested inputs to produce an array of output. Those outputs will then be interpreted in a separate report.

TABLE 3.1-1: UPSTREAM PASSAGE OF ADULT AMERICAN SHAD AND APPARENT PASSAGE EFFICIENCY AT FOUR LOWER SUSQUEHANNA RIVER DAMS.[2]

	Conowingo		Holtwood		Safe Harbor		York Haven		Overall
Year	N Passed	Efficiency (%)	N Passed	Efficiency (%)	N Passed	Efficiency (%)	N Passed	Efficiency (%)	Efficiency (%)
1997	90,971		28,063	31	20,828	74			
1998	39,904		8,235	21	6,054	74			
1999	69,712		34,702	50	34,150	98			
2000	153,546		29,421	19	21,079	72	4,687	22	3
2001	193,574		109,976	57	89,816	82	16,200	18	8
2002	108,001		17,522	16	11,705	67	1,555	13	1
2003	125,135		25,254	20	16,646	66	2,536	15	2
2004	109,360		3,428	3	2,109	62	219	10	0
2005	68,926		34,189	50	25,425	74	1,772	7	3
2006	56,899		35,968	63	24,929	69	1,913	8	3
2007	25,464		10,338	41	7,215	70	192	3	1
2008	19,914		2,795	14	1,252	45	21	2	0
2009	29,272		10,896	37	7,994	73	402	5	1
2010	37,757	45[3]	16,472	44	12,706	77	907	7	2
Mean	80,603		26,233	33	20,136	72	2,764	10	2

---

[2] Apparent passage efficiency at Holtwood, Safe Harbor, and York Haven Dams is defined as the ratio of the number of fish counted at a fish passage facility to the number counted at the passage facility of the downstream dam. Mean passage efficiency is the mean of the values in the % frequency columns. Overall apparent passage efficiency is defined as the number of fish counted at York Haven Dam to the number counted at Conowingo Dam. Fish passage efficiency at Conwowingo Dam was estimated by radio-telemetry (see SP 3.5). Passage count data for 1997-2009 are from SRAFRC (2010), data for 2010 from Pennsylvania Fish and Boat Commission (http://www.fish.state.pa.us/shad_susq.htm).

[3] Preliminary estimate from limited radio telemetry study. Additional study planned for 2012.

TABLE 3.1-2: ANNUAL STOCKING OF AMERICAN SHAD SPAWNERS (ADULT, TRAP-AND-TRANSPORT), STOCKING OF LARVAL AND JUVENILES TO THE SUSQUEHANNA RIVER AND RATE OF RETURN OF STOCKED LARVAE.

	Spawners Transported (N)[4]		Larvae / Juveniles Stocked	
Year	**From Out of Basin**	**From Conowingo Dam**	**(N x 10^6)**	**Rate of Return[5]**
1976			0.780	
1977			1.040	
1978			2.130	
1979			0.663	
1980	114		3.531	
1981	1,165		2.054	
1982	2,565	800	5.060	
1983	4,310	64	4.146	
1984	3,777	-	12.027	
1985	2,834	967	6.343	
1986	4,965	4,172	9.972	0.0014
1987	6,051	7,202	5.261	0.0021
1988		4,736	6.530	0.0021
1989		6,469	13.530	0.0016
1990		15,075	5.709	0.0055
1991		24,662	7.272	0.0033
1992		15,674	3.061	0.0049
1993		11,717	6.621	0.0037
1994		28,681	6.560	0.0049
1995		56,370	10.001	0.0057
1996		33,825	7.466	0.0147
1997		10,528	8.044	0.0106
1998		4,593	11.759	0.0038
1999		5,508	13.501	0.0057
2000		1,351	9.790	0.0019
2001			6.530	0.0030
2002			2.589	0.0006
2003			12.740	
2004			5.640	
2005			5.210	
2006			4.950	
2007			1.380	
2008			2.490	
2009			3.070	
2010			4.862	
Total	25,781	232,394	212.312	

---

[4] Data for 1976-2009 from SRAFRC (2010). 2010 data from Pennsylvania Fish and Boat Commission (http://www.fish.state.pa.us/shad_susq.htm).

[5] Data from Sadzinski and Hendricks (2007)

TABLE 4.4-1. MEAN AGE FREQUENCY DISTRIBUTION FOR ADULT FEMALE AMERICAN SHAD WITH REPRESENTATIVE LOW AND HIGH RANGE AGE FREQUENCY DISTRIBUTIONS.

	Mean	Low	High
Age 4	16	28	7
Age 5	44	54	30
Age 6	31	15	48
Age 7	9	3	15
Total	100	100	100

TABLE 4.4-2. DEMONSTRATION OF THE DIFFERENCE BETWEEN INPUT VALUES FOR AGE DISTRIBUTION OF REPEAT SPAWNERS AND ANNUAL PROPORTION OF REPEAT SPAWNERS.

Box 1. Demonstration of the difference between input values for age distribution of % repeat spawners and the output result reflecting annual proportion of repeat spawners.

In a hypothetical example, suppose that:
The population of American shad returning to Conowingo dam is consistent at 100,000 females per year (FY);

The age frequency distribution of first spawners at age 4, 5, 6, 7 (V4, V5, V6, V7) = 15%, 31% 45%, and 9% (see mid-range values in Table 1); and

The frequency distribution of repeat spawners at age 5, 6, 7 (R5, R6, R7) = 10%, 9%, 5%.

Note that the expected cumulative proportion of repeat spawners is 24%.

The annual proportion of repeat spawners in Year Y would be calculated as follows:

Total number of first spawning females:
V4 = (%V4 * F_Y-4) = (0.15 * 100,000) =15,000
V5 = (%V5 * F_Y-5) = (0.31 * 100,000) = 31,000
V6 = (%V6 * F_Y-6) = (0.45 * 100,000) = 45,000
V7 = (%V7 * F_Y-7) = (0.09 * 100,000) = 9,000
Total = 100,000
Total number of repeat spawning females:
R5 = (%R5 * V4_Y-1) = (0.10 * 15,000) =1,500
R6 = (%R6 * V5_Y-1)+(%R6 * R5_Y-1) = (0.09 * 31,000)+(0.09*1,500) = 2,925
R7 = (%R7 * V6_Y-1)+(%R7 * R6_Y-1) = (0.05 * 45,000)+(0.09*2,925) = 263
Total = 4,688
So, the proportion of repeat spawners in Year Y would be (4,688 / (4,688+100,000)) = 4%. The input values for % repeat spawner do not yield an equivalent annual proportion of repeat spawners

TABLE 4.4-3. LOW AND HIGH RANGE AGE FREQUENCY DISTRIBUTIONS FOR REPEAT SPAWNING FEMALE AMERICAN SHAD, INFLATED TO ACCOUNT FOR INCREASED FECUNDITY WITH AGE.

Low Range	**Repeat Spawner (%)**	**Fecundity Adjustment (%)**	**Repeat Spawner Equivalent (%)**
Age-5	4	+25	5.00
Age-6	4	+16	4.64
Age-7	2	+11	2.22
Total	10		
High Range	**Repeat Spawner (%)**	**Fecundity Adjustment (%)**	**Spawner Equivalent**
Age-5	13	+25	16.25
Age-6	11	+16	12.76
Age-7	6	+11	6.66
Total	30		

FIGURE 2.0-1. HYDROELECTRIC PROJECTS AND FISH PASSAGE FACILITIES OF THE LOWER SUSQUEHANNA RIVER.

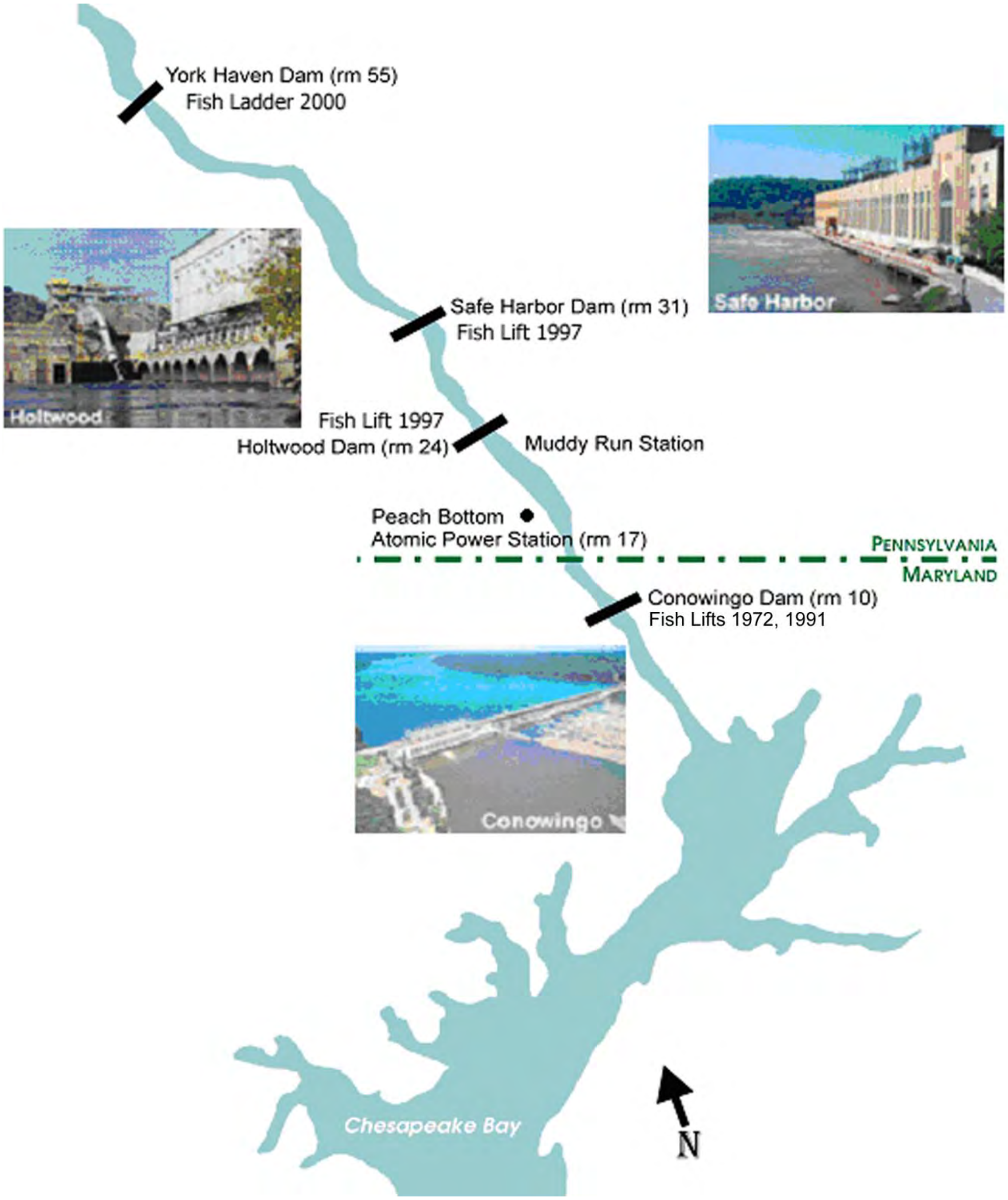
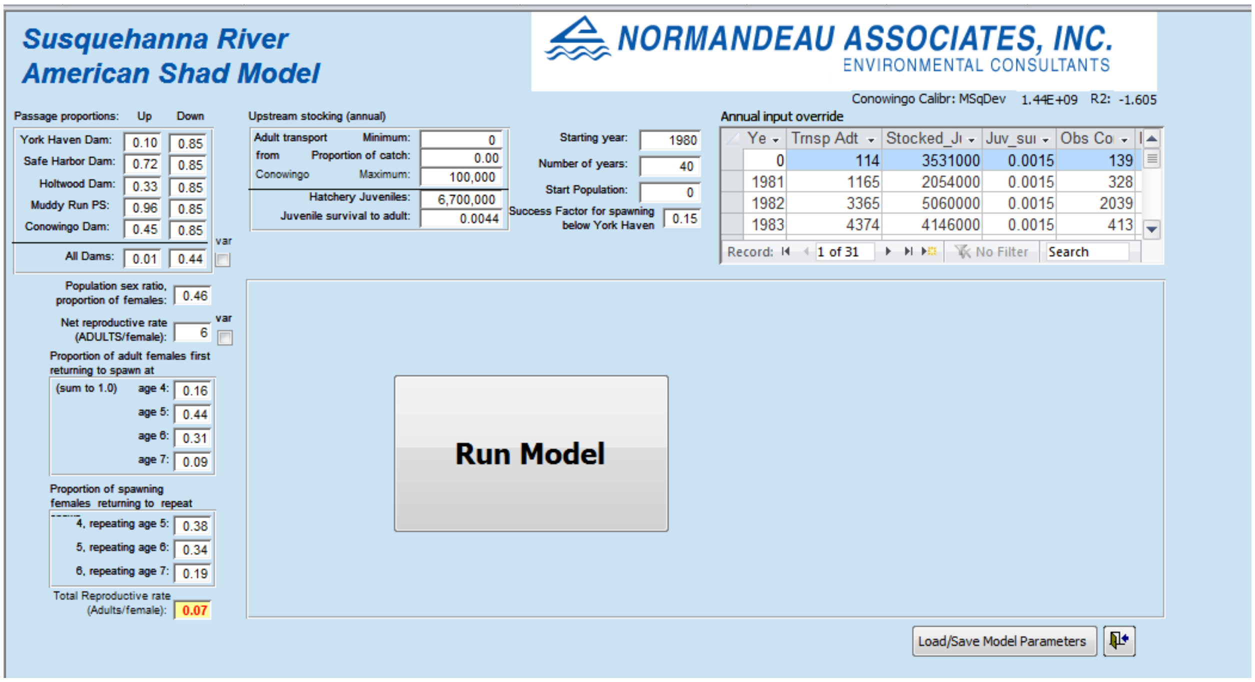


FIGURE 4.2-1. SUSQUEHANNA RIVER AMERICAN SHAD POPULATION MODEL. EXAMPLE OF MODEL DASHBOARD.



Conowingo Calibr: MSqDev 1.44E+09 R2: -1.605

Passage proportions:	Up	Down
York Haven Dam:	0.10	0.85
Safe Harbor Dam:	0.72	0.85
Holtwood Dam:	0.33	0.85
Muddy Run PS:	0.96	0.85
Conowingo Dam:	0.45	0.85
All Dams:	0.01	0.44

var ☐

Population sex ratio, proportion of females: 0.46

Net reproductive rate (ADULTS/female): 6 var ☐

Proportion of adult females first returning to spawn at (sum to 1.0)
age 4: 0.16
age 5: 0.44
age 6: 0.31
age 7: 0.09

Proportion of spawning females returning to repeat
4, repeating age 5: 0.38
5, repeating age 6: 0.34
6, repeating age 7: 0.19

Total Reproductive rate (Adults/female): 0.07

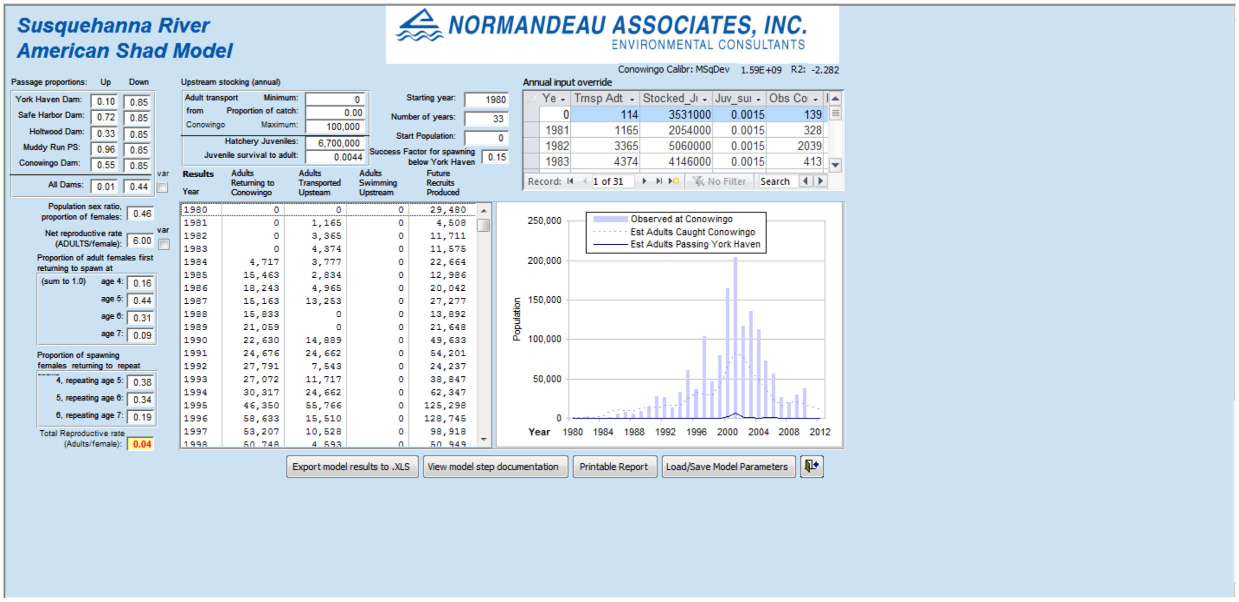
Upstream stocking (annual)
Adult transport from Conowingo Minimum: 0
Proportion of catch: 0.00
Maximum: 100,000
Hatchery Juveniles: 6,700,000
Juvenile survival to adult: 0.0044

Starting year: 1980
Number of years: 40
Start Population: 0
Success Factor for spawning below York Haven: 0.15

Annual input override

Ye	Trnsp Adt	Stocked_Jı	Juv_suı	Obs Co
0	114	3531000	0.0015	139
1981	1165	2054000	0.0015	328
1982	3365	5060000	0.0015	2039
1983	4374	4146000	0.0015	413

FIGURE 4.2-2. EXAMPLE OF TABULAR AND GRAPHICAL OUTPUT.



Conowingo Calibr: MSqDev 1.59E+09 R2: -2.282

Passage proportions:	Up	Down
York Haven Dam:	0.10	0.85
Safe Harbor Dam:	0.72	0.85
Holtwood Dam:	0.33	0.85
Muddy Run PS:	0.96	0.85
Conowingo Dam:	0.55	0.85
All Dams:	0.01	0.44

var ☐

Population sex ratio, proportion of females: 0.46

Net reproductive rate (ADULTS/female): 6.00 var ☐

Proportion of adult females first returning to spawn at (sum to 1.0)
age 4: 0.16
age 5: 0.44
age 6: 0.31
age 7: 0.09

Proportion of spawning females returning to repeat
4, repeating age 5: 0.38
5, repeating age 6: 0.34
6, repeating age 7: 0.19

Total Reproductive rate (Adults/female): 0.04

Upstream stocking (annual)
Adult transport from Conowingo Minimum: 0
Proportion of catch: 0.00
Maximum: 100,000
Hatchery Juveniles: 6,700,000
Juvenile survival to adult: 0.0044

Starting year: 1980
Number of years: 33
Start Population: 0
Success Factor for spawning below York Haven: 0.15

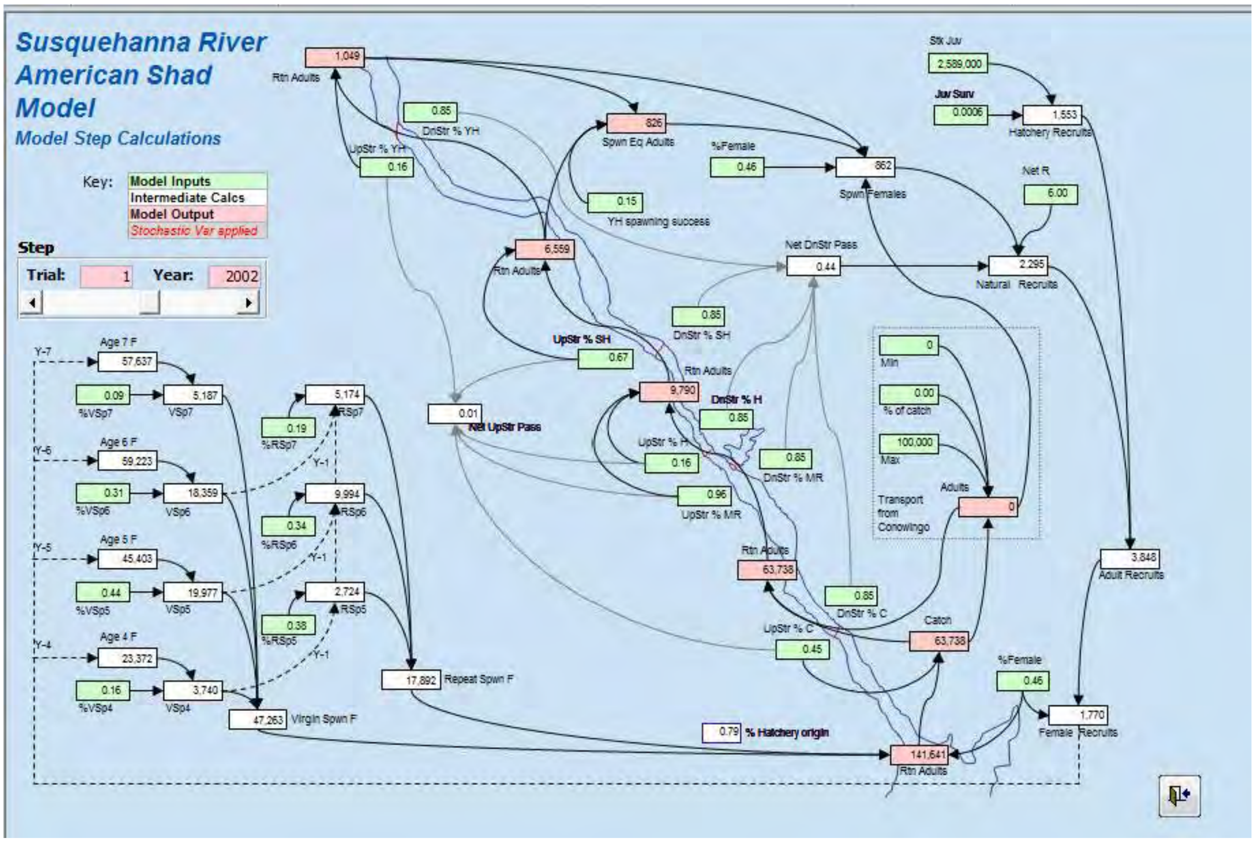
Annual input override

Ye	Trnsp Adt	Stocked_Jı	Juv_suı	Obs Co
0	114	3531000	0.0015	139
1981	1165	2054000	0.0015	328
1982	3365	5060000	0.0015	2039
1983	4374	4146000	0.0015	413

Results

Year	Adults Returning to Conowingo	Adults Transported Upstream	Adults Swimming Upstream	Future Recruits Produced
1980	0	0	0	29,480
1981	0	1,165	0	4,508
1982	0	3,365	0	11,711
1983	0	4,374	0	11,575
1984	4,717	3,777	0	22,664
1985	15,463	2,834	0	12,986
1986	18,243	4,965	0	20,042
1987	15,163	13,253	0	27,277
1988	15,833	0	0	13,892
1989	21,059	0	0	21,648
1990	22,630	14,889	0	49,633
1991	24,676	24,662	0	54,201
1992	27,791	7,543	0	24,237
1993	27,072	11,717	0	38,847
1994	30,317	24,662	0	62,347
1995	46,350	55,766	0	125,298
1996	58,633	15,510	0	128,745
1997	53,207	10,528	0	98,918
1998	50,748	4,593	0	50,949

FIGURE 4.2-3. EXAMPLE CONCEPTUAL DIAGRAM WITH ANNUAL STEP INPUT / OUTPUT.



Susquehanna River American Shad Model

Model Step Calculations

Key:
- Model Inputs
- Intermediate Calcs
- Model Output
- Stochastic Var applied

Step

Trial: 1 Year: 2002

FIGURE 4.2-4. SENSITIVITY OF VARYING NET REPRODUCTIVE RATE (NET R) WITH TWO LEVELS OF NET UPSTREAM PASSAGE (1.0, 0.5).

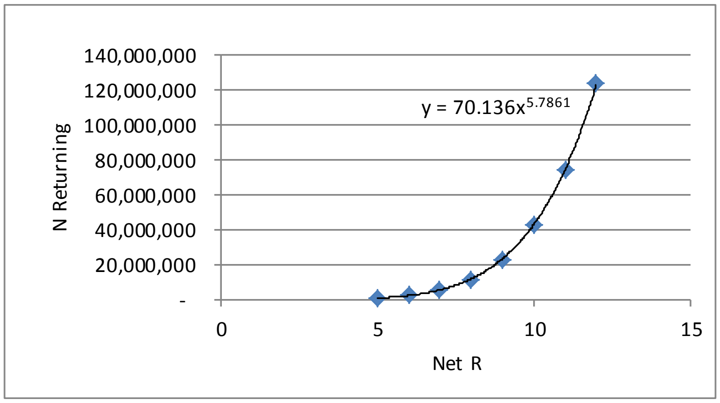
Net R

Net upstream passage 1.0

Net downstream passage 1.0

Result = Number of American shad returning to Conowingo in year 30

Net R	N Returning
5	786,567
6	2,226,446
7	5,398,934
8	11,679,507
9	23,141,989
10	42,771,567
11	74,681,459
12	124,409,087



Net upstream passage 0.5

Net downstream passage 1.0

Result = Number of American shad returning to Conowingo in year 30

Net R	N Returning
5	16,278
6	44,853
7	105,254
8	222,663
9	432,843
10	786,693
11	1,354,022
12	2,226,389

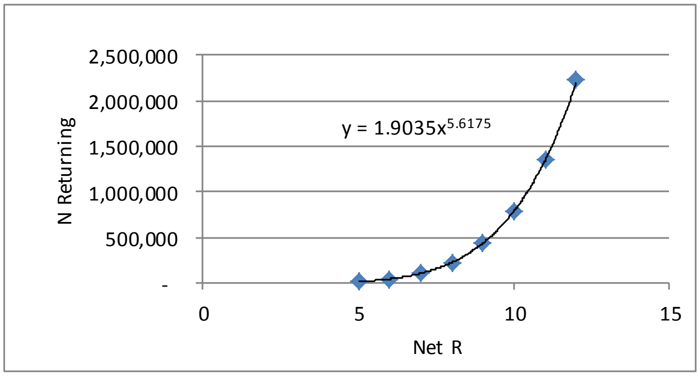


FIGURE 4.2-5. SENSITIVITY OF VARYING NET UPSTREAM PASSAGE WITH TWO LEVELS OF NET REPRODUCTIVE RATE (NET R: 8, 12).

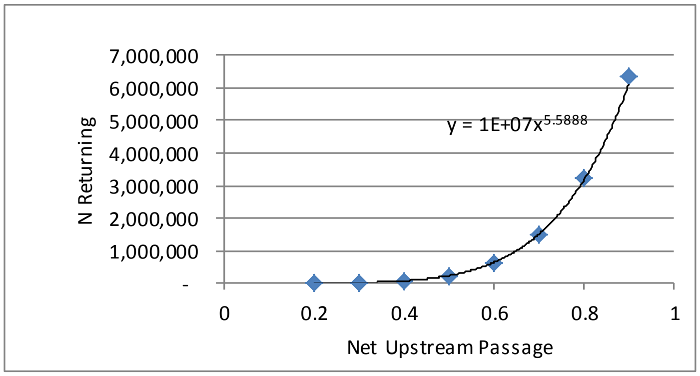
Net upstream passage (all facilities)

Net R: 8.0

Net downstream passage: 1.0

Result = Number of American shad returning to Conowingo in year 30

Net U.P.	N Returning
0.2	1,430
0.3	13,009
0.4	63,815
0.5	222,663
0.6	624,000
0.7	1,500,663
0.8	3,224,485
0.9	6,352,609



Net R: 12.0

Net downstream passage 1.0

Result = Number of American shad returning to Conowingo in year 30

Net U.P.	N Returning
0.2	12,996
0.3	123,193
0.4	623,789
0.5	2,226,389
0.6	6,353,543
0.7	15,500,900
0.8	33,697,063
0.9	67,060,178

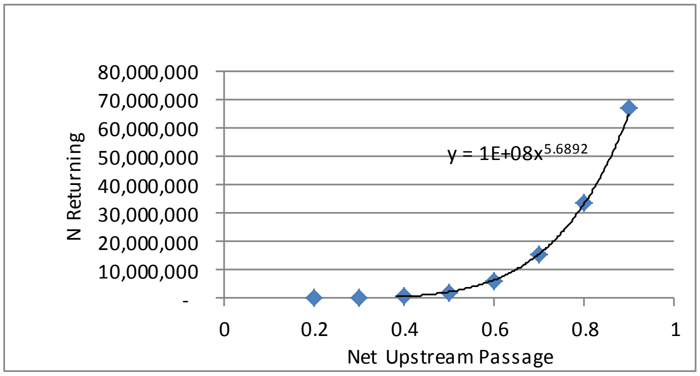


FIGURE 4.2-6. SENSITIVITY OF VARYING NET DOWNSTREAM PASSAGE WITH TWO LEVELS OF NET REPRODUCTIVE RATE (NET R: 8, 12).

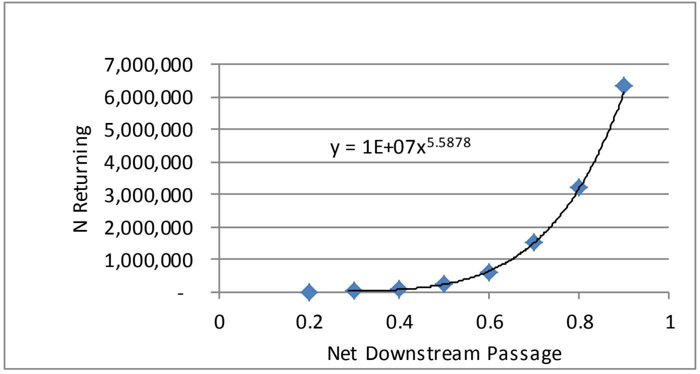
Net downstream passage (all facilities)

Net R: 8.0

Net upstream passage: 1.0

Result = Number of American shad returning to Conowingo in year 30

Net D.P.	N Returning
0.2	1,433
0.3	13,004
0.4	63,835
0.5	222,639
0.6	623,837
0.7	1,500,776
0.8	3,223,874
0.9	6,352,393



Net R: 12.0

Net upstream passage 1.0

Result = Number of American shad returning to Conowingo in year 30

Net D.P.	N Returning
0.2	13,004
0.3	123,209
0.4	623,837
0.5	2,226,446
0.6	6,352,393
0.7	15,499,143
0.8	33,701,109
0.9	67,068,489

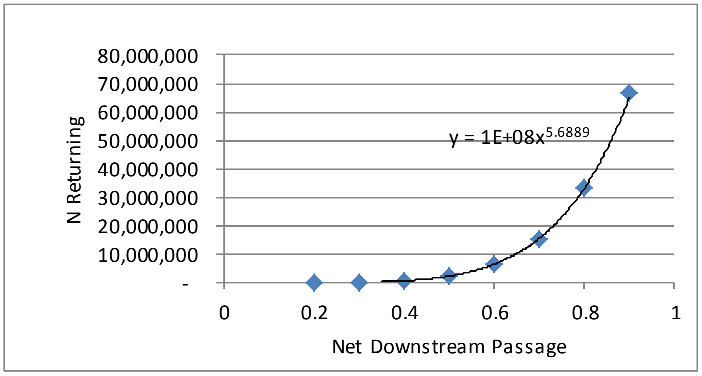
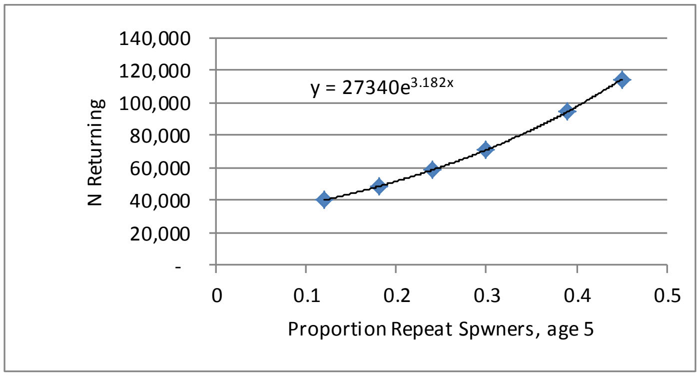


FIGURE 4.2-7. SENSITIVITY OF VARYING PROPORTION OF REPEAT SPAWNERS (AT AGE 4) WITH TWO LEVELS OF NET REPRODUCTIVE RATE (8, 12).

Repeat spawning proportions

Net R: 8.0
Net upstream passage: 0.5
Net downstream passage: 0.8
RS5=RS4/3; RS6=RS5/2

R.S. Age 4	N Returning
0.12	39,917
0.18	48,493
0.24	58,822
0.3	71,228
0.39	94,654
0.45	114,080



Net R: 12.0
Net upstream passage 0.5
Net downstream passage: 0.8
RS5=RS4/3; RS6=RS5/2
Result = Number of American shad returning to Conowingo in year 30

R.S. Age 4	N Returning
0.12	397,237
0.18	479,446
0.24	578,000
0.3	695,550
0.39	914,896
0.45	1,096,100

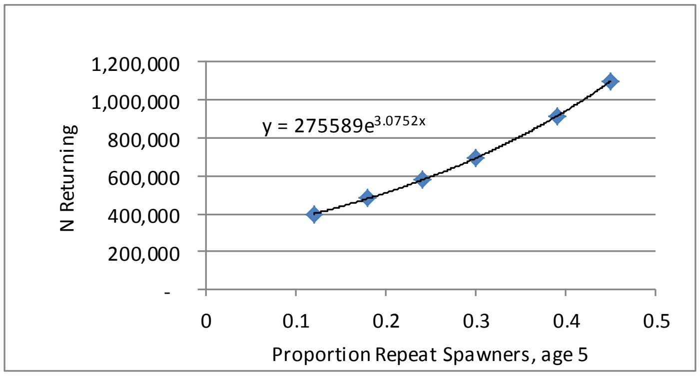


FIGURE 4.2-8. SENSITIVITY OF VARYING PROPORTION SPAWNING DOWNSTREAM OF YORK HAVEN DAM.

York Haven spawning proportion

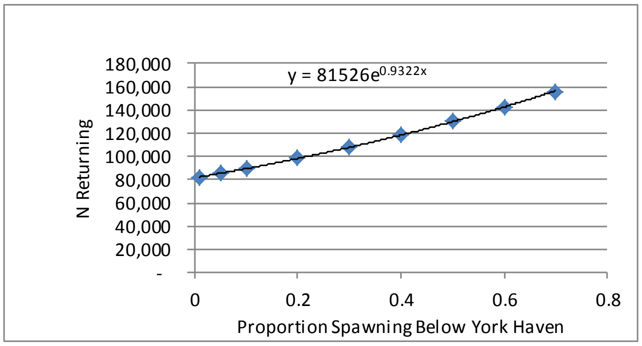
Net R: 8.0

Net upstream passage: 0.52 (0.85 @4 dams)

Net dowstream passage: 0.8

Result = Number of American shad returning to Conowingo in year 30

YH Spawn	N Returning
0.01	81,939
0.05	85,233
0.1	89,526
0.2	98,430
0.3	108,265
0.4	118,787
0.5	130,263
0.6	142,546
0.7	155,711



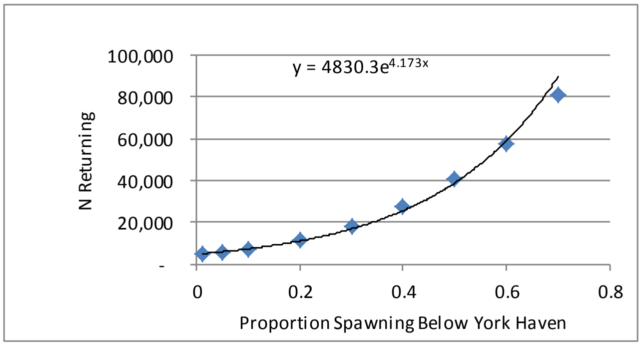
Net R: 8.0

Net upstream passage: 0.31 (0.85 @3 dams, 0.50@ YH)

Net dowstream passage: 0.8

Result = Number of American shad returning to Conowingo in year 30

YH Spawn	N Returning
0.01	4,609
0.05	5,691
0.1	7,333
0.2	11,800
0.3	18,339
0.4	27,617
0.5	40,437
0.6	57,876
0.7	81,137



Net R: 12

Net upstream passage: 0.31 (0.85 @3 dams, 0.50@ YH)

Net dowstream passage: 0.8

Result = Number of American shad returning to Conowingo in year 30

YH Spawn	N Returning
0.01	42,741
0.05	53,028
0.1	68,704
0.2	111,735
0.3	174,950
0.4	265,565
0.5	391,750
0.6	564,739
0.7	796,498

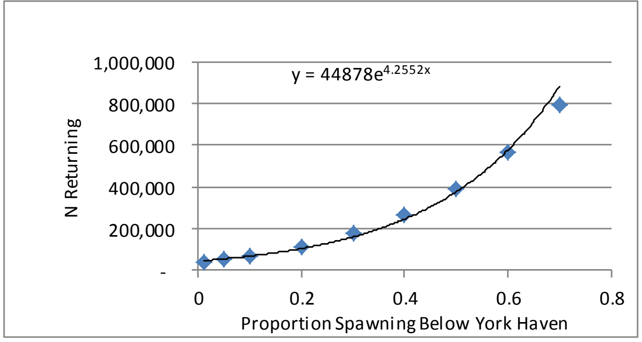
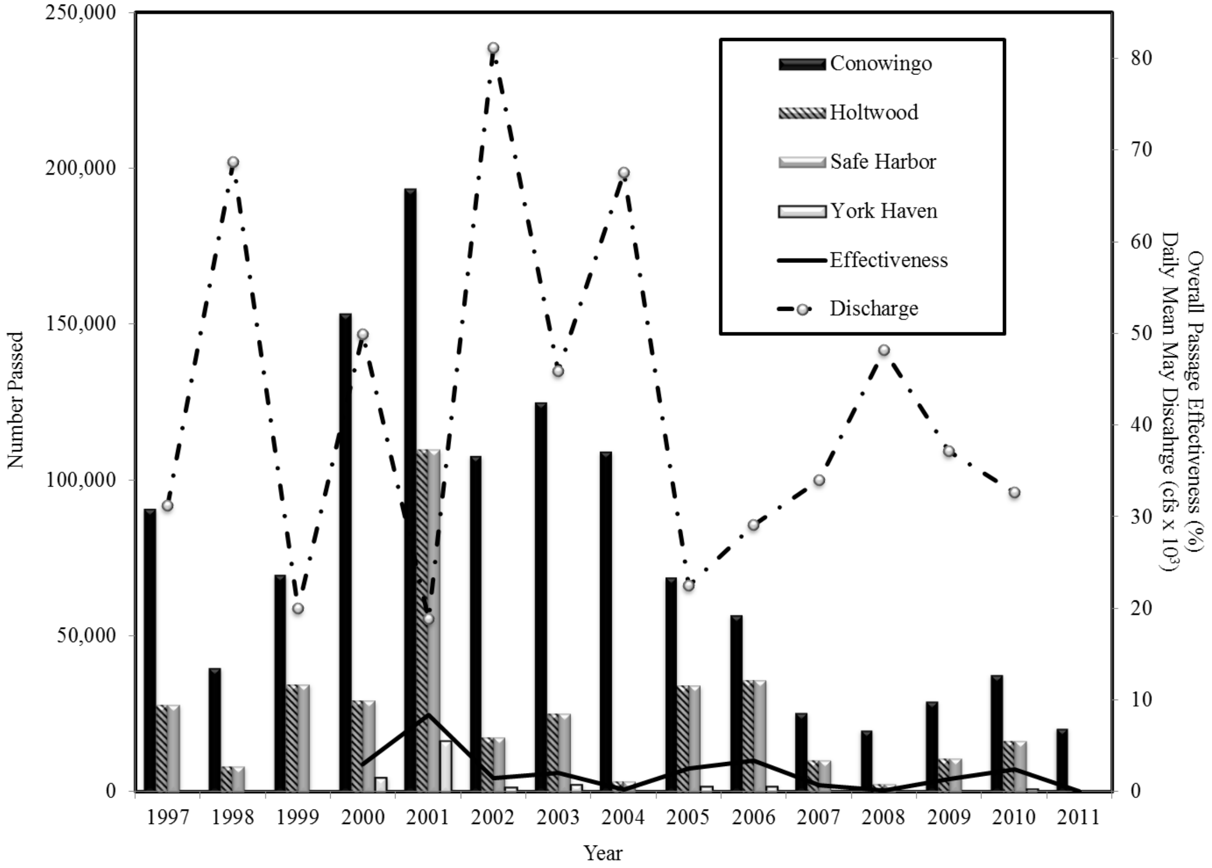


FIGURE 4.3-1: ANNUAL AMERICAN SHAD PASSAGE COUNTS AT SUSQUEHANNA RIVER DAMS, 1997-2010, WITH OVERALL PASSAGE EFFECTIVENESS[1].



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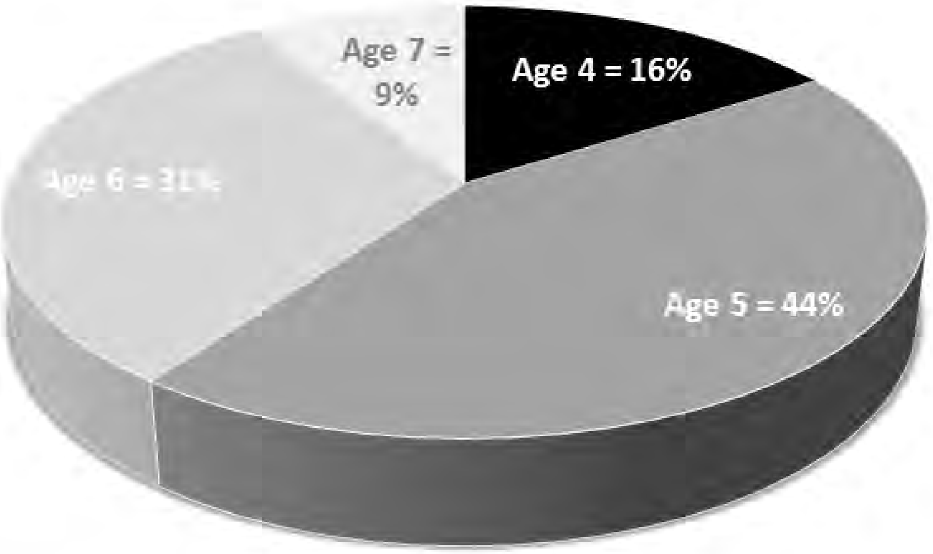
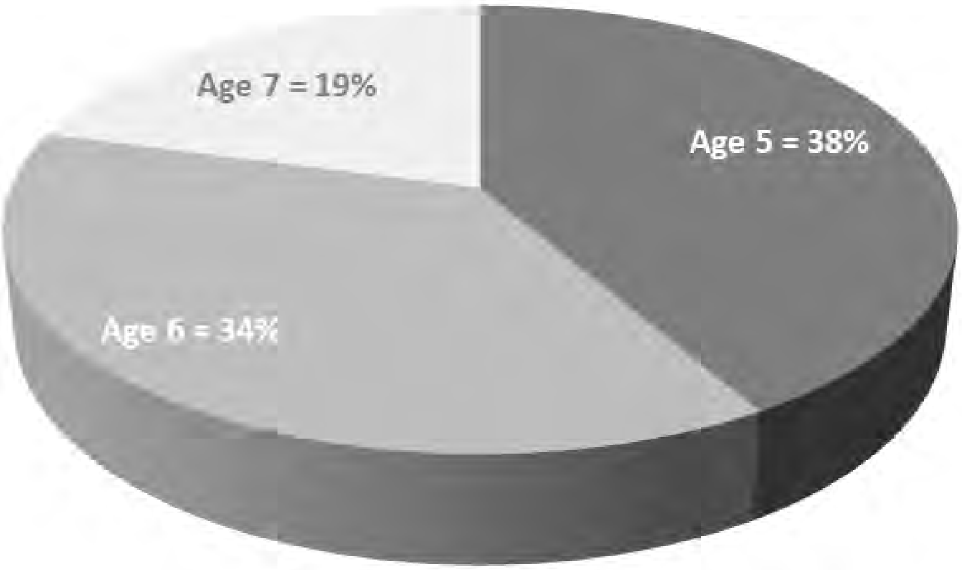
[1] Overall effectiveness is defined as the percentage of Conowingo Dam passage counts that also passed York Haven Dam.

FIGURE 4.3-2: BASELINE VALUES FOR AGE FREQUENCY DISTRIBUTION OF: A. FIRST SPAWNING AND B. REPEAT SPAWNING FEMALE AMERICAN SHAD.

A.



B.



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