# POWER DAM SEDIMENT CAPACITY AND FATE MODELING


## Abstract

A geomorphic and sediment transport study to assess existing conditions, predict downstream changes in the Pigg River, and optimize recovery after the removal of Power Dam. Findings detail potential upstream and downstream changes in the context of its current evolutionary state. The removal of Power Dam is a unique opportunity to reconnect miles of river habitat, and initiate a trajectory of recovery.

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# Introduction

The Friends of the Rivers of Virginia (FORVA) is working with the US Fish and Wildlife Service (USFWS) to develop a plan for the removal of the Power Dam on the Pigg River. The dam has long out-lived its useful life and is a barrier to fish passage and the endangered Roanoke Logperch. The 100 year old dam currently creates a linear impoundment that extends over 2.2 miles upstream and has trapped sediment for a distance of over 3 miles. Removal of the dam would restore connectivity of 25 miles of river upstream and could put 3-5 miles of affected river on a path to recovery. As a part of the removal process, FORVA has completed studies on upstream sediment, habitat, water quality, and flooding. A completed sediment sampling study estimated that over 325,000 cubic yards of sediment (largely medium to fine sand) are trapped behind the dam. Due to the linear nature of the reservoir, a large portion of this sediment could be released downstream after dam removal. Concerns over the fate of this sediment initiated an additional study to predict transport and movement outcomes with a variety of removal strategies. This report summarizes data collection and modeling efforts completed to provide these predictions. It includes background data on existing conditions, information on the methods used, and interpretation of modeling results. Results are presented in the context of existing river conditions, and are included with recommendations for optimizing the dam removal and river recovery.

# Results Summary

A brief summary of the study results is provided below. These results are further detailed in the report.

1) The Pigg River is in a disturbed state due to watershed development, human alteration, and sediment imbalances. Over 90% of the river downstream of the dam has been impacted due to sediment transport issues.
2) Removal of the Power Dam will cause both temporary and permanent geomorphic changes to the river downstream. The volume of trapped sediment behind the dam is greater than the river can effectively flush downstream.
3) A notching strategy will not be an effective way of controlling the release of sediment. The recommended strategy will involve a quick progression to the final configuration. This will allow the fastest restoration of the upstream channel and accelerate downstream recovery.
4) The upstream channel could equilibrate in a matter of months. Downstream redistribution of sediments will continue for at least a year. Increases in sediment concentrations after storms should be expected for several years.
5) The biggest changes to the Pigg will be in the area just downstream of the dam. Several feet of sand deposition could be expected. A new baseflow channel will form, leaving bars, terraces, and potentially new floodplains.
6) Implementation of a geomorphic and habitat monitoring plan could help inform potential management actions after the dam removal. Any potential problems could be mitigated with a variety of stream restoration techniques.

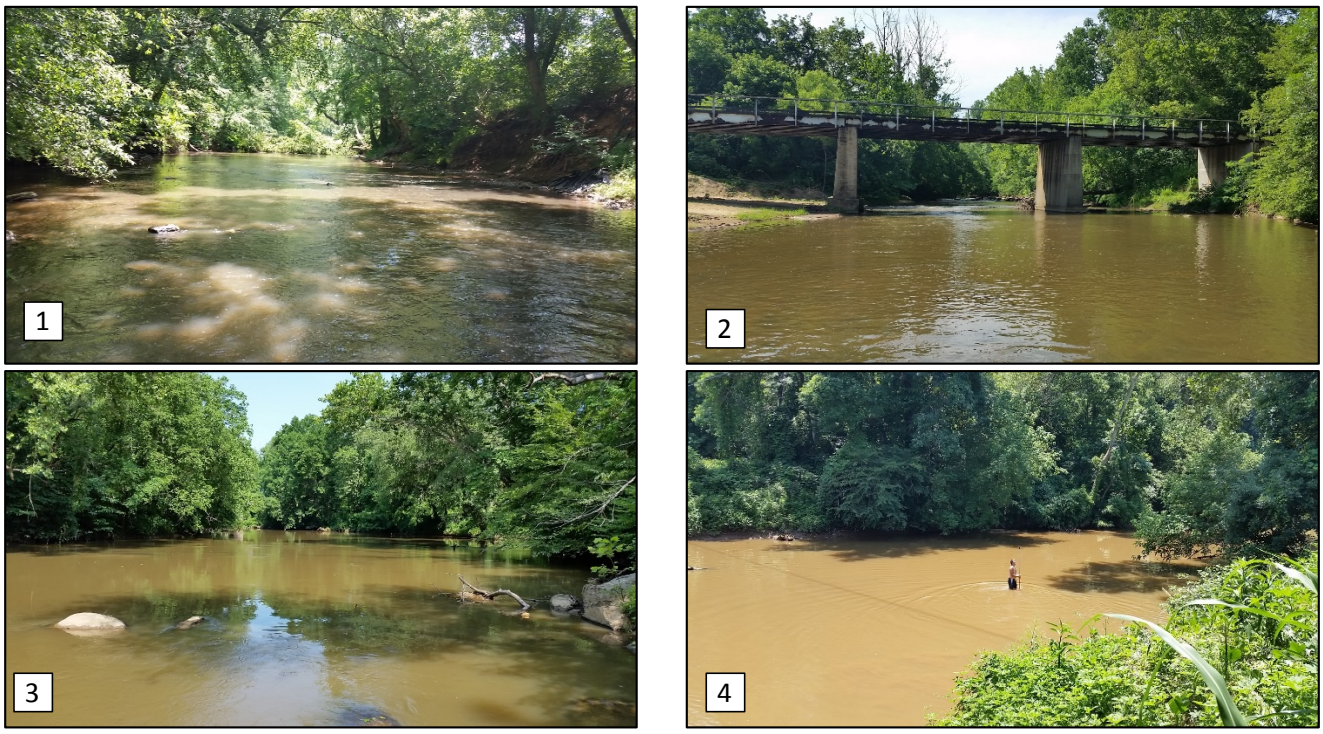
## Background Data

The sediment modeling study included a mixture of field and modeling work. It also leveraged prior study work that included upstream sediment sampling, flood modeling, and biological studies. The field work included cross sectional surveys at strategic locations beginning at the dam and progressing nearly 50 river miles downstream to Leesville Lake. A total of 18 cross sections were surveyed (Maps, Appendix A). Surveying was set up by Cornerstone Land Surveying (Rocky Mount, VA) and tied to state plane coordinates and the 1988 North American Vertical Datum. Control points were set using survey grade GPS and standard surveying procedure. Coordinates and elevations are available for repeating surveys in post-project conditions. In general, cross sections were collected near bridge crossings for access, but moved to riffle areas that were outside the influence of bridge hydraulics. Research on other dam removals shows that changes are typically more pronounced near the dam site, so additional cross sections were targeted in this area. Each cross section included a set of streambed sediment samples, photographs, and geomorphic measurements to characterize the river. The full data is provided in Appendix B. Sediment samples were analyzed for grain size distribution at the NC State University Soil Science Lab (Appendix C). In general, the river was found to be substantially incised, overly wide, and deep compared to natural streams. Table 1 includes comparisons of the Pigg to reference reach data collected in Virginia streams with similar drainage areas. The Pigg River, especially just downstream of the dam, has almost double the cross sectional area of natural rivers. The Pigg is also over 30% wider and 50% deeper. This enlargement is a further symptom of human intervention, watershed development, and the sediment starvation that is common downstream of dams. All of these combine to disrupt the sediment balance along the river, and lead to many of the field observations made during this study.

**Table 1.** Reference streams and the Pigg River. USGS reports (Lotspeich, 2009) (Keaton et al., 2005).

| Regional Streams | Drainage area (sm) | XS area (sf) | Width (ft) | Depth (ft) | Slope (ft/ft) |
|---|---|---|---|---|---|
| Piedmont | 69.6 | 147 | 45.3 | 3.3 | 0.002 |
| Valley and ridge | 70.1 | 325 | 64 | 5.1 | .0011 |
| Valley and ridge | 76.1 | 234 | 73 | 3.2 | .0022 |
| Pigg River | 70 | 700 | 85 | 8.3 | .0016 |
| Difference | | 100% | 33% | 53% | |

The complexity of bed habitats and frequency of riffles and deep pools was found to be low, similar to findings in a prior biomonitoring study (Hitt et al., 2009). Much of the river contains the type of cobble and gravel size material that is typical for rivers in this landscape position. The d50 for many cross sections fell in the coarse gravel range. However, sand has infiltrated much of this material, and buried it in many cross sections. Sand embeddedness can be a problem for aquatic organisms that depend on coarse substrates for habitat and food. This sand embeddedness was found to increase rapidly progressing downstream, with substantial deposits of sand being found as close as the first bridge crossing (approximately 5 miles from the dam). The photograph set below provides a visual description of the decreases in bed complexity and increases in sand content progressing downstream. Based on the field observations, only 10% or less of the river within the study area could be characterized with a natural bed material distribution.

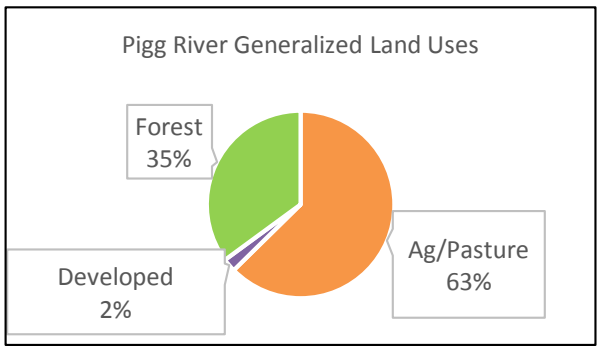



**Pigg River Photographs:** near the dam (1), 20 miles downstream (2), halfway to Leesville Lake (3), and nearing the lake (4).

The field observations, sampling data, and geomorphic measurements show a river in a state of dynamic evolution. The river has been disturbed enough to progress through initial deepening stages, and is currently in a widening stage. This widening will eventually lead to bank collapse, the formation of new bars, terraces, and eventually floodplains within the current channel footprint (Schumm et al., 1984). It is clear that these changes are partly due to disruption in the sediment balance of the river. The Power Dam has played a role in these changes by trapping sediment, and passing more erosive flows downstream. The current depth of sand deposits downstream is an additional indicator of where the Pigg is headed. It is likely that these deposits will continue to expand even if the dam is left in place.

## Watershed Analysis

The watershed of the Pigg River to Leesville Lake is more than 380 square miles. However, the watershed size to the dam site is only 70 square miles. General estimates of land uses were made using National Landcover data compiled at a large scale. Although percentages are not precise, they are a good indicator of effective land uses and trends. The watershed consists largely of agricultural or forested land uses. Forested areas appear to be on steeper terrain, with agriculture on the most suitable areas and following the valleys of stream systems. Urban development is mostly centered on the Town of Rocky Mount and along nearby highway corridors. Concentrated urban development comprises less than 3% of the total watershed, but 10% of the subwatershed above the dam. A 10% development threshold is commonly associated with stream impacts, and is a likely contributor to the amount of sediment trapped behind Power Dam. The Pigg River at Leesville Lake has previously been on the 303(d) list for bacteria. A TMDL



study completed in 2009 mainly attributed water quality problems to cattle and agricultural runoff. Although progress has been made to reduce bacterial contamination (Dail and Nash, 2015), most of the effort has been focused on fencing and septic upgrades. These improvements do little to reduce sediment laden runoff. The amount of farmland and proximity to stream systems increases the exposure to sources of sediment. Continued development will also increase stream flows and lead to further land and streambank erosion. Future changes to the watershed will only increase the current trend of disturbance and downstream deposition in the Pigg. Predictions of changes as a result of the dam removal should be tempered by existing watershed trends.

## Stream Gage Data

The US Geological Survey (USGS) has maintained stream gaging stations at several locations in the watershed. Summary statistic data was acquired for three sites. The best and most complete record of data was found on the Pigg River near Sandy Level. This monitoring station has a watershed area of 350 square miles and includes an excellent record of over 50 years of streamflow data. Published statistical analysis of storm events were compiled and proportioned to be representative of the dam site. Storm event peaks were duplicated in a watershed hydrologic model to develop hydrographs for event analysis. Daily averaged stream flows were tabulated from 1990-2014. This data was prepared and used with both annual and long term sediment transport analysis.

## Sediment Model Development

The latest public release of HEC-RAS (4.1) was used to perform all sediment modeling on this project. HEC-RAS is a one dimensional hydraulic model. It is commonly used for sediment transport investigations and also for dam removal studies. The length of river under study, nature of sediment, and questions posed also contributed towards choosing this approach. The model was built using data from a variety of sources. Upstream cross sections were compiled from a flood modeling study completed by Mattern and Craig (Austin, 2015) . Upstream sediment data was utilized from a sampling study completed by Froehling and Robertson, Inc (Roberson and Whitt, 2007). Field data collected as part of this study was used for the cross section and sediment data for reaches downstream of the dam. A concept plan for notched dam removal (USFWS) was used to create various scenarios of transport investigation. USGS gage station data was used to complete both storm and long term flow time series for analysis.

Sediment transport routines in HEC-RAS were completed using the Yang equation, Exner 5 sorting method, and Ruby fall velocity method. The Yang equation is particularly suited for the transport of sand and was chosen due to the character of upstream sediment. This method is commonly used for dam removal studies, especially those concerned with habitat and sand deposition. The maximum depth of erosion was entered for each cross section. This was created according to depth of refusal data (ranging 8-20 feet) in the upstream cross sections and assumed constant at 2 feet in downstream reaches. This puts a further focus on erosional development upstream and potential deposition downstream. Grain size distributions were entered using sampling data from this study and the previous impoundment sampling. A flow data series was used as the upstream boundary condition and normal depth was used for the downstream boundary. Sediment boundary conditions included a calculated rating curve for the upstream cross section. Sediment transport simulations were developed to investigate the effect of various notching strategies, upstream channel restoration, downstream deposition, and changes to sediment concentrations during storms. This required a combination of model runs that span from short reaches to the entirety of the river, under different dam geometries, and varying timeframes. The results presented here are a compilation of these results, including interpretation based on professional judgment.

## Sediment Transport Capacity

Transport capacity is an estimate of how much sediment a river can move at different flow rates. Comparison of these rates for different reaches is a first step in getting an overall view of sediment balances along a river. It is especially useful in dam removal to determine how well the upstream supply of sediment (upstream of the area impounded by the dam) is in balance with the capability of the downstream reaches to move sediment. This technique has been commonly used as a first step in other dam removal studies (such as in Randle and Greimann, 2004). Figures 1 and 2 show the potential sediment transport capacity of the Pigg River 3-5 miles upstream of the impoundment, with different notch sizes, and in the reach just downstream of the dam (first 2 miles).

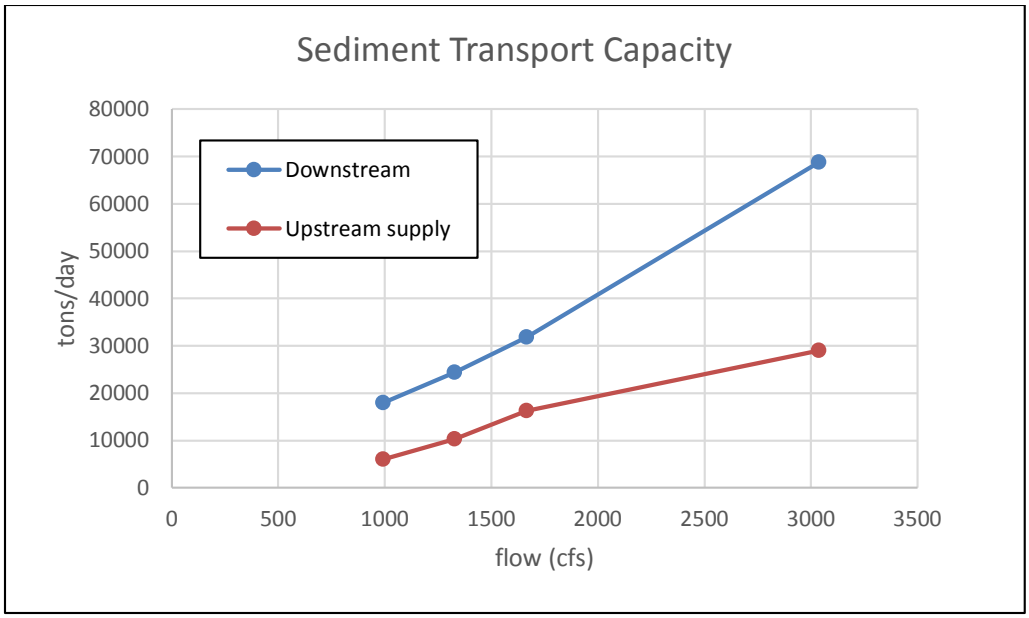



**Figure 1.** Sediment transport capacity upstream and downstream of Power Dam, Frankling County, Va.

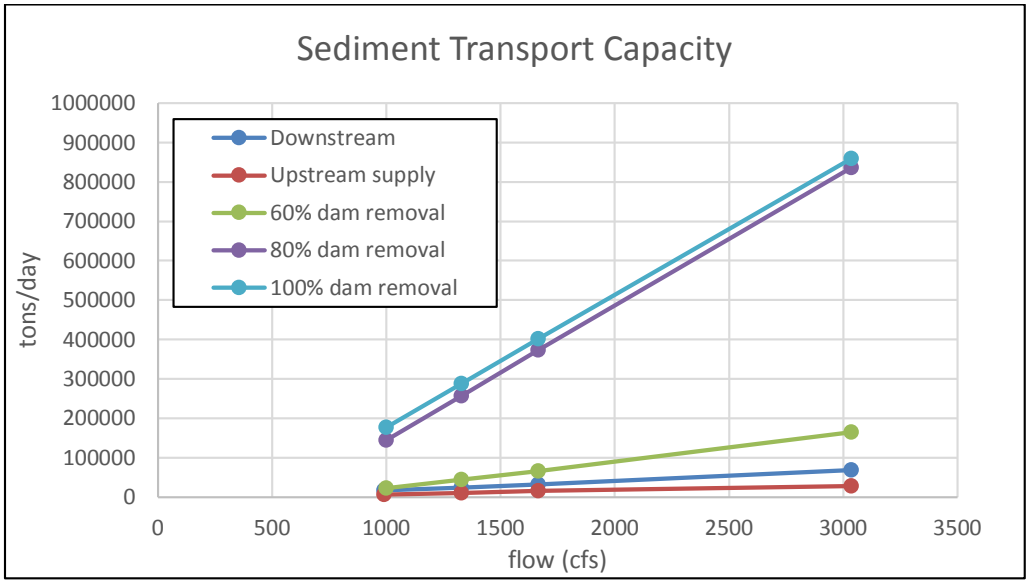



**Figure 2.** Sediment transport capacity at various stages of dam removal - Power Dam, Frankling County, Va.

In Figure 1, the downstream sediment transport capacity is higher than the upstream supply for all flowrates. This means that, after dam removal and restoration of the upstream river, all the sediment that could be supplied downstream could be transported. This is a positive indicator of the long-term sediment transport continuity that could be achieved. However, Figure 2 shows the increased sediment transport capacities that will be realized as the channel forms after dam removal. The differences between the lines on the graph can be thought of as the magnitude of sediment imbalance as the upstream channel develops. Even with a small notching of the dam, the potential supply of sediment from the impoundment will be much greater than the downstream reach can move. This is an indicator of potential deposition downstream. The curves are also an indicator of how quickly deposited sediments can be moved. Based on these initial calculations, it appears that the trapped sediment could be evacuated very quickly, or over the course of a few annual flood sized storms. However, it also appears that some of this sediment may not be able to be flushed far downstream. With the knowledge that long term sediment continuity can be achieved, additional parts of this study focused on predicting the details of channel restoration upstream and deposition downstream.

## Notching Simulations

The inbalances shown in the sediment transport capacity analysis led the project managers to consider whether a notching strategy could effectively manage sediment movement downstream during the dam removal. Short term transport simulations were created to focus on potential notching strategies. These simulations were created to investigate whether a notching strategy could limit sediment transport to a level within the capacity of the downstream reach. This simulation generated calculations to predict the movement of sediment over time. Simulations were setup to investigate the planned notching scenarios and also a variety of other notch sizes. Figure 3 shows the original notching plans and potential river profiles upstream.

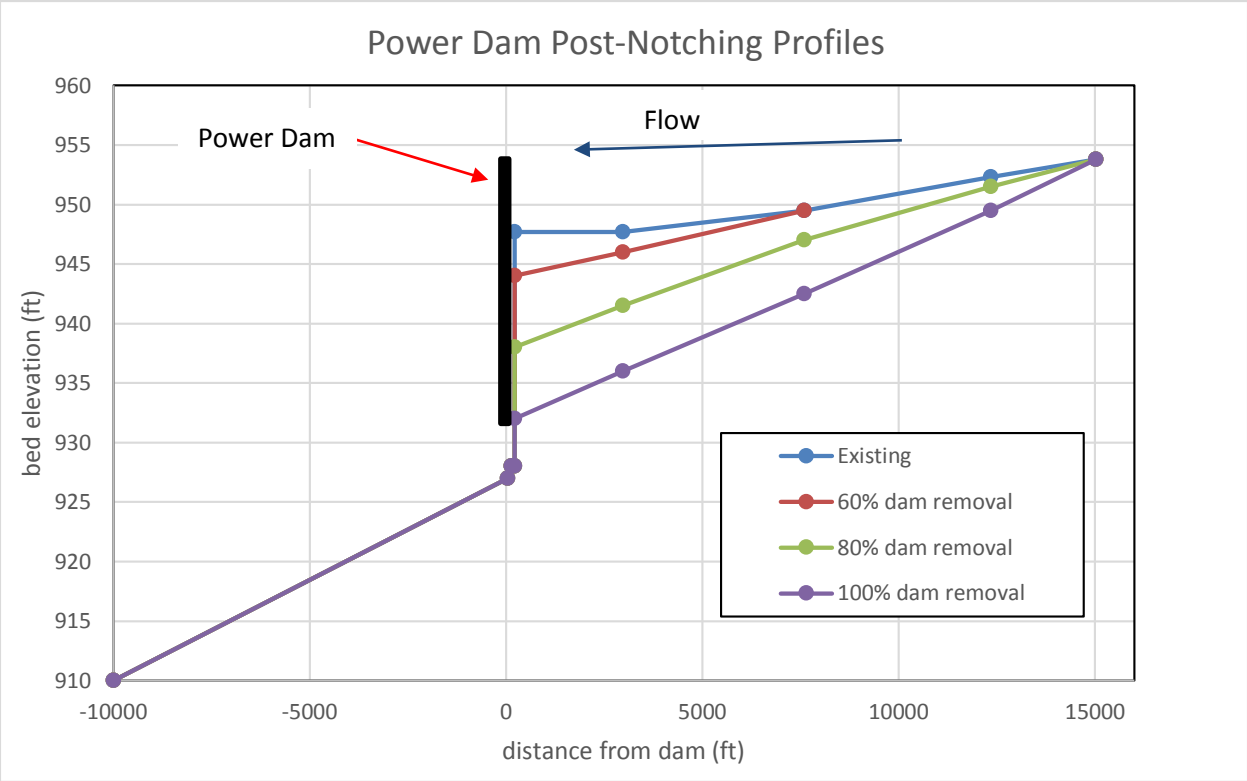



**Figure 3.** Potential profiles and slopes resulting from notching scenarios at Power Dam, Pigg River, Franklin Co, Va.

The potential river profiles were created based on averaging the slope between cross sections and also using the depth to refusal data. It appears that the final upstream slope can eventually match the downstream. This is further evidence of the sediment balance that might be restored. This graph can be used to visualize the amount of sediment trapped behind the dam. The current depth of the impoundment is only a portion of the height of the dam. As a result, each successive profile shows a new wedge of sediment that will be released. Once a notching goes below the blue line (current river bed), the amount of sediment that can be liberated will be substantial even with small changes to the dam height. This is primarily due to the long distance that sediment has been trapped and the height of the dam. Table 2 provides volume calculations based on sediment wedge sizes from the profiles in Figure 3.

**Table 2.** Sediment availability estimates for notching sizes, Power Dam, Franklin County, Va.

| | Volume released (CY) | Total Volume (CY) | Mass (tons) | Total (tons) |
|---|---|---|---|---|
| 60% dam removal | 86,820 | 86,820 | 91,422 | 91,422 |
| 80% dam removal | 77,356 | 164,176 | 81,456 | 172,878 |
| 100% dam removal | 106,855 | 271,031 | 112,519 | 285,397 |

An initial notch in the dam was simulated using daily flowrates for one year. This notch represents approximately 60% removal of the dam, and includes a floodplain and channel opening. Predicted river profiles over time are shown in Figure 4. The simulation predicts rapid development of the channel upstream of the dam. The profile is predicted to equilibrate within a time period of a few months. The transported sediment will initially move slowly downstream, primarily depositing in the stretches just downstream of the dam. This progression confirms what was expected based on the initial transport capacity calculations. The high transport capability after notching events allows the trapped sediment to be mobilized quickly. However, the overly wide channel downstream performs as a temporary sink, allowing deposits to develop.

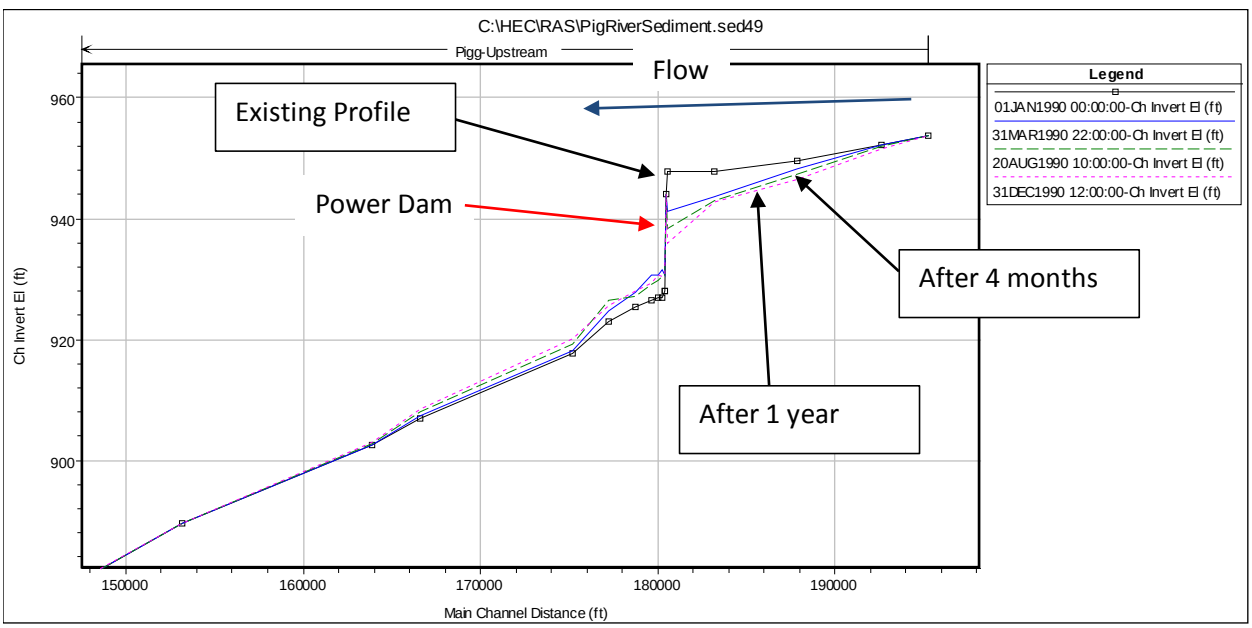



**Figure 4.** Initial and predicted river profiles after 60% dam removal – Power Dam, Franklin County, Va.

Figure 5 shows the potential cross section changes that can occur during notches upstream of the dam. The trapped sediments are quickly mobilized, likely progressing as a headcut that travels upstream. The cross section cuts down through the historic deposition to the elevation of the notch or depth of refusal. Figure 6 is an example of the potential cross sectional changes that are predicted downstream. After an initial period of sediment evacuation upstream and deposition downstream, deposits then begin to erode as new bars and features develop. Overall, the changes in bed elevation due to deposition are small, and get further distributed over the course of a year. The blue line depicts initial deposition of sediments, and the dashed green line shows the erosion and reformation of the channel over time.

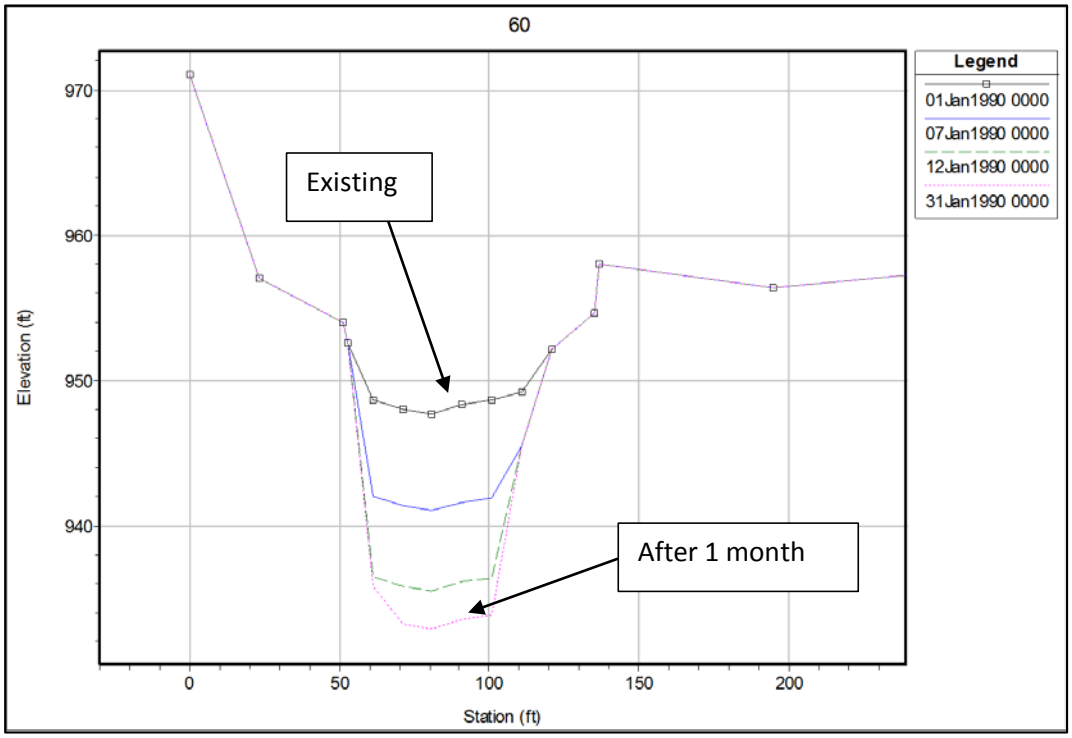



**Figure 5.** Changes in bed elevation 100 ft upstream of Power Dam (XS 60) after 60% removal due to movement of sediment. Pigg River, Franklin County, Va.

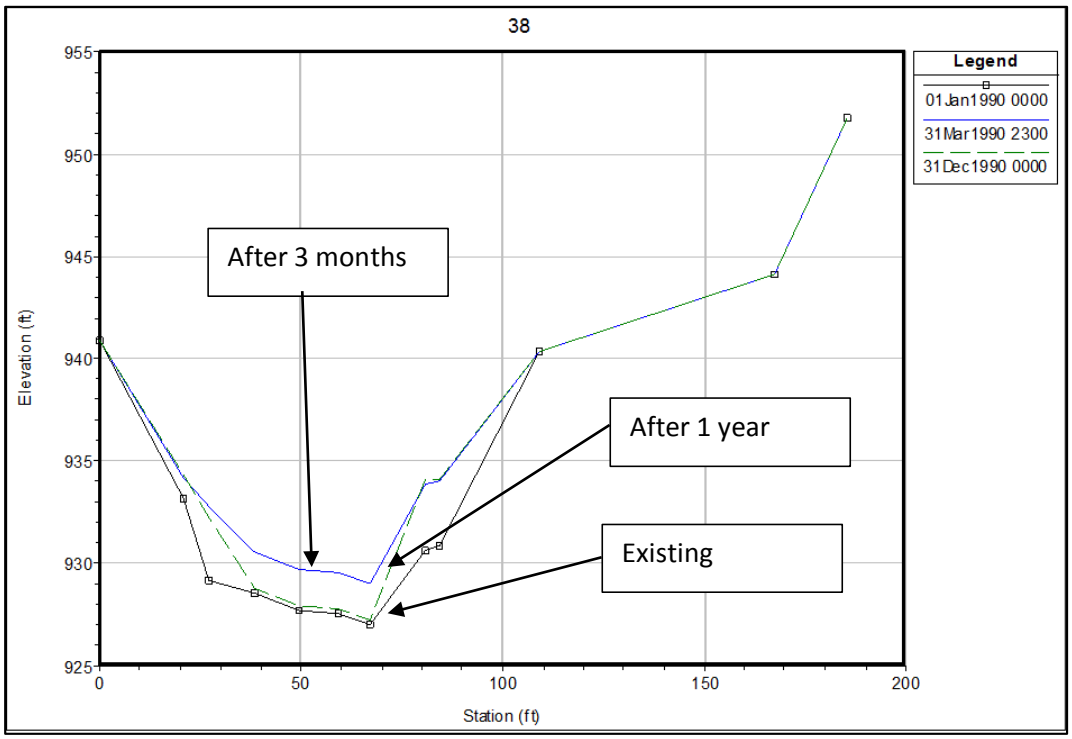



**Figure 6.** Changes in bed elevation 200 ft downstream of Power Dam (XS 38) after 60% removal due to movement of sediment. Pigg River, Franklin County, Va.

Additional notching simulations were performed to create comparisons of sediment transport. In all cases, the upstream channel profile is predicted to develop over the course of a few months. Even if the final notch was cut right from the beginning, the profile appears to equalize itself in a 4-5 month timeframe. This is an encouraging pattern for the possibilities of restoring the upstream channel. The long, linear nature of the reservoir and the confined nature of the upstream valley likely contribute to this progression. This pattern has also been observed in other dam removals, where notching or removals result in a rapid headcut progression and channel formation upstream (Kibler et. al 2011 , Doyle et al. 2003). Figure 7 depicts upstream profile development by notching at the base of the dam. The channel bed quickly lowers itself to the notch elevation and moves upstream until the profile equilibrates.

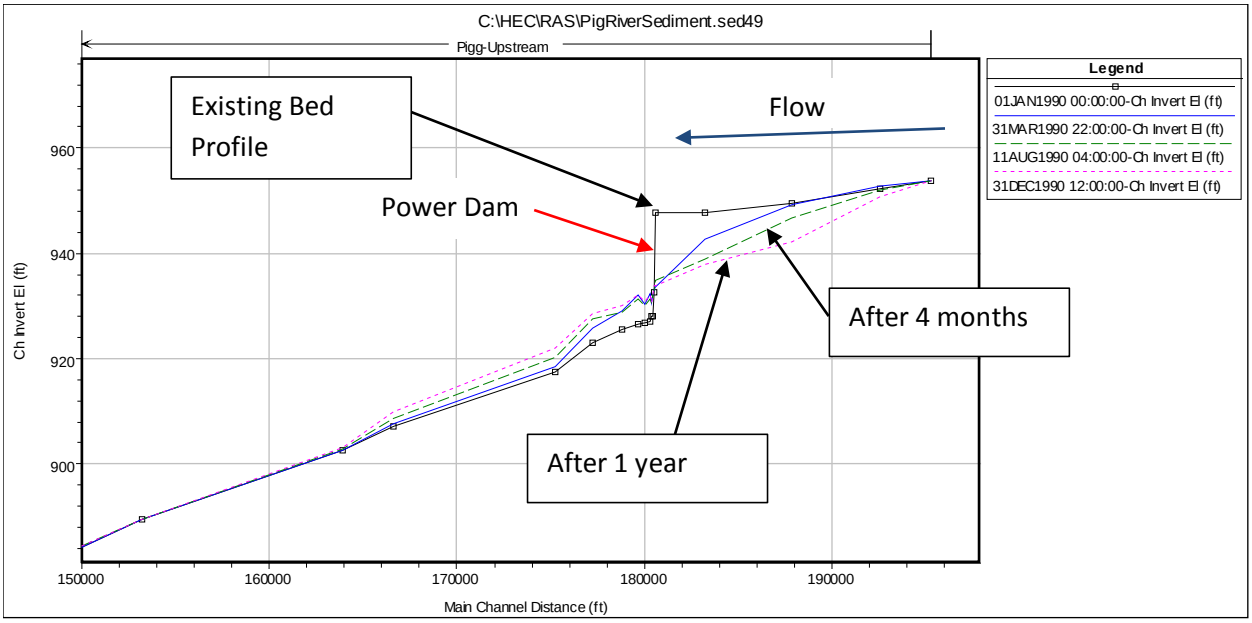



**Figure 7.** River bed changes upstream and downstream of Power Dam after 100% dam removal, Pigg River, Franklin County, Va.

The rapid development of the upstream channel also has implications for downstream changes. The faster that upstream channel formation can stabilize, the sooner mass transport downstream can be lessened. A closer examination of downstream processes found that in all notching scenarios, the upstream channel will develop in several months and continued redistribution of sediments will occur for at least a year. An approach that would maximize transport in a shorter period would be just as effective at upstream restoration and better at limiting the timeframe of downstream adjustments. This finding effectively eliminates the value of a notching strategy, and leads to a recommendation of implementing a full dam removal all at once.

## Downstream Adjustment

The potential pattern of downstream deposition can be examined closer with longer term simulations. Simulations of three years and 25 years were run to better predict the depth of sediment deposits, duration of increased sediment concentrations, and changes down to Leesville Lake. These results are most useful when compared to an existing conditions simulation. An existing conditions simulation, completed over time with the dam in place, is a useful baseline.

## Existing Conditions

A simulation of sediment transport in the existing conditions provides a few important insights. One is that the current impoundment is not quite full. If left in place, the dam will continue to accumulate sediment. Although the trapping rates may be diminished, it appears that the dam continues to be a disruption in the sediment supply to downstream reaches. This simulation shows changes to the river bed just downstream to be very slow. Most sediment that can currently pass the dam can now be transported farther downstream. This creates an increase in sediment concentrations throughout the Pigg River during storm events. Existing predictions show sediment concentrations in the 3,000-5,000mg/l range. This is a substantial amount of suspended sediment and is high even compared to recent measurements on area rivers like the Roanoke (Jastram et al., 2015). The simulated existing transport dynamics are consistent with the field observations that depict a sediment starved reach near the dam, and transport limited reaches farther downstream.  A model simulation that mimics field

observations also adds confidence in the modeling approach, inputs used, and methodology (Cui and Wilcox, 2008).

## Proposed Conditions

A longer term simulation of the dam removal shows the continued development of downstream deposits over time. The notching simulations revealed the biggest changes occurring during the first few months, with some additional redistribution over the first year. Although initial deposits in the near downstream area could be several feet, a pattern of new channel formation, bar or terrace development, and profile complexity is also predicted. Simulations of one year or longer show a new baseflow channel forming inside of the deposited sediments, and what could be new bars or terraces stabilizing on the margins of cross sections. This prediction is similar to those of other simulation and research studies on dam removal (Tullos et al. 2014, East et al., 2015). It should be noted that one dimensional models such as this one have been found to over-predict deposition because of the averaging nature of the calculations. These models may also not be able to fully described the development of bars due to the hydraulics that develop them. Development of vegetation on these deposits could further promote stabilization over time. Figures 8 and 9 show the deposition and bar development that might occur with a complete dam removal. These figures make it easier to visualize the initial deposition and new channel formation that is predicted. As a simulation of final notching all at once, these predictions are conservative views of the maximum changes that could occur.

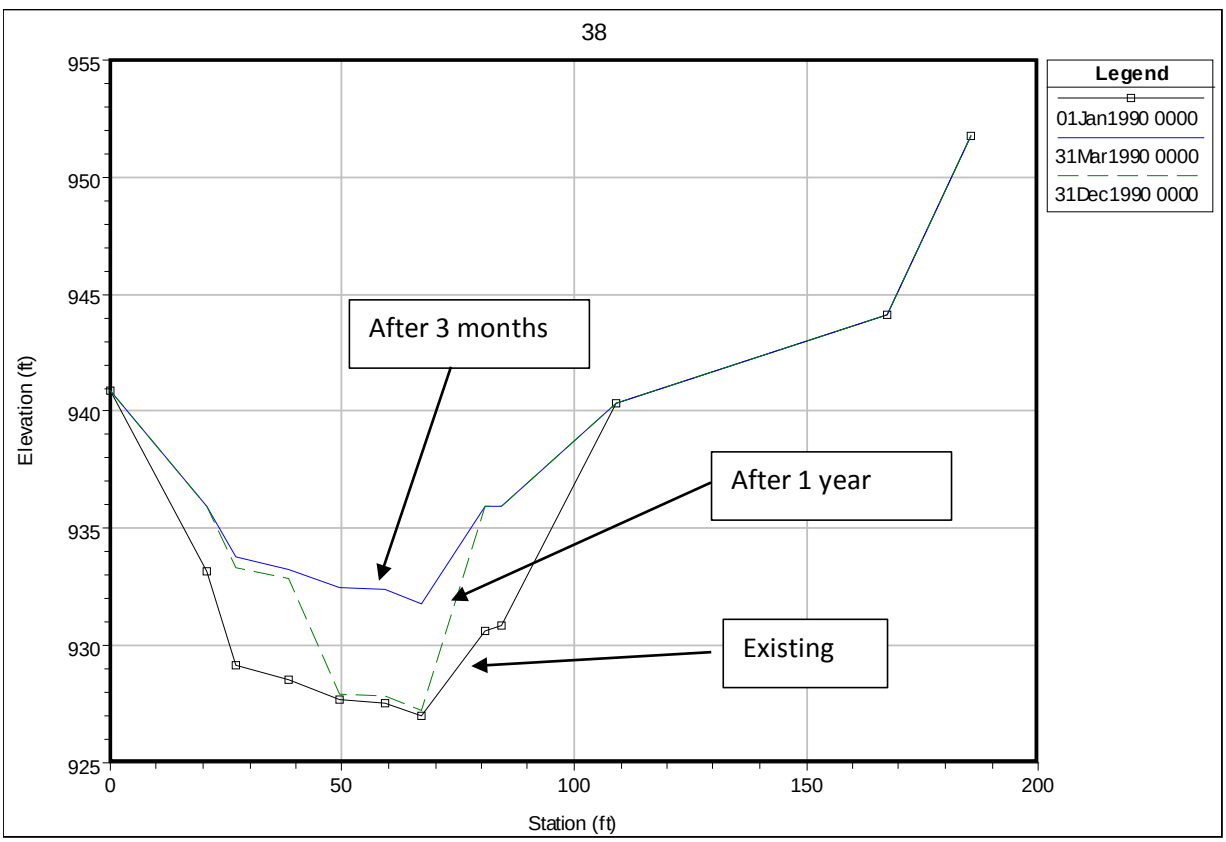



**Figure 8.** New channel formation inside initial deposits 200 feet downstream of Power Dam after complete dam removal (XS 38). Pigg River, Franklin County, Va.

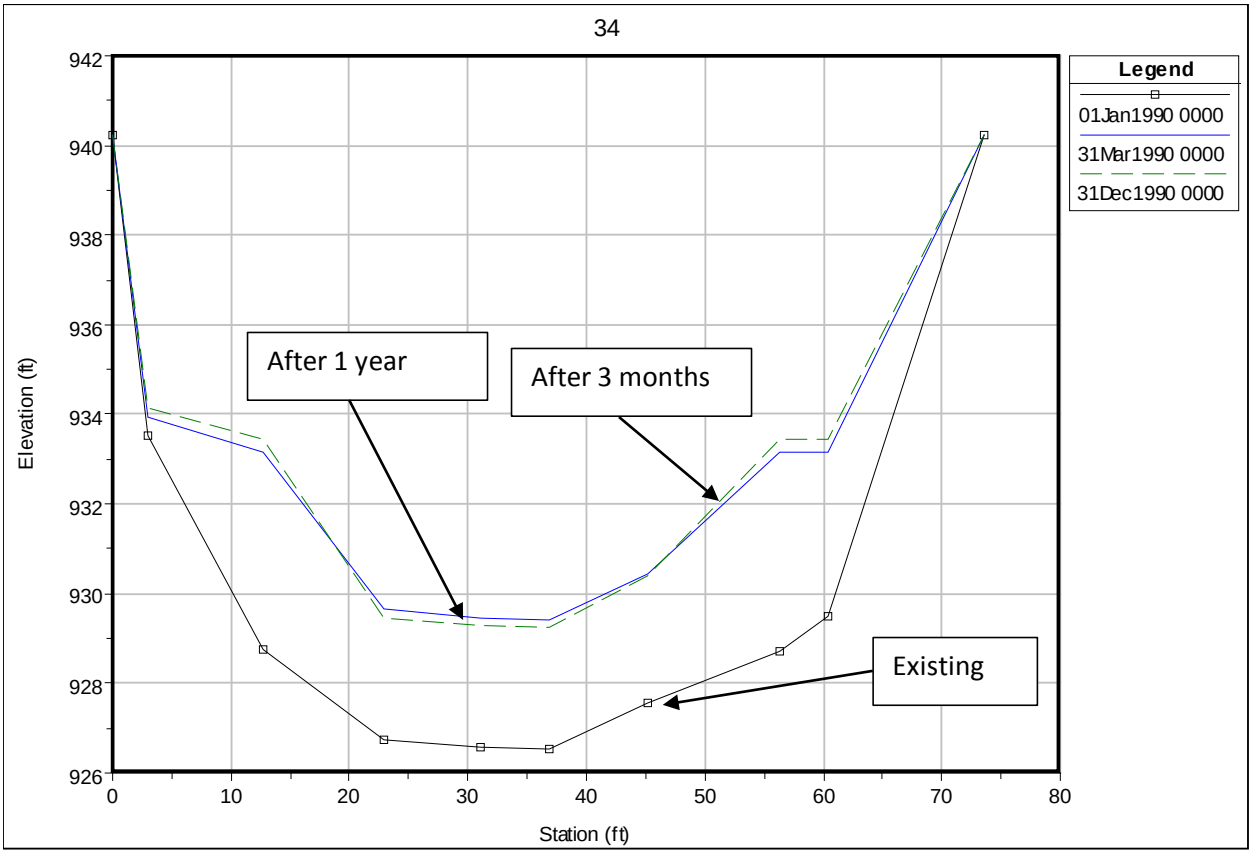



**Figure 9.** New channel formation inside initial deposits 0.3 miles downstream of Power Dam after complete dam removal (XS 34). Pigg River, Franklin County, Va.

During initial notching events, sediment concentrations are predicted to be in the 3,000-5,000 mg/l range during normal flow. This is similar to what occurs in the existing conditions during storm events. After the final notching, there could be higher spikes (> 10,000mg/l) in sediment concentrations, and especially during storms. Over time, the spikes in sediment concentration will be reduced, with concentrations lessening 3-5 years after the final configuration is achieved. These predicted increases are a common finding in dam removal studies. Published studies show increases of 4-10 times existing levels, which are similar to what is predicted at this site (Bountry et al. 2009).

A final model simulation was completed to predict downstream development over a period of 25 years. The cross sections and profiles from this simulation are provided in Appendix D. Existing and predicted river profiles are also shown. The results show a continuing trend of sediment redistribution and bed restoration over time. The overall river profile over long periods of time is nearly indistinguishable from existing conditions. The more permanent deposits are seen on the channel margins as point bars or terraces, and are most noticeable less than 3 miles from the dam (Appendix A and D).

## Discussion

The Pigg River downstream of Power Dam is in an evolutionary state of widening that will eventually lead to bank collapse and the formation of new terraces or floodplains. Nearly 90% of the river length from the dam to Leesville Lake has been modified by human intervention, and impacted due to sediment inbalances. Bed complexity and the frequency of riffles and deep pools has also been affected, as these features are more and more uncommon progressing downstream. Approximately 10% of the river, just downstream of the dam, remains in a mostly unembedded natural rocky streambed. This reach, however, is degraded from eroding banks and is the most exposed to potential bank collapse.

Field observations noted infiltration with sand in the remaining substrates, and it appears likely that continued sand loads will eventually compromise these features even with the dam in place.

Model simulations predict that the current impoundment can be restored to its original configuration in a short time period that could be measured in months. The actual recovery period could vary depending on flow conditions and any unknown features buried beneath the accumulated sediments. When the channel approaches a restored state, the bed material will coarsen as the historic streambed is uncovered. High flows may speed this process even further, as predictions indicate that a few large storms could move much of the trapped sediment. Debris blockages or bank collapse could, however, limit the trajectory or slow the profile development. It appears that the 2.2 miles currently impounded and at least a total of 3 miles or more upstream of the dam would be set on a path to recovery with the removal. A map showing the limits of the upstream study is provided in Appendix B. This length of river should approach its historic configuration and develop a natural pattern of riffles and pools suitable for river habitats. In addition, the 25 miles upstream and the 50 miles downstream of the dam would flow connected with no additional known barriers.

The flat slope of the river downstream of the dam and overly wide channel reduce its capacity to flush large sediment loads. This combined with the volume of sediment trapped behind the dam and relatively low flow rates will lead to downstream deposition. Sediment transport simulations confirm that both temporary and permanent geomorphic changes are likely. Changes to the river bed material will be most evident in the area just downstream of the dam. The first few downstream miles will serve as a temporary sediment sink. Simulations predict that several feet of sediment could be deposited along this reach. Most of this deposition will occur concurrently with the upstream channel development. After an initial period of deposition, these deposits appear to be redistributed over time, as a baseflow channel develops with alternating bars and terraces. This process of deposition and channel narrowing may mimic or even accelerate the evolutionary process that is already underway, and result in greater sediment balance, floodplain connection, and complexity over time. This process is predicted to be well developed within one to three years after dam removal. Although the changes near the dam will be more noticeable, approximately 90% of the downstream river length will be unchanged compared to current conditions. The deposition in the area nearest the dam will limit sediment transport further downstream. In addition, the current level of sand embeddedness will make the small amount of accumulation predicted nearly undetectable. Over time, it appears that the sediment supply and transport along the entire river can be brought into a better balance. The majority of disturbance and redistribution is predicted to happen in a period of just a few years. However, increases in turbidity and suspended sediment load will persist for longer periods of time. Predictable increases may last at least 3-5 years, and lessen depending on feature development, vegetation growth, or as other stabilization improves.

The predicted locations of deposition are accessible in case geomorphic or habitat improvement efforts are warranted in future years. This is different from many stretches of the Pigg river, where steep valleys or forest prevent access. Restoration or improvement of channel features such as riffles and pools could be accomplished if deposits appear to have lasting detrimental impacts. Development and implementation of a 5 year annual monitoring plan would help track upstream channel development, downstream deposition, and recovery. Geomorphic surveys of cross section dimensions, features, and possibly sediment sampling would provide further insight on predictions and inform potential restoration efforts if needed.

The results of this study were presented in a stakeholder meeting including state and federal agency personnel. Additional discussion and questions from that meeting are answered in a more specific format in Appendix E.

# References


Austin, Tom. Hydraulic Analysis Summary Report, Pigg River Power Dam Removal. August, 2015. Prepared by Mattern and Craig Consulting Enginners and Surveyors, Roanoke, Va.

Bountry, J. and Greimann, B.P. 2009. Sediment Considerations for Potential Dam Removal Projects. Technical Report No. SRH-2009-39. US Department of the Interior Bureau of Reclamation.

Commonwealth of Virginia. 2014 Clean Water Act Section 319 Nonpoint Source Pollution Management Program Annual Report. February 13, 2015.

Cui, Y. and Wilcox, A. 2008. Development and application of numerical models of sediment transport associated with dam removal. Chapter 23 in "Sedimentation Engineering: Theory, Measurements, Modeling, and Practice, ASCE Manual 110," Garcia, M.H., ed., 995-1020, ASCE, Reston, VA, ISBN 978-0784408149

Dail, M., and Nash, P. Pigg River IP Steering Committee. Pigg River and Old Womans Creek Watersheds TMDL Implementation Plan. June 4, 2009.

Doyle, M. W., E. H. Stanley, and J. M. Harbor, Channel adjustments following two dam removals in Wisconsin, Water Resour. Res., 39(1), 1011, doi:10.1029/2002WR001714, 2003.

East, A., Pess, G, Bountry, J., Magirl, C., Ritchie, A., Logan, J., Randle, Mastin, M., Minear, J., Duda, J., Liermann, M., McHenry, M., Beechie, T., Shafroth, P. Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change, Geomorphology, Volume 228, 1 January 2015, Pages 765-786, ISSN 0169-555X, http://dx.doi.org/10.1016/j.geomorph.2014.08.028.

Hitt, N., Jones, J. and Convery, K. 2009. Biomonitoring for the Rocky Mount Power Dam Removal Project: Establishing Baseline Conditions Final report. Conservation Management Institute, Virginia Tech University.

Jastram, J.D., Krstolic, J.L., Moyer, D.L., and Hyer, K.E., 2015, Fluvial geomorphology and suspended-sediment transport during construction of the Roanoke River Flood Reduction Project in Roanoke, Virginia, 2005–2012: U.S. Geological Survey Scientific Investigations Report 2015–5111, 53 p., http://dx.doi.org/10.3133/sir20155111.

Keaton, J.N., Messinger, T, and Doheny, E.J., 2005. Development and Analysis of Regional Curves for Streams in the Non-Urban Valley and Ridge Physiographic Province, Marylnad, Virginina, and West Virginia. U.S. Geological Survey Scientific Investigations Report 2005–5076.

Kibler, K. Tullos, D., Kondolf, M., 2011. Evolving Expectations of Dam Removal Outcomes: Downstream Geomorphic Effects Following Removal of a Small, Gravel-Filled Dam. Journal of the American Water Resources Association. Vol. 47, No. 2.

Lotspeich, R.R., 2009, Regional curves of bankfull channel geometry for non-urban streams in the Piedmont Physiographic Province, Virginia: U.S. Geological Survey Scientific Investigations Report 2009– 5206, 51 p.

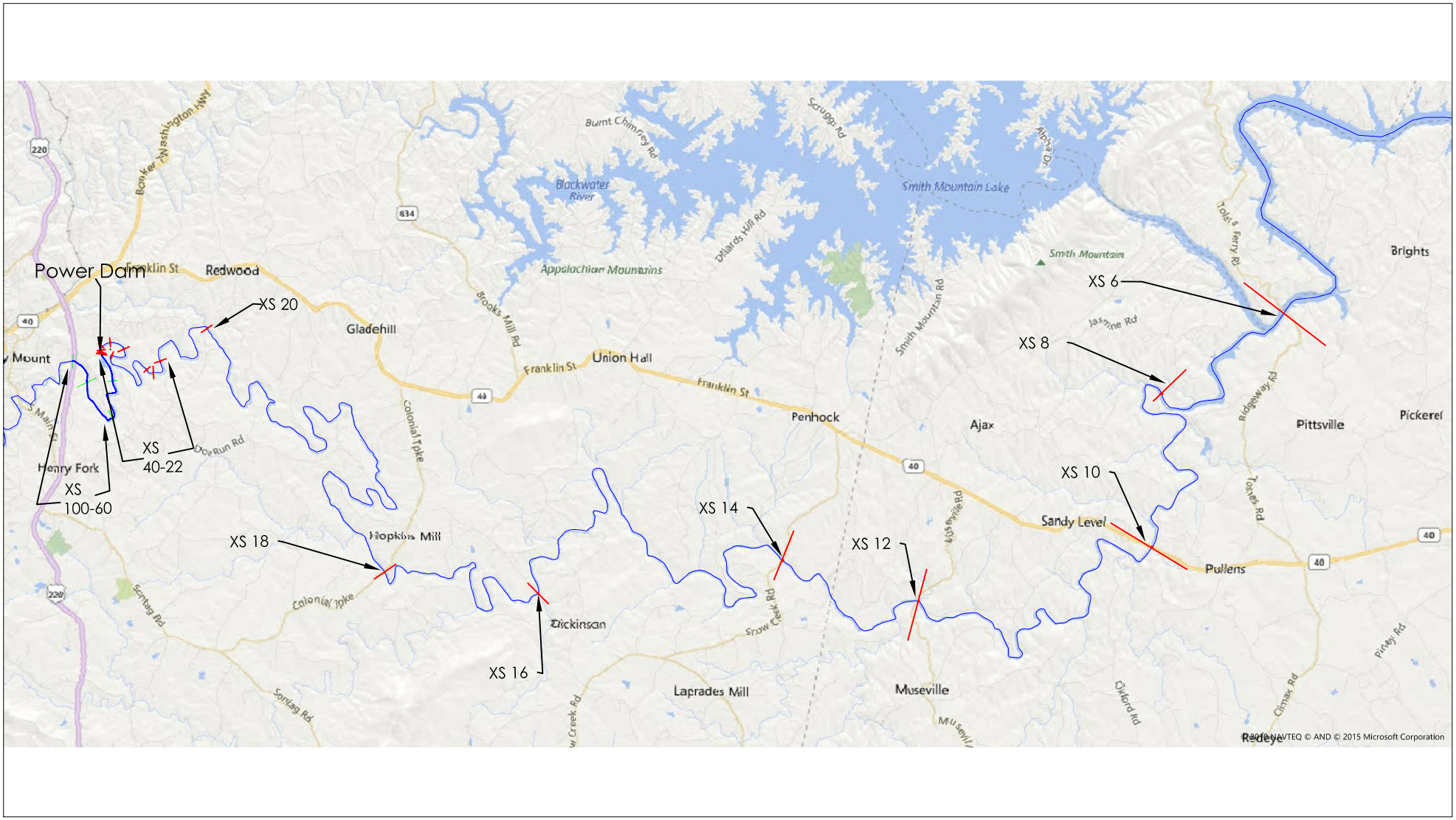
Randle, T.J. and Greinmann, B., 2004. Sediment Impact Analysis for the Proposed Hemlock Dam Removal Project. US Department of the Interior Bureau of Reclamation.

Roberson, R., Whitt, G. Sediment Sampling and Analysis Study, Pigg River Power Dam, Franklin County, Virginia. October, 2007. Prepared by Froehling and Roberson, Inc. Roanoke, Va.

Schumm, S.A., M.D. Harvey, and C.C. Watson, 1984. Incised Channels: Morphology, Dynamics, and Control. Water Resources Publications, Littleton, Colorado, 200 pp.

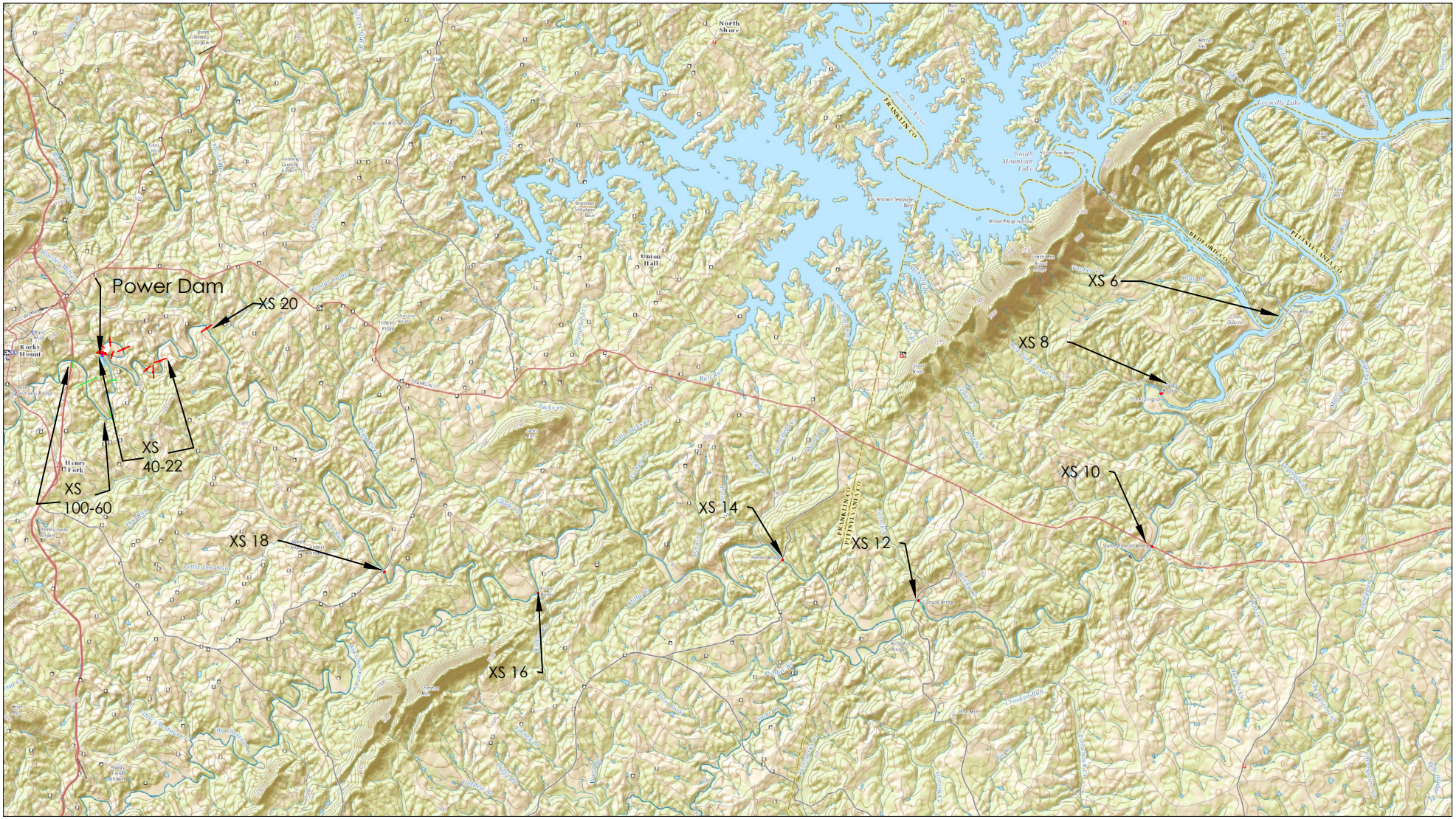
Tullos, D., Finn D., Walter C. 2014. Geomorphic and Ecological Disturbance and Recovery from Two Small Dams and Their Removal. PLoS ONE 9(9):e108091. doi:10.1371/journal.pone.0108091

# Appendix A – Project Maps



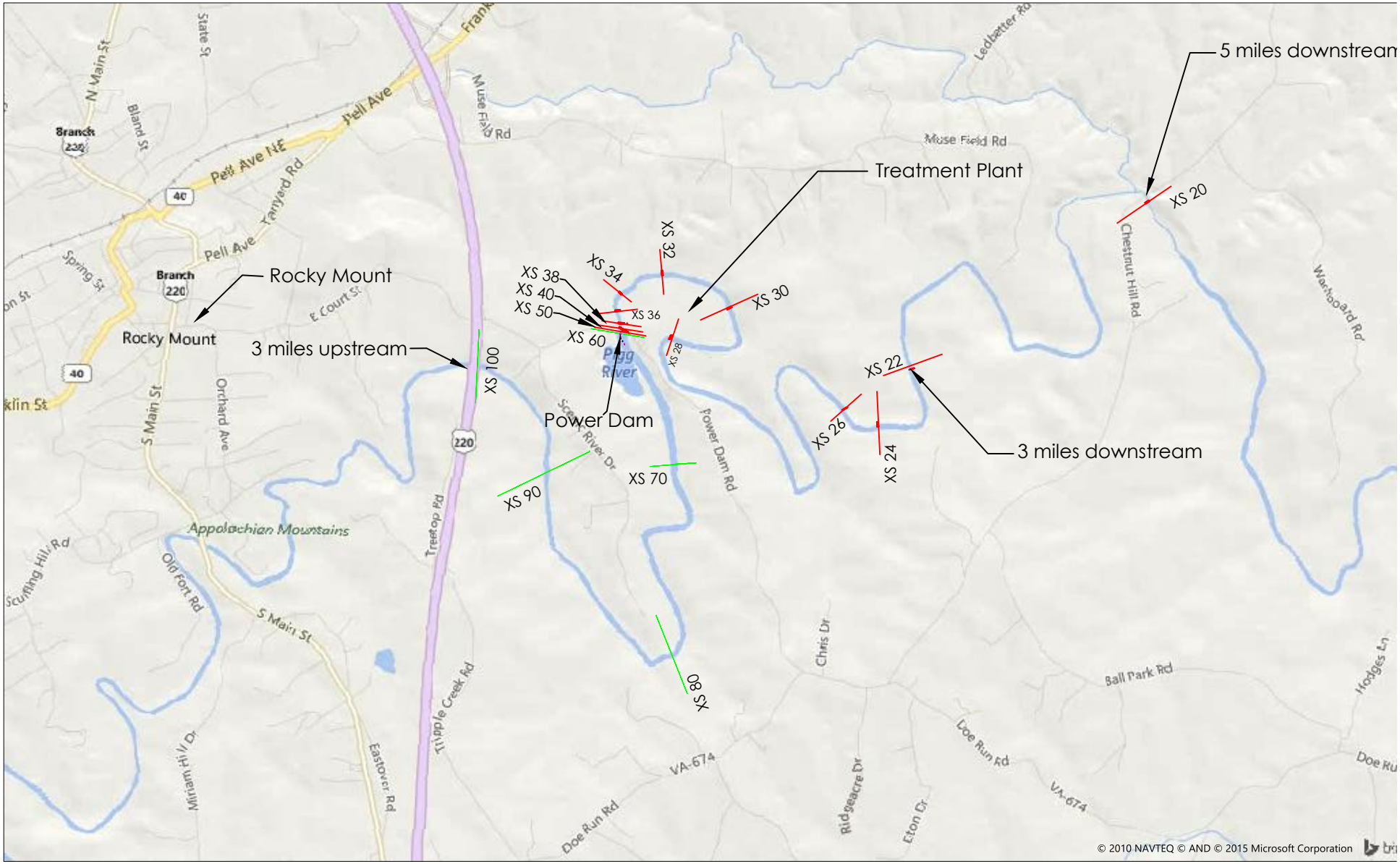

Power Dam Sediment Study
Cross Section Locations
Pigg River from Rocky Mount to Leesville Lake

0 2 4 Miles
Scale 1 inch = 2 miles




Power Dam Sediment Study
Cross Section Locations
Pigg River from Rocky Mount to Leesville Lake

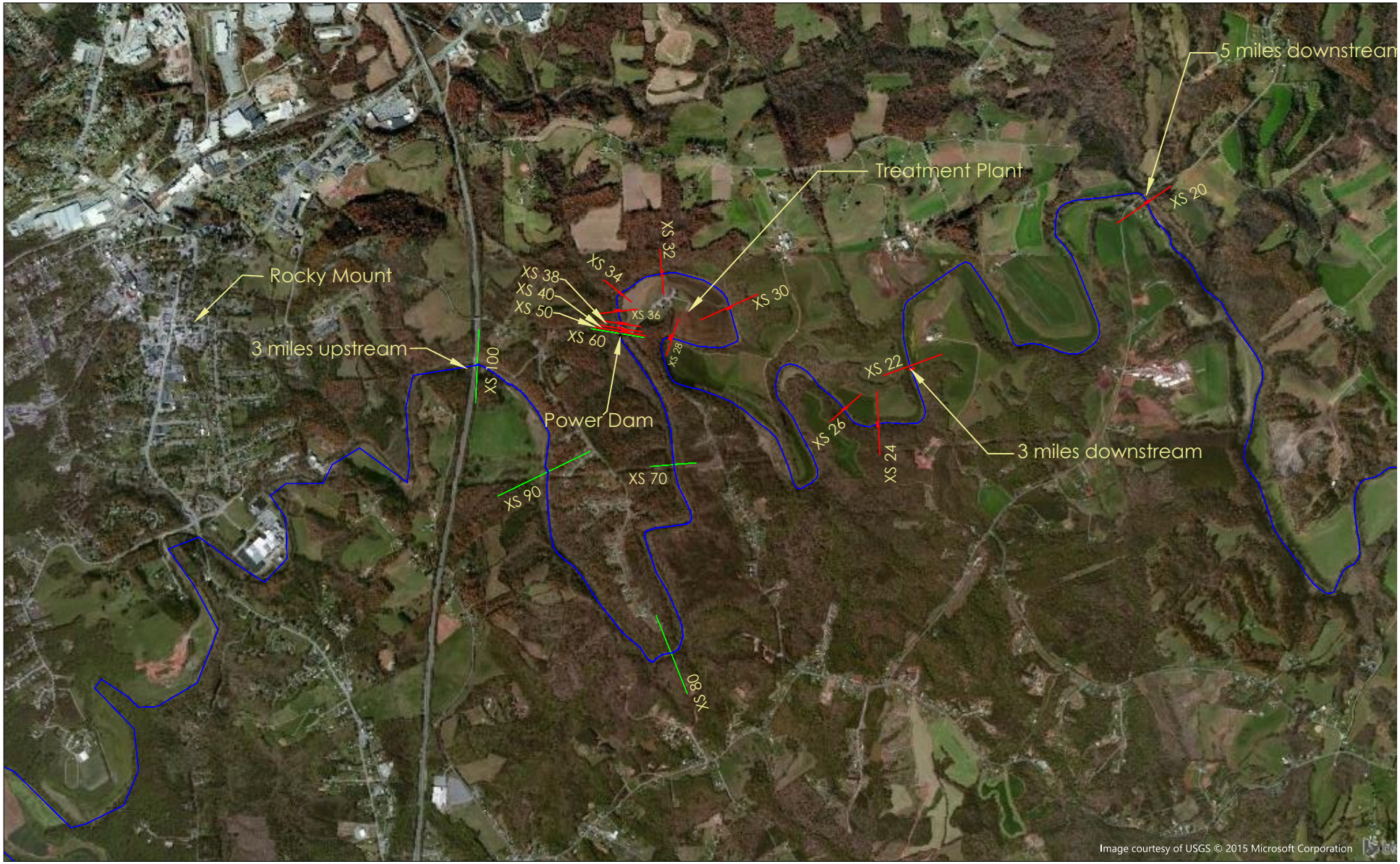
0 2 4 Miles
Scale 1 inch = 2 miles




Power Dam Sediment Study
Cross Section Locations
Current impoundment area and downstream area to Chestnut Hill Rd.

0 0.5 1 Miles

Scale 1 inch = 0.5 mile




Power Dam Sediment Study
Cross Section Locations
Current impoundment area and downstream area to Chestnut Hill Rd.

0 0.5 1 Miles

Scale 1 inch = 0.5 miles

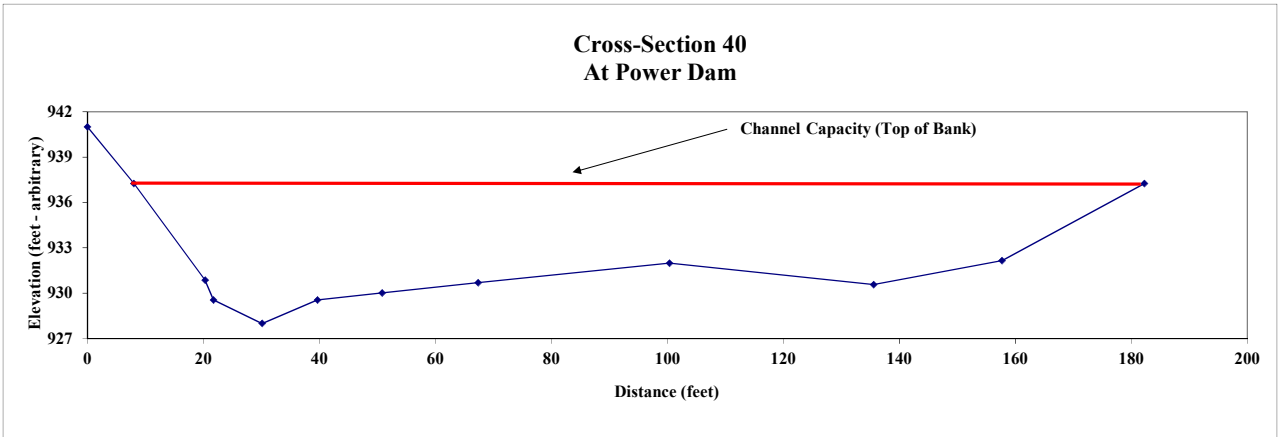
# Appendix B – Cross Section Surveys

| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 40 |
| **Feature** | Pool **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| 0 | 940.99 | GS | |
| 8 | 937.25 | Est | |
| 20.3 | 930.85 | GS | |
| 21.76 | 929.55 | GS | |
| 30.13 | 928 | GS | |
| 39.69 | 929.55 | GS | |
| 50.83 | 930.02 | GS | |
| 67.37 | 930.69 | GS | |
| 100.36 | 931.98 | GS | |
| 135.58 | 930.57 | GS | |
| 157.72 | 932.16 | GS | |
| 182.29 | 937.25 | GS | |

**Photo of Cross-Section 40**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 997.2 | | | |
| **Width** | 174.3 | | | |
| **Mean Depth** | 5.7 | | | |
| **Max Depth** | 9.3 | | | |
| **w/d Ratio** | 30.5 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

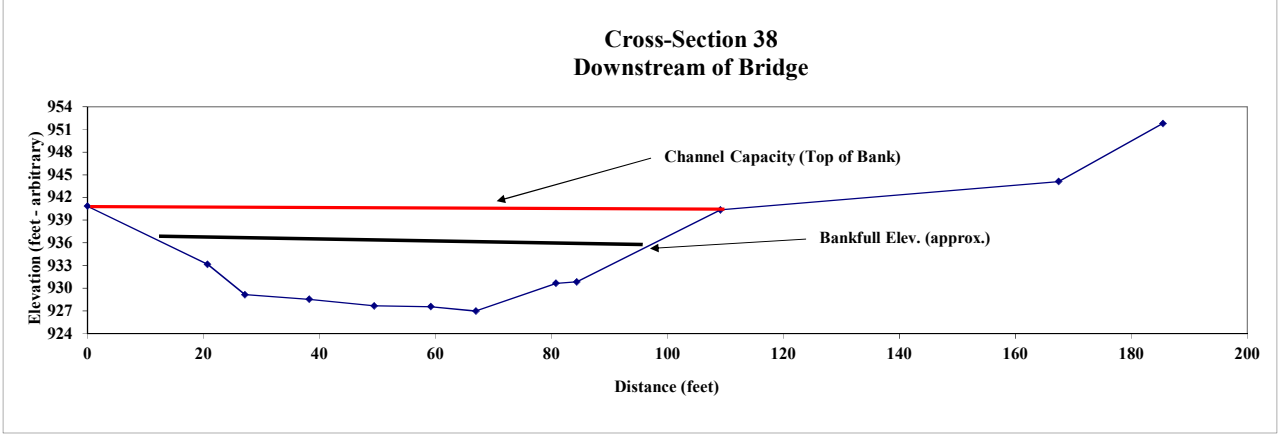


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 38 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| 0 | 940.85 | GS | |
| 20.67 | 933.17 | GS | |
| 27.14 | 929.14 | GS | |
| 38.26 | 928.53 | GS | |
| 49.45 | 927.67 | GS | |
| 59.2 | 927.56 | GS | |
| 66.99 | 926.98 | GS | |
| 80.8 | 930.65 | GS | |
| 84.39 | 930.83 | GS | |
| 109.17 | 940.36 | GS | |
| 167.45 | 944.11 | GS | |
| 185.45 | 951.79 | GS | |

**Photo of Cross-Section 38 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 906.6 | | | |
| **Width** | 109.2 | | | |
| **Mean Depth** | 8.3 | | | |
| **Max Depth** | 13.9 | | | |
| **w/d Ratio** | 13.1 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

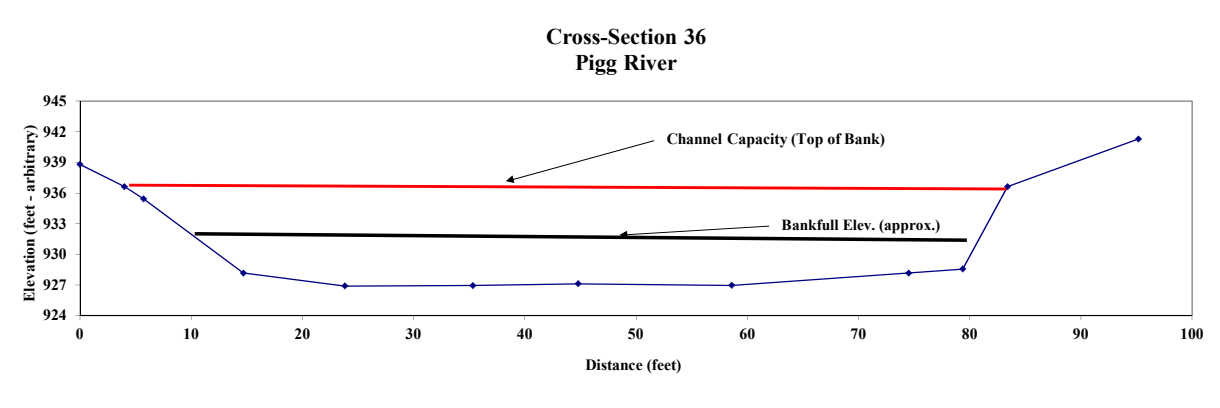


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 36 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| 0 | 938.79 | GS | |
| 4 | 936.62 | Est | |
| 5.71 | 935.43 | GS | |
| 14.69 | 928.14 | GS | |
| 23.82 | 926.89 | GS | |
| 35.34 | 926.92 | GS | |
| 44.8 | 927.1 | GS | |
| 58.6 | 926.94 | GS | |
| 74.53 | 928.16 | GS | |
| 79.39 | 928.54 | GS | |
| 83.41 | 936.62 | GS | |
| 95.18 | 941.29 | GS | |

**Photo of Cross-Section 36 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 663.8 | | | |
| **Width** | 83.4 | | | |
| **Mean Depth** | 8.0 | | | |
| **Max Depth** | 9.7 | | | |
| **w/d Ratio** | 10.5 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

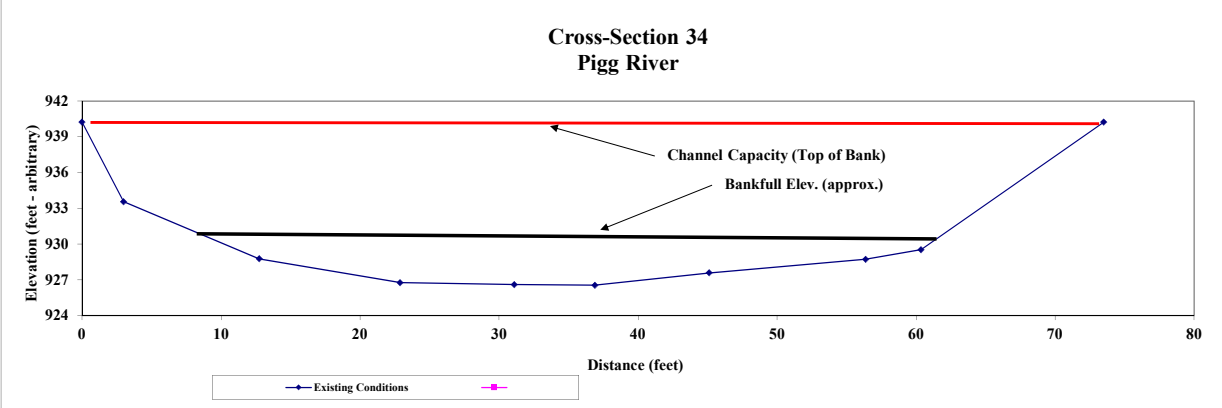


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 34 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| **Existing Conditions** | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **940.24** | **Est** | |
| 3 | 933.54 | GS | 0 |
| 12.76 | 928.75 | GS | 9.76 |
| 22.89 | 926.76 | GS | 19.89 |
| 31.09 | 926.58 | GS | 28.09 |
| 36.89 | 926.54 | GS | 33.89 |
| 45.11 | 927.57 | GS | 42.11 |
| 56.37 | 928.71 | GS | 53.37 |
| 60.36 | 929.51 | GS | 57.36 |
| 73.51 | 940.24 | GS | 70.51 |
| | | | |
| | | | |

**Photo of Cross-Section 34 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 765.4 | | | |
| **Width** | 73.5 | | | |
| **Mean Depth** | 10.4 | | | |
| **Max Depth** | 13.7 | | | |
| **w/d Ratio** | 7.1 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

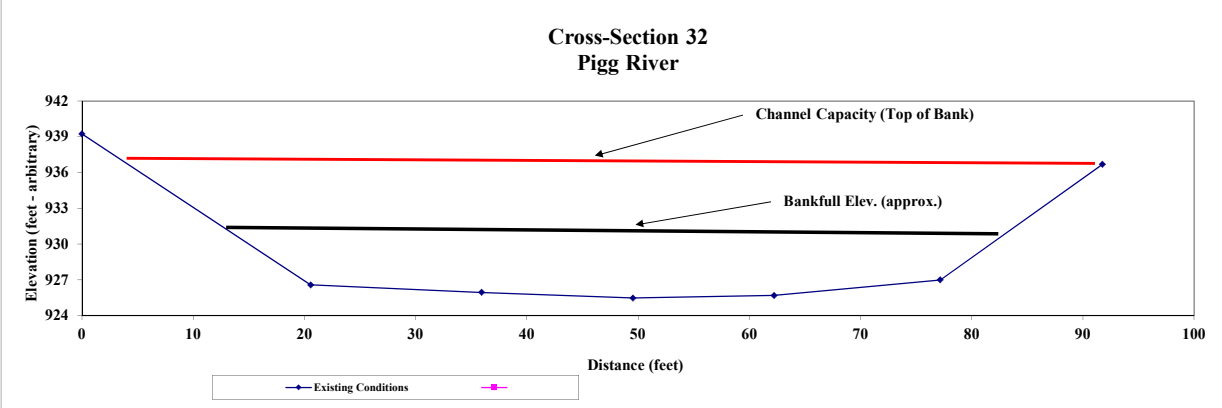


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 32 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **939.23** | **Est** | |
| 20.57 | 926.56 | GS | |
| 35.93 | 925.93 | GS | |
| 49.54 | 925.47 | GS | |
| 62.23 | 925.68 | GS | |
| 77.16 | 926.98 | GS | |
| 91.76 | 936.7 | GS | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Photo of Cross-Section 32 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 677.3 | | | |
| **Width** | 91.8 | | | |
| **Mean Depth** | 7.4 | | | |
| **Max Depth** | 11.2 | | | |
| **w/d Ratio** | 12.4 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

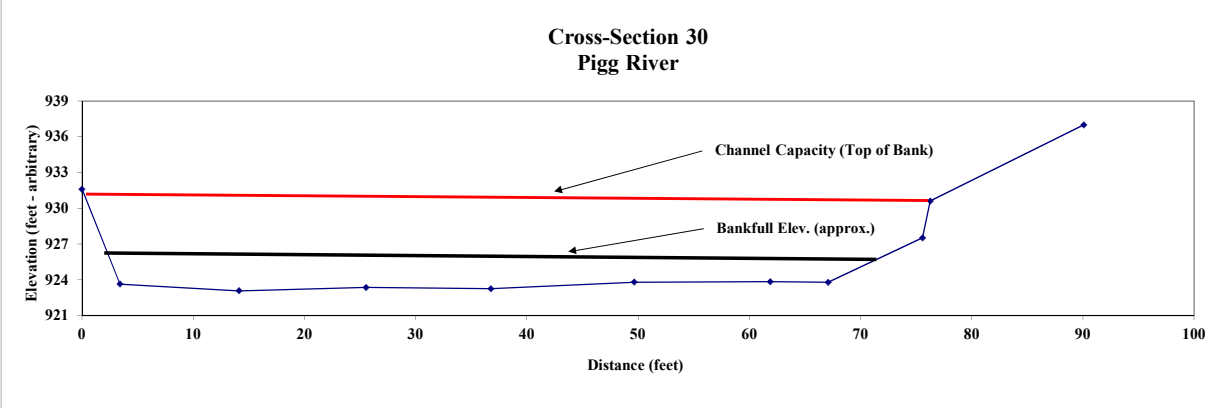


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 30 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **931.59** | **Est** | |
| 3.42 | 923.63 | GS | |
| 14.12 | 923.07 | GS | |
| 25.56 | 923.34 | GS | |
| 36.76 | 923.24 | GS | |
| 49.67 | 923.79 | GS | |
| 61.88 | 923.84 | GS | |
| 67.09 | 923.77 | GS | |
| 75.58 | 927.51 | GS | |
| 76.28 | 930.59 | GS | |
| 90.08 | 937 | GS | |
| | | | |

**Photo of Cross-Section 30 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 569.1 | | | |
| **Width** | 76.3 | | | |
| **Mean Depth** | 7.5 | | | |
| **Max Depth** | 8.5 | | | |
| **w/d Ratio** | 10.2 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

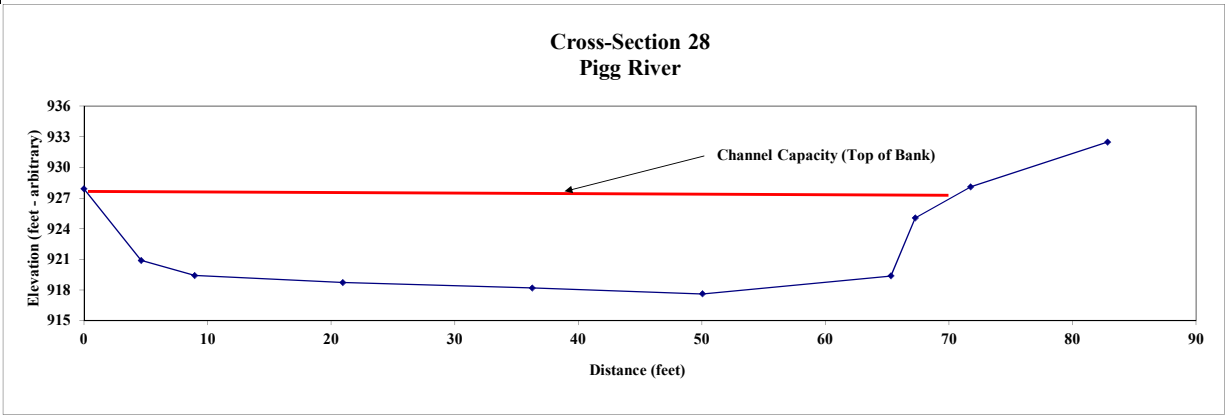


| | | | |
|---|---|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study | | |
| **Cross Section** | 28 | | |
| **Feature** | Pool | **Station:** | |
| **Date** | | | |
| **Crew** | Bass, Cornerstone | | |

| 2015 | | | |
|---|---|---|---|
| **Existing Conditions** | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **927.88** | **Est** | |
| 4.64 | 920.87 | GS | |
| 8.96 | 919.41 | GS | |
| 20.94 | 918.7 | GS | |
| 36.29 | 918.18 | GS | |
| 50.06 | 917.6 | GS | |
| 65.32 | 919.35 | GS | |
| 67.28 | 925.03 | GS | |
| 71.76 | 928.09 | GS | |
| 82.85 | 932.48 | GS | |
| | | | |
| | | | |

**Photo of Cross-Section 28 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 576.3 | | | |
| **Width** | 67.3 | | | |
| **Mean Depth** | 8.6 | | | |
| **Max Depth** | 10.3 | | | |
| **w/d Ratio** | 7.9 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

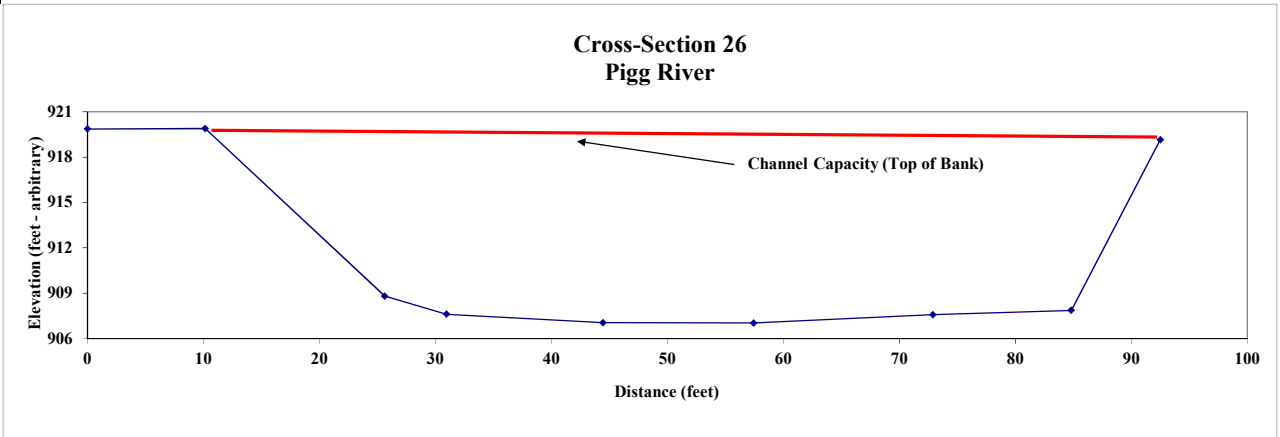


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 26 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **919.86** | **Est** | |
| 10.16 | 919.89 | GS | |
| 25.62 | 908.81 | GS | |
| 30.95 | 907.61 | GS | |
| 44.44 | 907.05 | GS | |
| 57.44 | 907.03 | GS | |
| 72.9 | 907.58 | GS | |
| 84.82 | 907.86 | GS | |
| 92.51 | 919.15 | GS | |
| | | | |
| | | | |
| | | | |

**Photo of Cross-Section 26 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 870.9 | | | |
| **Width** | 82.4 | | | |
| **Mean Depth** | 10.6 | | | |
| **Max Depth** | 12.8 | | | |
| **w/d Ratio** | 7.8 | | | |
| **FP Width** | | | | |
| **ER** | | | | |



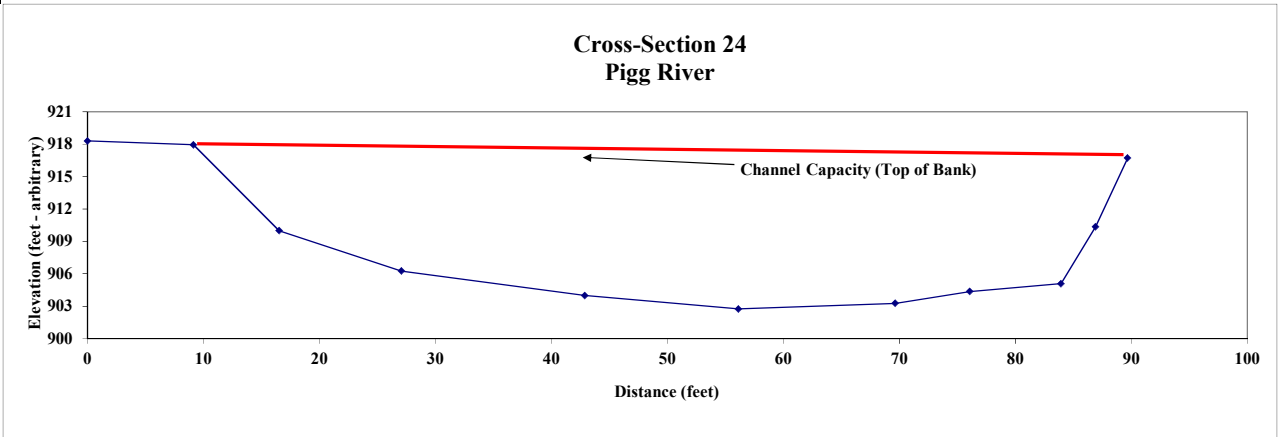
| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 24 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **918.3** | **Est** | |
| 9.12 | 917.95 | GS | |
| 16.52 | 909.99 | GS | |
| 27.07 | 906.26 | GS | |
| 42.87 | 903.98 | GS | |
| 56.13 | 902.75 | GS | |
| 69.64 | 903.26 | GS | |
| 76.08 | 904.36 | | |
| 83.93 | 905.09 | | |
| 86.92 | 910.35 | | |
| 89.68 | 916.71 | | |
| | | | |

| Station | Elevation | Length | Grade Ahead | Grade Back |
|---|---|---|---|---|
| 0+00.00 | 918.295' | 9.116' | -3.82% | 3.82% |
| 0+09.12 | 917.946' | 7.408' | -107.46% | 107.46% |
| 0+16.52 | 909.986' | 10.544' | -35.31% | 35.31% |
| 0+27.07 | 906.263' | 15.807' | -14.38% | 14.38% |
| 0+42.87 | 903.989' | 13.254' | -9.30% | 9.30% |
| 0+56.13 | 902.757' | 13.511' | 3.72% | -3.72% |
| 0+69.64 | 903.260' | 6.445' | 17.07% | -17.07% |
| 0+76.08 | 904.360' | 7.849' | 9.32% | -9.32% |
| 0+83.93 | 905.092' | 2.989' | 175.88% | -175.88% |
| 0+86.92 | 910.350' | 2.759' | 230.49% | -230.49% |
| 0+89.68 | 916.709' | | | |

**Photo of Cross-Section 24**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 752.3 | | | |
| **Width** | 69.6 | | | |
| **Mean Depth** | 10.8 | | | |
| **Max Depth** | 15.6 | | | |
| **w/d Ratio** | 6.4 | | | |
| **FP Width** | | | | |
| **ER** | | | | |



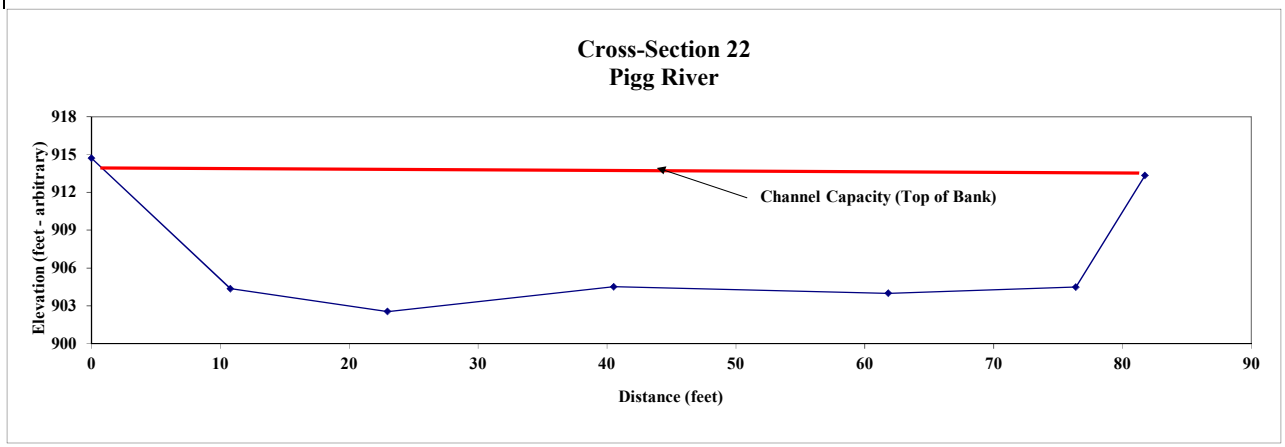
| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 22 |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **914.72** | **Est** | |
| 10.77 | 904.36 | GS | |
| 22.98 | 902.54 | GS | |
| 40.53 | 904.51 | GS | |
| 61.82 | 903.99 | GS | |
| 76.39 | 904.48 | GS | |
| 81.75 | 913.34 | GS | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

| Station | Elevation | Length | Grade Ahead | Grade Back |
|---|---|---|---|---|
| 0+00.00 | 914.719' | 10.774' | -96.15% | 96.15% |
| 0+10.77 | 904.359' | 12.206' | -14.92% | 14.92% |
| 0+22.98 | 902.538' | 17.546' | 11.26% | -11.26% |
| 0+40.53 | 904.513' | 21.290' | -2.46% | 2.46% |
| 0+61.82 | 903.990' | 14.569' | 3.35% | -3.35% |
| 0+76.39 | 904.477' | 5.361' | 165.37% | -165.37% |
| 0+81.75 | 913.343' | | | |

**Photo of Cross-Section 22**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 740.9 | | | |
| **Width** | 81.8 | | | |
| **Mean Depth** | 9.1 | | | |
| **Max Depth** | 12.2 | | | |
| **w/d Ratio** | 9.0 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

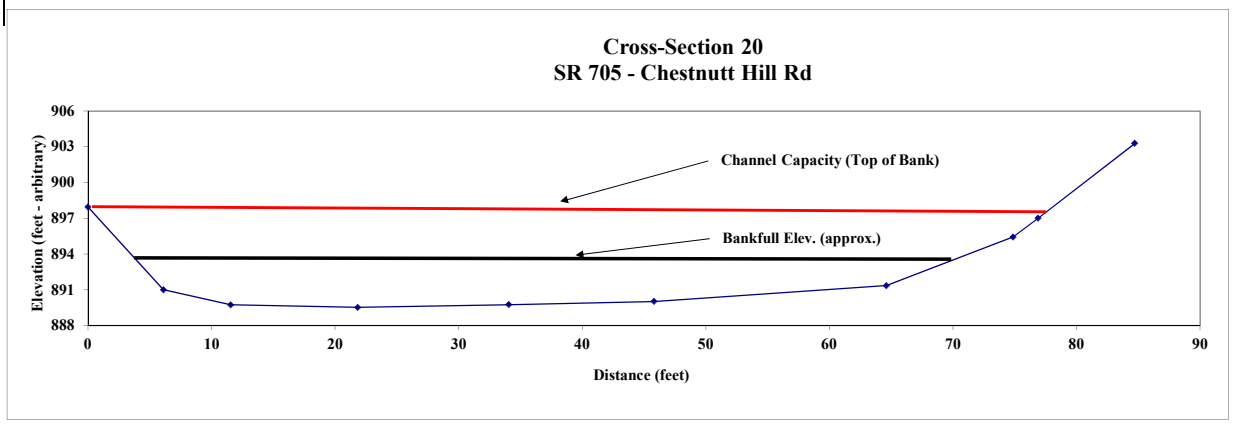


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 20 at 705/Chestnutt Hill Rd |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **897.94** | **Est** | |
| 6.11 | 890.99 | GS | |
| 11.55 | 889.73 | GS | |
| 21.84 | 889.52 | GS | |
| 34.05 | 889.74 | GS | |
| 45.81 | 890.01 | GS | |
| 64.61 | 891.33 | GS | |
| 74.86 | 895.42 | GS | |
| 76.9 | 897 | Est | |
| 84.72 | 903.28 | GS | |
| | | | |
| | | | |

**Photo of Cross-Section 20 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 510.1 | | | |
| **Width** | 76.9 | | | |
| **Mean Depth** | 6.6 | | | |
| **Max Depth** | 8.4 | | | |
| **w/d Ratio** | 11.6 | | | |
| **FP Width** | | | | |
| **ER** | | | | |



| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 18 at 718/Colonial Turnpike |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| **Existing Conditions** | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **785.23** | **Est** | |
| 5 | 780.62 | GS | |
| 9.32 | 777.93 | GS | |
| 29.63 | 776.56 | GS | |
| 46.32 | 776.41 | GS | |
| 61.98 | 776.73 | GS | |
| 82.53 | 778.15 | GS | |
| 107.6 | 785.23 | GS | |
| | | | |
| | | | |
| | | | |
| | | | |

| **0** |
|---|
| 4.32 |
| 24.63 |
| 41.32 |
| 56.98 |
| 77.53 |
| 102.6 |

**Photo of Cross-Section 18 - Looking Downstream**

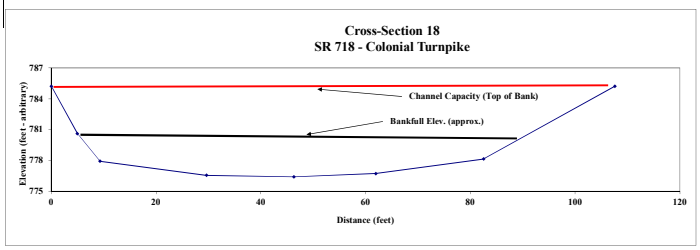
| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 718.3 | | | |
| **Width** | 107.6 | | | |
| **Mean Depth** | 6.7 | | | |
| **Max Depth** | 8.8 | | | |
| **w/d Ratio** | 16.1 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

**Area Calculations**

| Existing Width | Existing Depth | Existing Area |
|---|---|---|
| 0.0 | 0 | 0 |
| 5.0 | 4.61 | 11.53 |
| 4.3 | 7.30 | 25.73 |
| 20.3 | 8.67 | 162.18 |
| 16.7 | 8.82 | 145.95 |
| 15.7 | 8.50 | 135.62 |
| 20.6 | 7.08 | 160.08 |
| 25.1 | 0.00 | 88.75 |
| **107.6** | **Sum** | **718.30** |

**Area Calculations**

| 2004 BankFull Width | 2004 BankFull Depth | 2004 BankFull Area |
|---|---|---|
| 0.0 | 0.00 | 0.00 |
| 0.0 | 30.06 | 0.00 |
| 0.0 | 9.51 | 0.00 |
| 0.0 | -15.56 | 0.00 |
| 0.0 | 87.04 | 0.00 |
| 0.0 | 87.04 | 0.00 |
| 0.0 | 87.04 | 0.00 |
| 0.0 | 0.00 | 0.00 |
| **0.0** | **Sum** | **0.00** |

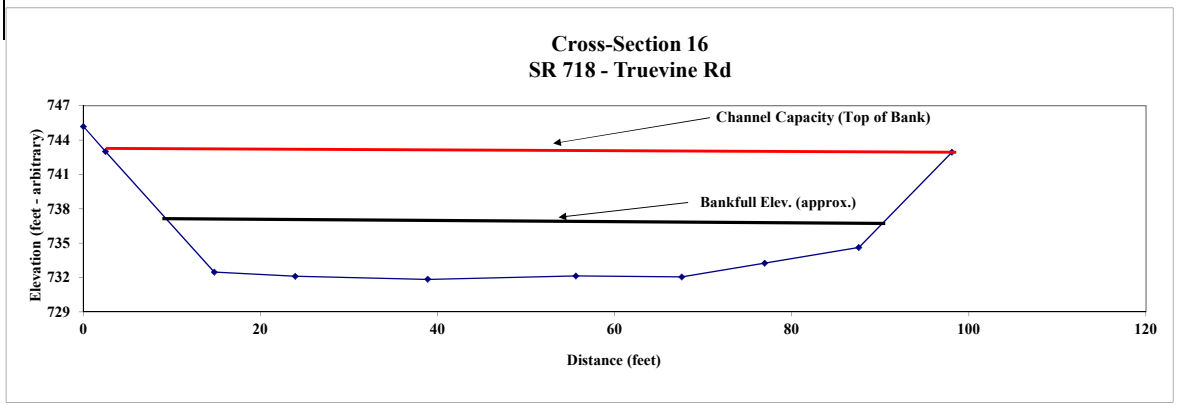


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 16 at 646/Truevine Rd |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| 0 | 745.19 | GS | |
| **2.5** | **743** | **Est** | |
| 14.77 | 732.45 | GS | |
| 23.93 | 732.09 | GS | |
| 38.88 | 731.83 | GS | |
| 55.63 | 732.13 | GS | |
| 67.59 | 732.04 | GS | |
| 76.96 | 733.24 | GS | |
| 87.58 | 734.6 | GS | |
| 98.1 | 742.94 | Est | |
| | | | |
| | | | |

**Photo of Cross-Section 16 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 881.2 | | | |
| **Width** | 95.6 | | | |
| **Mean Depth** | 9.2 | | | |
| **Max Depth** | 11.2 | | | |
| **w/d Ratio** | 10.4 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

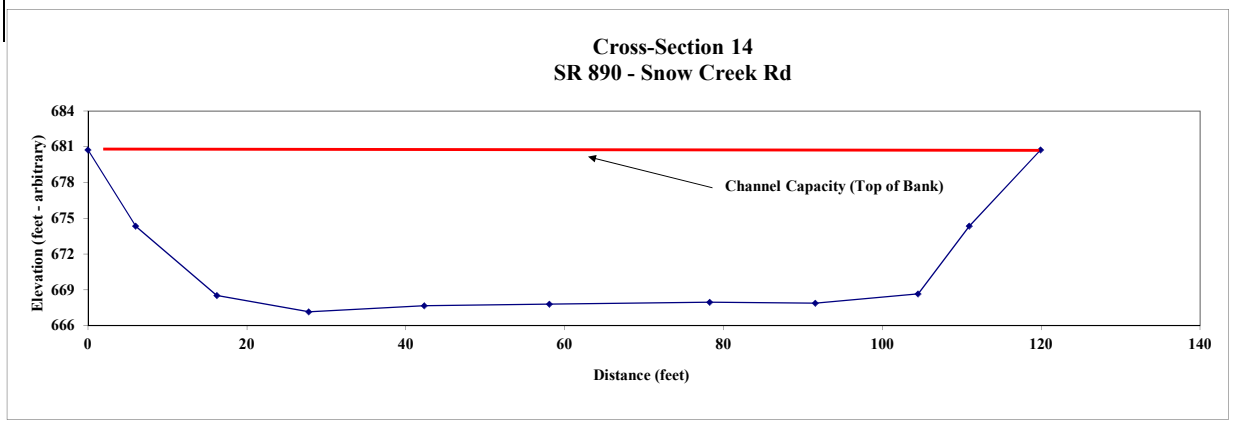


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 14 at 890/Snow Creek Rd |
| **Feature** | Riffle **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | | |
|---|---|---|---|---|
| Existing Conditions | | | | |
| **Station** | **Elevation** | **Notes** | | |
| **0** | **680.74** | | | |
| **6** | 674.33 | **Est** | | 0 |
| 16.23 | 668.5 | GS | | 10.23 |
| 27.81 | 667.14 | GS | | 21.81 |
| 42.34 | 667.64 | GS | | 36.34 |
| 58.08 | 667.78 | GS | | 52.08 |
| 78.29 | 667.95 | GS | | 72.29 |
| 91.58 | 667.86 | GS | | 85.58 |
| 104.48 | 668.64 | GS | | 98.48 |
| 110.93 | 674.33 | Est | | 104.93 |
| 119.91 | 680.74 | GS | | 113.91 |
| | | | | |

**Photo of Cross-Section 14 - Looking Downstream**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 604.7 | | | |
| **Width** | 104.5 | | | |
| **Mean Depth** | 5.8 | | | |
| **Max Depth** | 7.2 | | | |
| **w/d Ratio** | 18.1 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

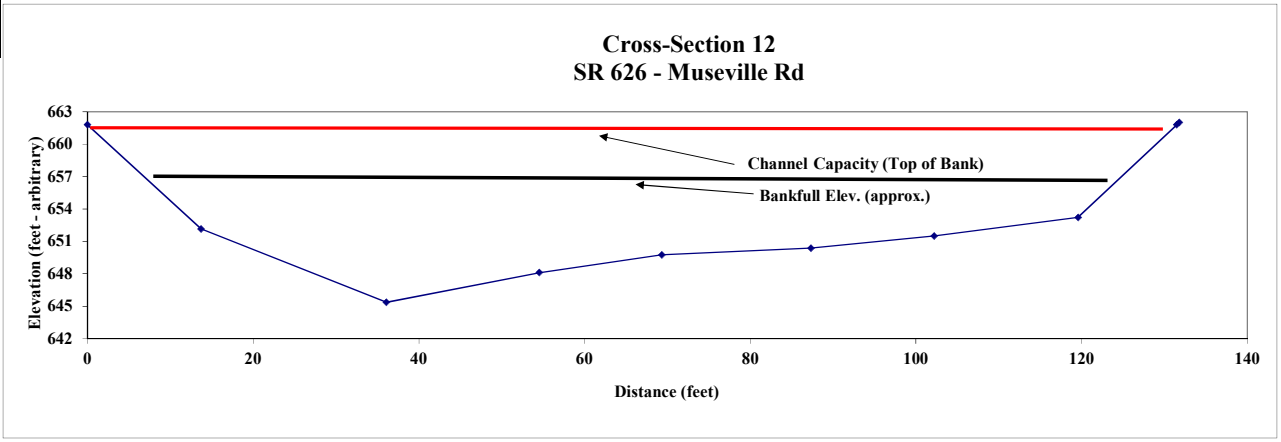


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 12 at 626/Museville Rd |
| **Feature** | Pool **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| **0** | **661.79** | | |
| **13.72** | 652.15 | **Est** | |
| 36.08 | 645.36 | GS | |
| 54.55 | 648.11 | GS | |
| 69.33 | 649.75 | GS | |
| 87.32 | 650.37 | GS | |
| 102.22 | 651.49 | GS | |
| 119.58 | 653.21 | GS | |
| 131.5 | 661.79 | est | |
| 131.78 | 662.02 | GS | |
| | | | |
| | | | |

**Photo of Cross-Section 12**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 1347.5 | | | |
| **Width** | 131.5 | | | |
| **Mean Depth** | 10.2 | | | |
| **Max Depth** | 16.4 | | | |
| **w/d Ratio** | 12.8 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

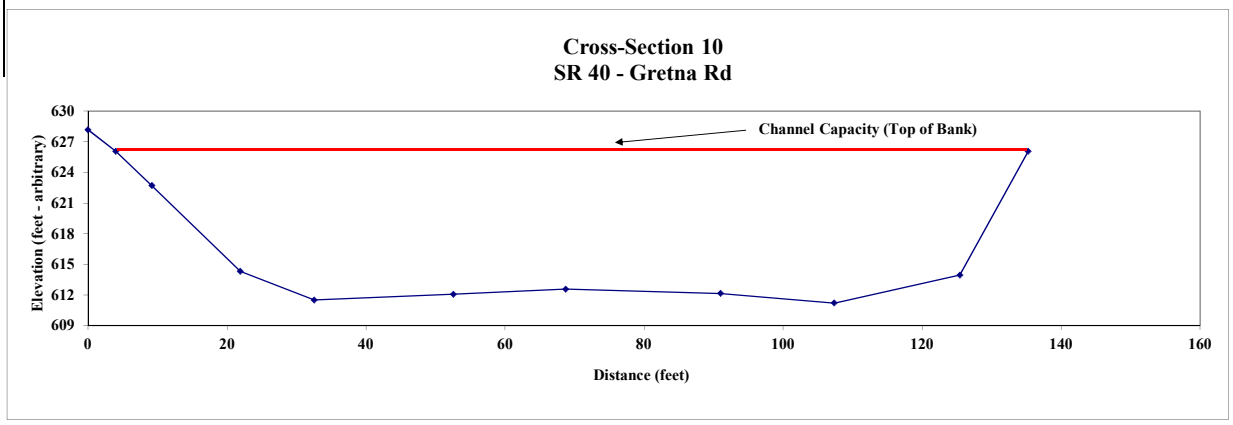


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 10 at 40/Gretna Rd |
| **Feature** | Run **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| 0 | 628.17 | gs | |
| 4 | 626.06 | est | |
| 9.22 | 622.69 | gs | |
| 21.93 | 614.29 | GS | |
| 32.54 | 611.5 | GS | |
| 52.56 | 612.04 | GS | |
| 68.73 | 612.56 | GS | |
| 91.01 | 612.13 | GS | |
| 107.38 | 611.19 | GS | |
| 125.44 | 613.94 | est | |
| 135.28 | 626.06 | GS | |
| | | | |

**Photo of Cross-Section 10**

| | Existing CAP | Existing BKFL | | |
|---|---|---|---|---|
| **Area** | 1512.7 | | | |
| **Width** | 107.4 | | | |
| **Mean Depth** | 14.1 | | | |
| **Max Depth** | 17.0 | | | |
| **w/d Ratio** | 7.6 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

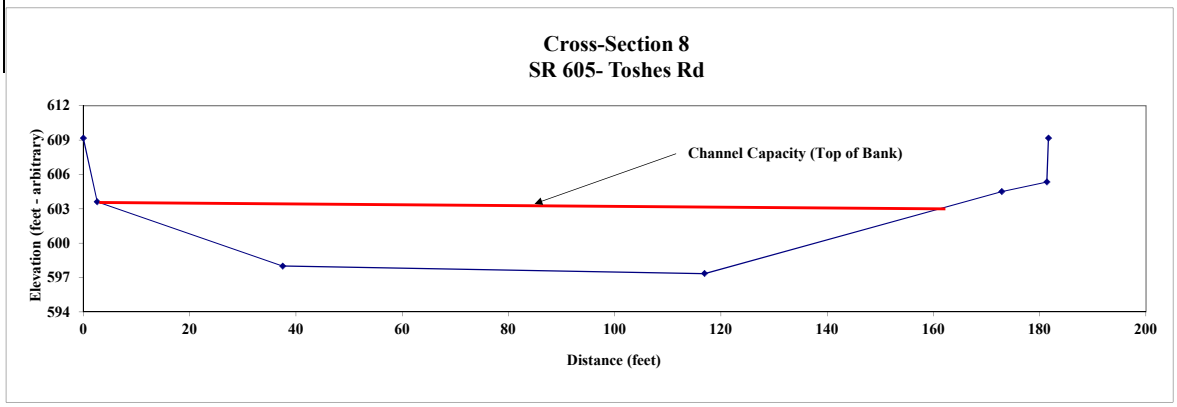


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 8 at 605/Toshes Rd |
| **Feature** | Pool **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| 0 | 609.18 | gs | |
| 2.57 | 603.6 | est | |
| 37.54 | 598 | gs | |
| 116.92 | 597.34 | GS | |
| 172.89 | 604.5 | GS | |
| 181.37 | 605.33 | | |
| 181.67 | 609.18 | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Photo of Cross-Section 8**

| | Existing CAP | Existing | | |
|---|---|---|---|---|
| **Area** | 1705.8 | | | |
| **Width** | 181.7 | | | |
| **Mean Depth** | 9.4 | | | |
| **Max Depth** | 11.8 | | | |
| **w/d Ratio** | 19.3 | | | |
| **FP Width** | | | | |
| **ER** | | | | |

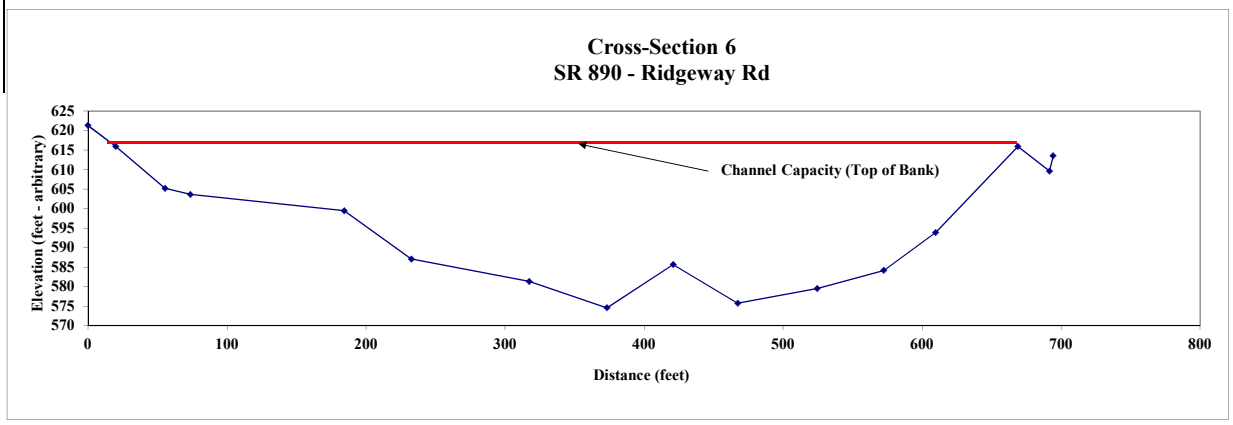


| | |
|---|---|
| **Project Name** | Power Dam/Pigg River Sediment Study |
| **Cross Section** | 6 at 890/Ridgeway Rd |
| **Feature** | Lake **Station:** |
| **Date** | |
| **Crew** | Bass, Cornerstone |

| 2015 | | | |
|---|---|---|---|
| Existing Conditions | | | |
| **Station** | **Elevation** | **Notes** | |
| 0 | 621.29 | gs | |
| 20 | 615.88 | est | |
| 55.46 | 605.15 | gs | |
| 73.66 | 603.61 | gs | |
| 184.46 | 599.4 | gs | |
| 232.67 | 587 | gs | |
| 317.48 | 581.3 | gs | |
| 373.26 | 574.5 | gs | |
| 420.95 | 585.6 | gs | |
| 467.56 | 575.7 | gs | |
| 524.71 | 579.5 | gs | |
| 572.47 | 584.1 | gs | |
| 609.72 | 593.85 | gs | |
| 668.97 | 615.88 | gs | |
| 691.74 | 609.57 | gs | |
| 694.31 | 613.54 | gs | |

**Photo of Cross-Section 6**

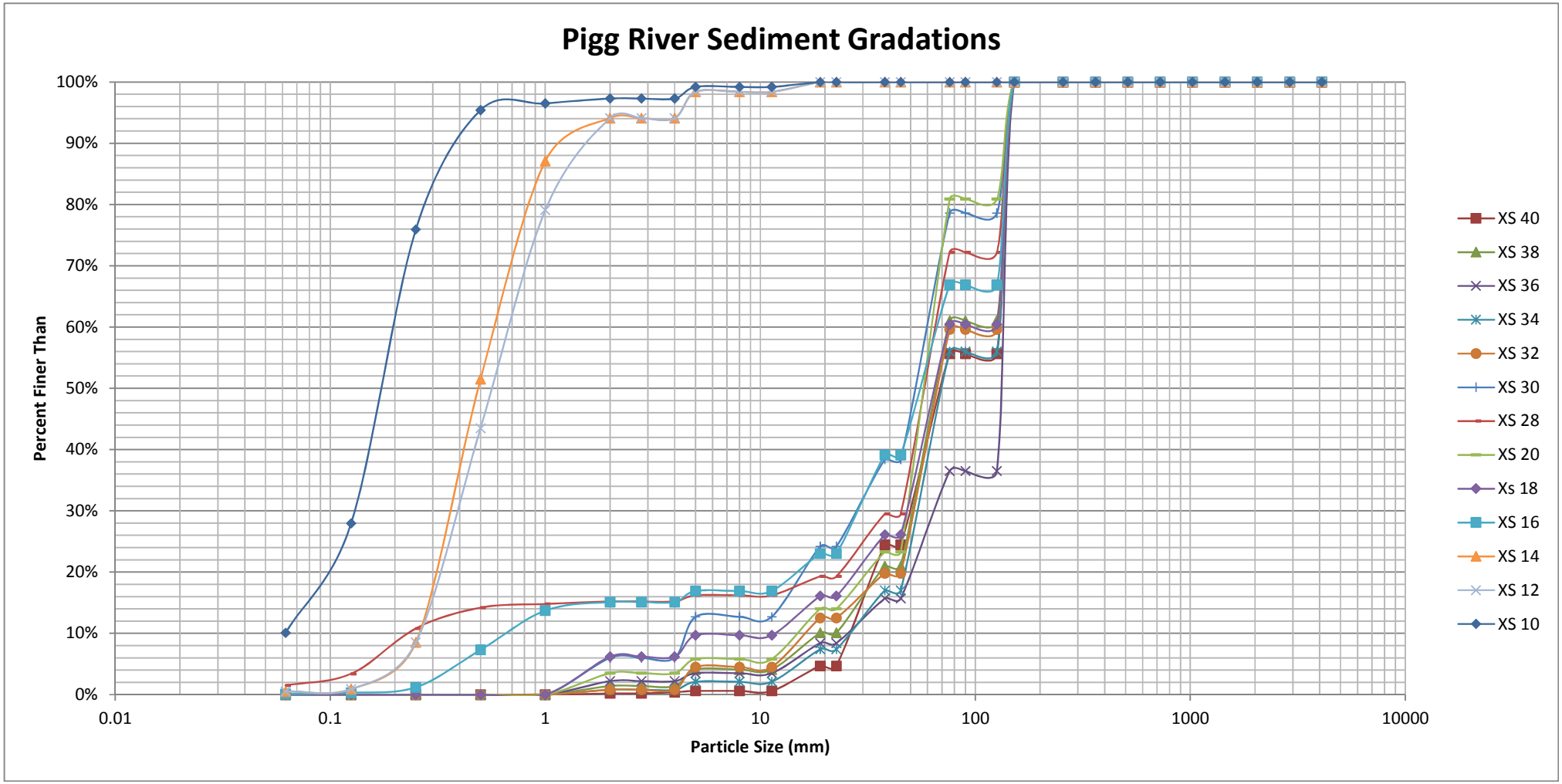
| | Existing CAP | Existing | | |
|---|---|---|---|---|
| **Area** | 16526.0 | | | |
| **Width** | 649.0 | | | |
| **Mean Depth** | 25.5 | | | |
| **Max Depth** | 41.4 | | | |
| **w/d Ratio** | 25.5 | | | |
| **FP Width** | | | | |
| **ER** | | | | |



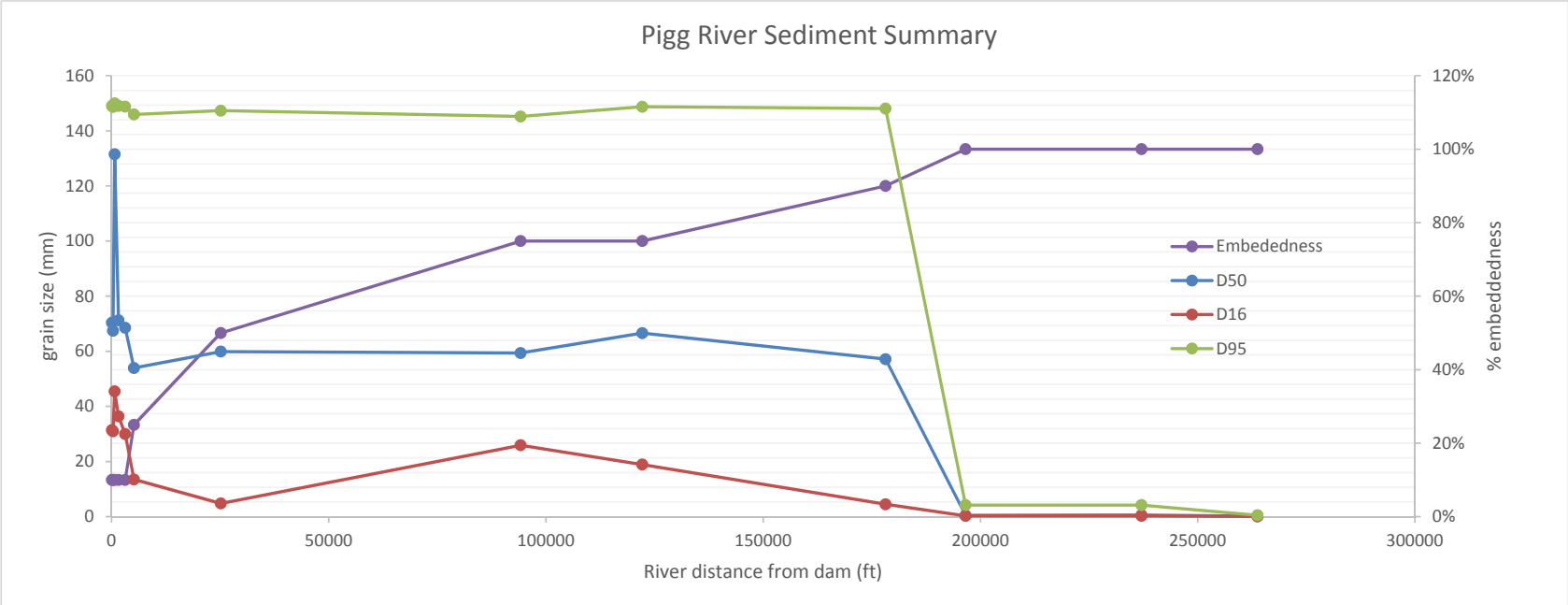
# Appendix C – Sediment Sampling Data

| Sample ID | total sample weight | % Cobble 3"-10" | % Coarse Gravel 1.5 - 3" | % Coarse Gravel .75 - 1.5" | % Medium Gravel 5mm - .75" | % Fine Gravel 2mm-5mm | % < 2mm total | % sand 0.05-2mm | % very coarse 1.0-2.0mm | % Coarse 0.50-1.0 mm | % Medium 0.25-0.50 mm | % fine 0.10-0.25 mm | % Very fine 0.05-0.10 mm | % silt/clay <0.05mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **XS 40** | 5824.0 | 44.5 | 31.3 | 19.8 | 4.1 | 0.2 | 0.2 | | | | | | | |
| **XS 38** | 5227.2 | 39.0 | 40.1 | 10.9 | 6.0 | 2.7 | 1.4 | | | | | | | |
| **XS 36** | 9546.8 | 63.5 | 20.8 | 7.3 | 4.9 | 1.3 | 2.2 | | | | | | | |
| **XS 34** | 7477.4 | 44.0 | 39.0 | 9.6 | 5.3 | 1.3 | 0.8 | | | | | | | |
| **XS 32** | 8276.3 | 40.4 | 39.8 | 7.3 | 8.0 | 3.7 | 0.8 | | | | | | | |
| **XS 30** | 5653.9 | 21.4 | 40.2 | 14.2 | 11.5 | 6.7 | 6.0 | | | | | | | |
| **XS 28** | 4723.8 | 27.8 | 42.7 | 10.2 | 3.1 | 1.0 | 15.3 | 13.8 | 0.4 | 0.6 | 3.4 | 7.4 | 1.9 | 1.5 |
| **XS 20** | 6303.5 | 19.1 | 57.6 | 9.3 | 8.2 | 2.3 | 3.5 | | | | | | | |
| **XS 18** | 6262.7 | 39.6 | 34.4 | 10.0 | 6.4 | 3.5 | 6.2 | | | | | | | |
| **XS 16** | 5820.3 | 33.1 | 27.7 | 16.1 | 6.1 | 1.8 | 15.2 | 15.1 | 1.4 | 6.4 | 6.1 | 0.9 | 0.2 | 0.1 |
| **XS 14** | 2400.6 | 0.0 | 0.0 | 0.0 | 1.6 | 4.3 | 94.1 | 93.6 | 7.0 | 35.6 | 43.0 | 7.6 | 0.4 | 0.5 |
| **XS 12** | | | | | | | | | | | | | | |
| **XS 10** | 1957.4 | 0.0 | 0.0 | 0.0 | 0.8 | 1.9 | 97.3 | 87.2 | 0.8 | 1.1 | 19.5 | 48.0 | 17.9 | 10.1 |

| Sample ID | Cobble Weight (g) | Cobble size (inches) | Cobble Weight (g) | Cobble size (inches) | Cobble Weight (g) | Cobble size (inches) | Cobble Weight (g) | Cobble size (inches) |
|---|---|---|---|---|---|---|---|---|
| **XS 40** | 1076.2 | 4 | 1514.6 | 5 | | | | |
| **XS 38** | 2039.3 | 5.5 | | | | | | |
| **XS 36** | 1500 | 5 | 640.8 | 4 | 922.1 | 4 | 3062.9 | 6 |
| **XS 34** | 1090.7 | 5.5 | 2201.2 | 6.5 | | | | |
| **XS 32** | 1138.4 | 4 | 2202.5 | 8 (flat) | | | | |
| **XS 30** | 537.6 | 3 | 670.4 | 3.5 | | | | |
| **XS 28** | 1310 | 4.5 | | | | | | |
| **XS 20** | 1202.8 | 4.5 | | | | | | |
| **XS 18** | 2477.3 | 5 | | | | | | |
| **XS 16** | 626.4 | 4 (flat) | 1298.6 | 4.5 | | | | |
| **XS 14** | | | | | | | | |
| **XS 12** | | | | | | | | |
| **XS 10** | | | | | | | | |


Pigg River Sediment Gradations
Percent Finer Than
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.01
0.1
1
10
100
1000
10000
Particle Size (mm)
XS 40
XS 38
XS 36
XS 34
XS 32
XS 30
XS 28
XS 20
Xs 18
XS 16
XS 14
XS 12
XS 10

| Dxx | Variable | XS1 | XS2 | XS3 | XS4 | XS5 | XS6 | XS7 | XS8 | XS9 | XS10 | XS11 | XS12 | XS13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D16 | 0.16 | 31 | 31 | 45 | 36 | 30 | 14 | 5 | 26 | 19 | 4 | 0 | 0 | 0 |
| D35 | 0.35 | 56 | 56 | 74 | 59 | 57 | 34 | 49 | 51 | 53 | 34 | 0 | 0 | 0 |
| D50 | 0.5 | 70 | 67 | 132 | 71 | 69 | 54 | 60 | 59 | 67 | 57 | 0 | 1 | 0 |
| D84 | 0.84 | 143 | 141 | 145 | 143 | 142 | 133 | 137 | 130 | 141 | 139 | 1 | 1 | 0 |
| D95 | 0.95 | 149 | 149 | 150 | 149 | 149 | 146 | 147 | 145 | 149 | 148 | 4 | 4 | 0 |
| Distance | | 96 | 249 | 360 | 893 | 1536 | 2026 | 20000 | 69000 | 28000 | 56000 | 18422 | 40500 | 26690 |
| | | 96 | 345 | 705 | 1598 | 3134 | 5160 | 25160 | 94160 | 122160 | 178160 | 196582 | 237082 | 263772 |
| Embededness | | 10% | 10% | 10% | 10% | 10% | 25% | 50% | 75% | 75% | 90% | 100% | 100% | 100% |

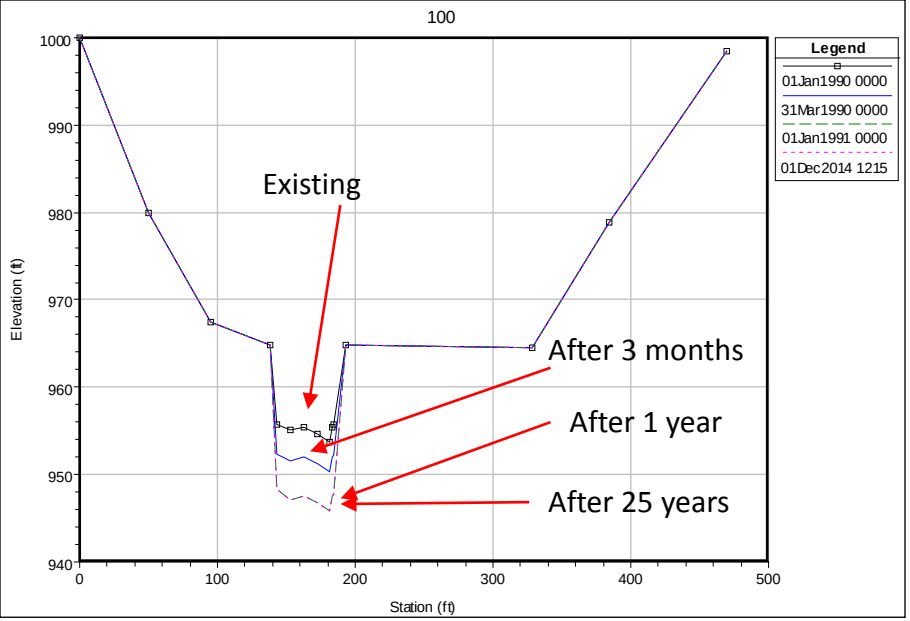


# Appendix D – Predicted Cross Section Output

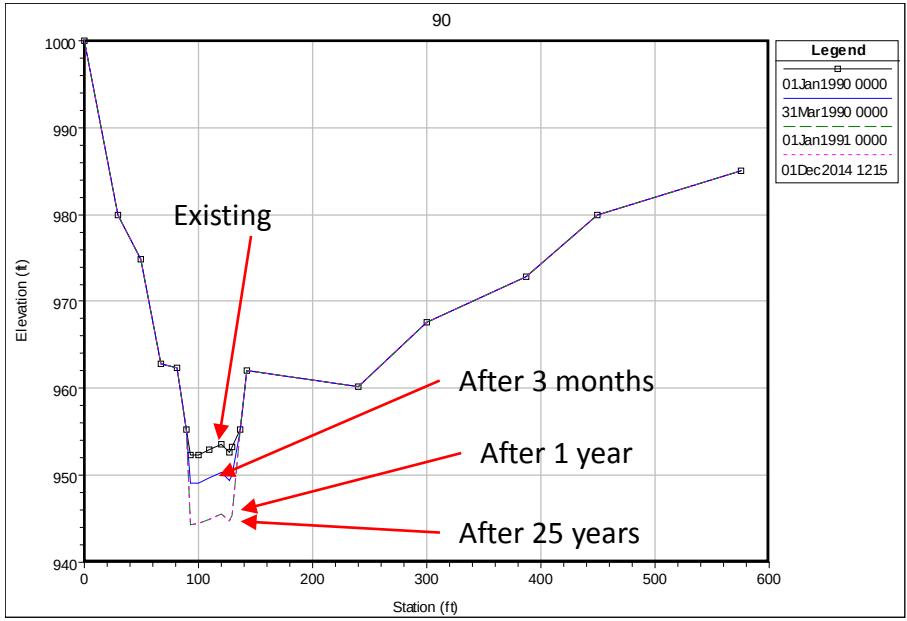
# Existing and Predicted Cross Section Plots
# Long-term simulation
# Using flow data from 1990-2014

Legend

- Existing
- After 3 months
- After 1 year
- After 25 years

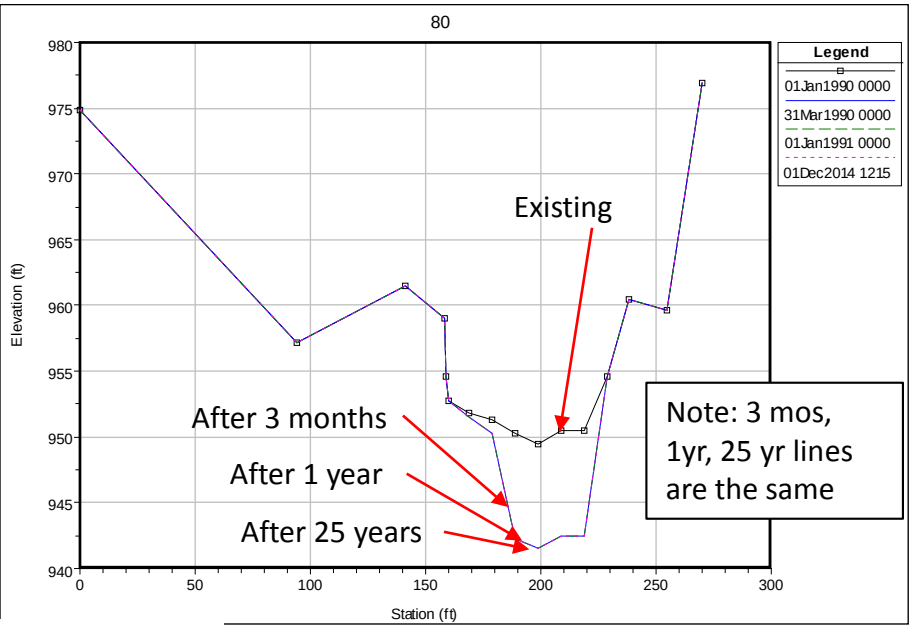



XS 100

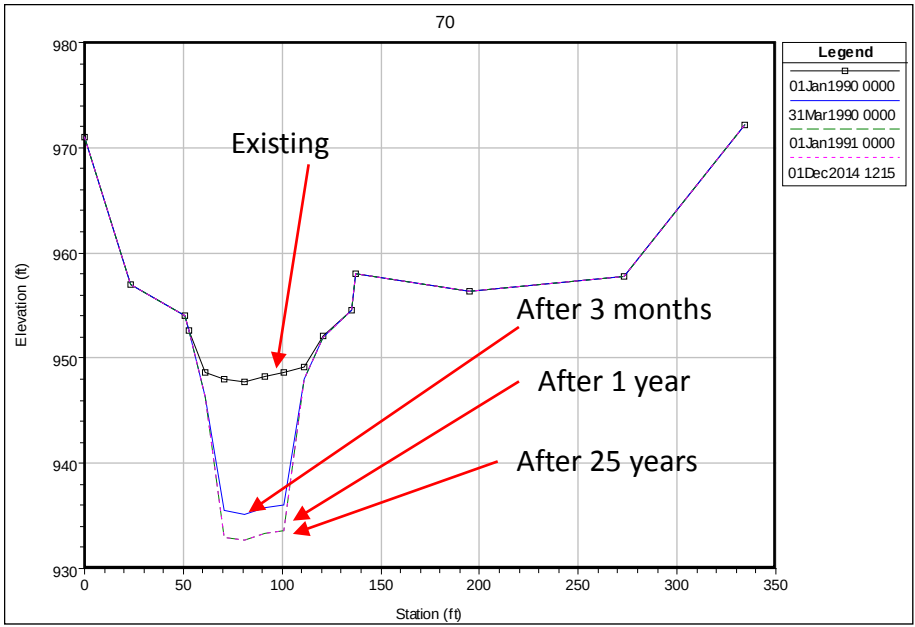


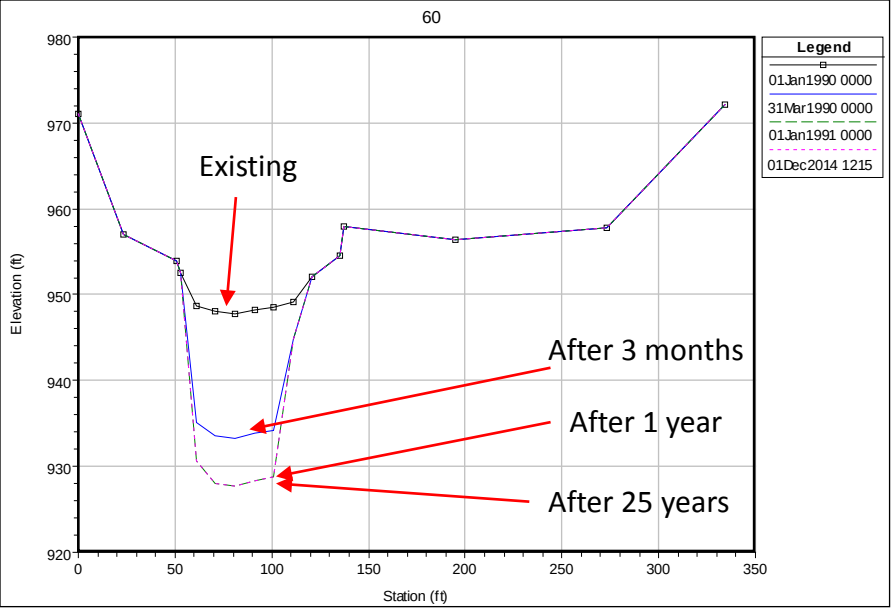

XS 90

XS 80

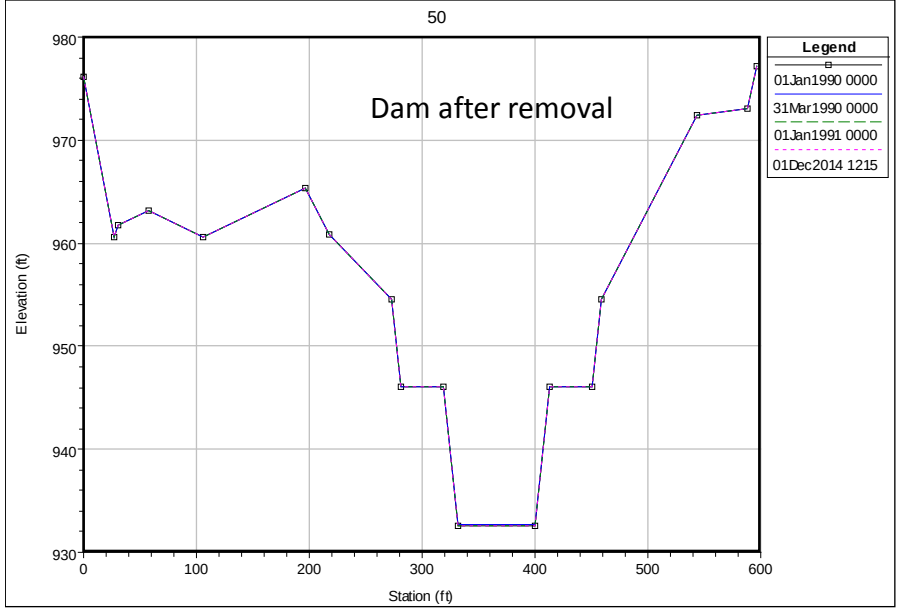



XS 70



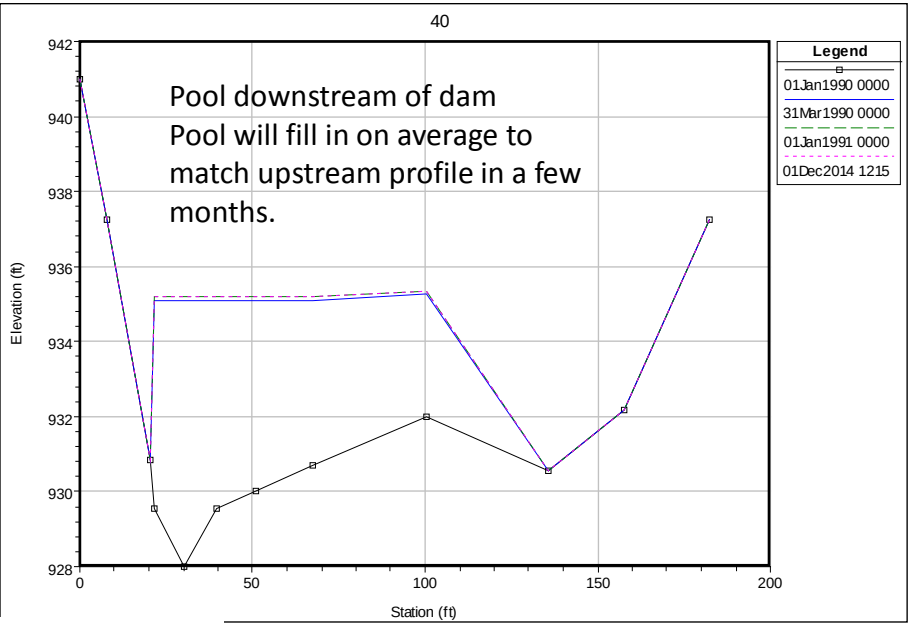



XS 60

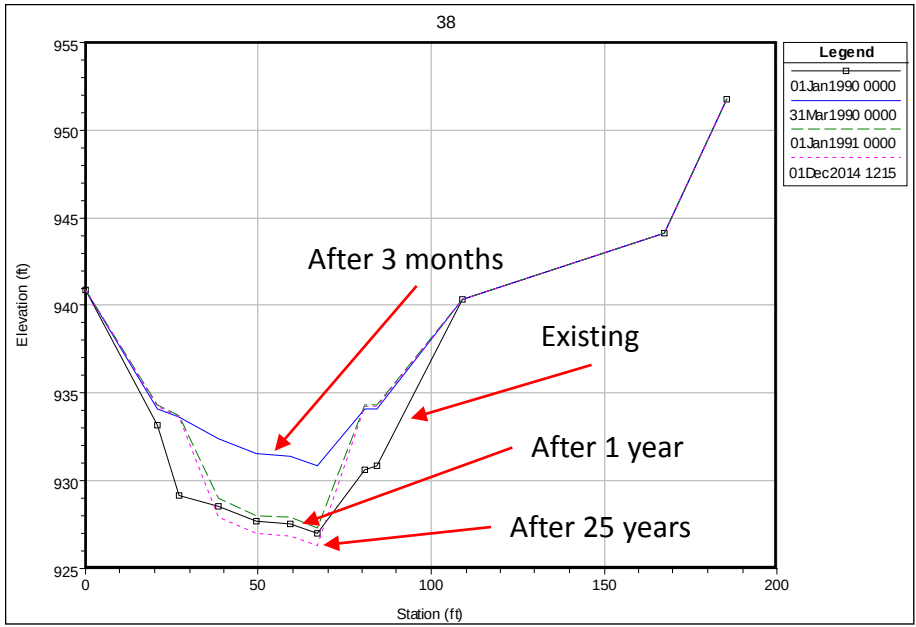


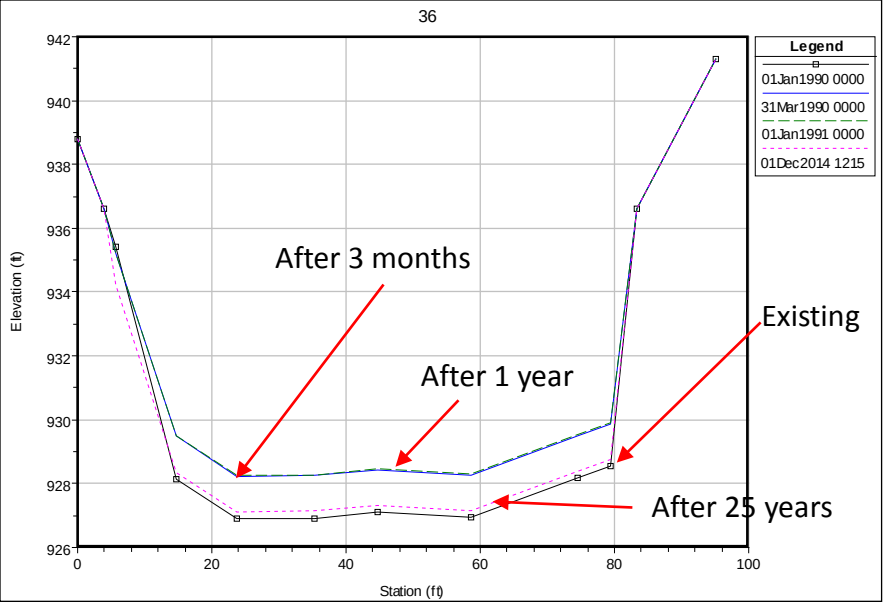

XS 50

XS 40

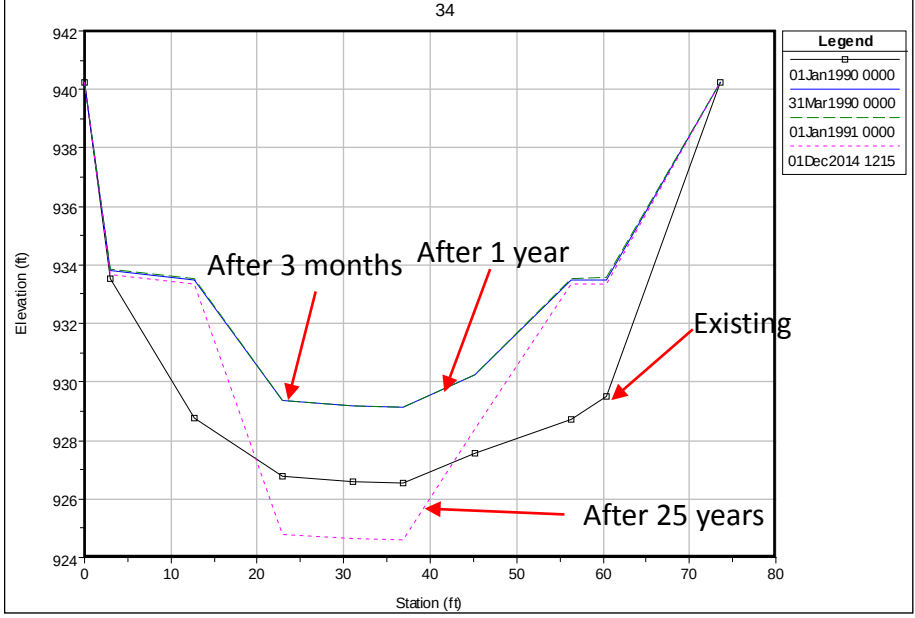



XS 38



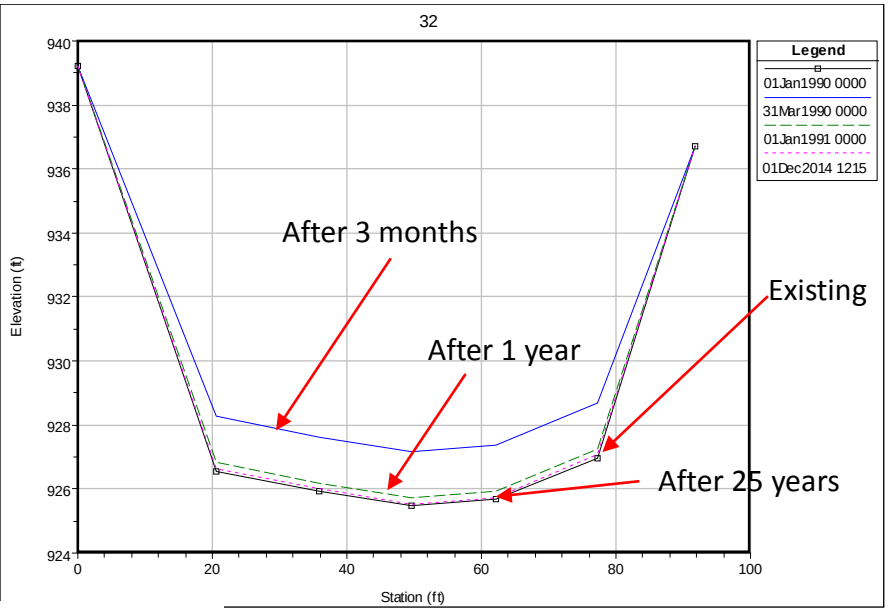



XS 36

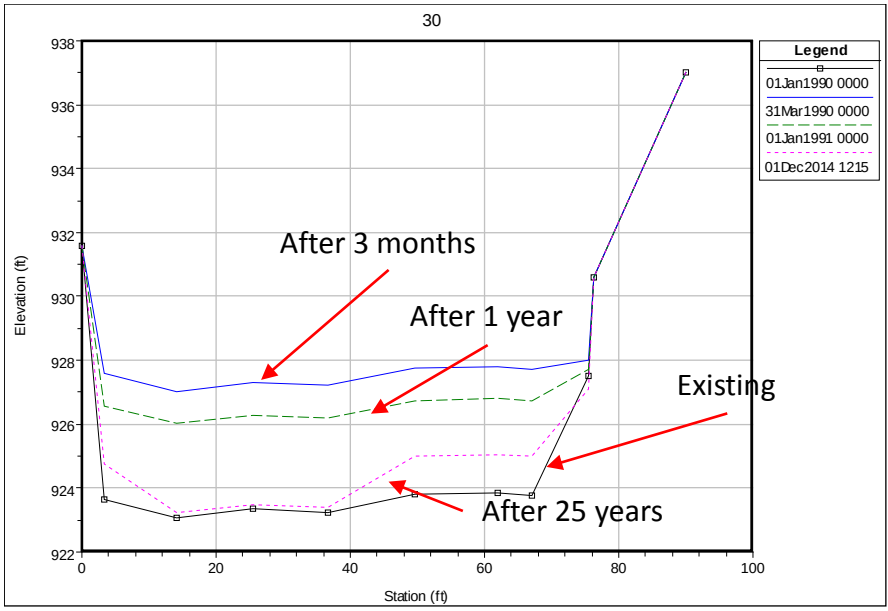


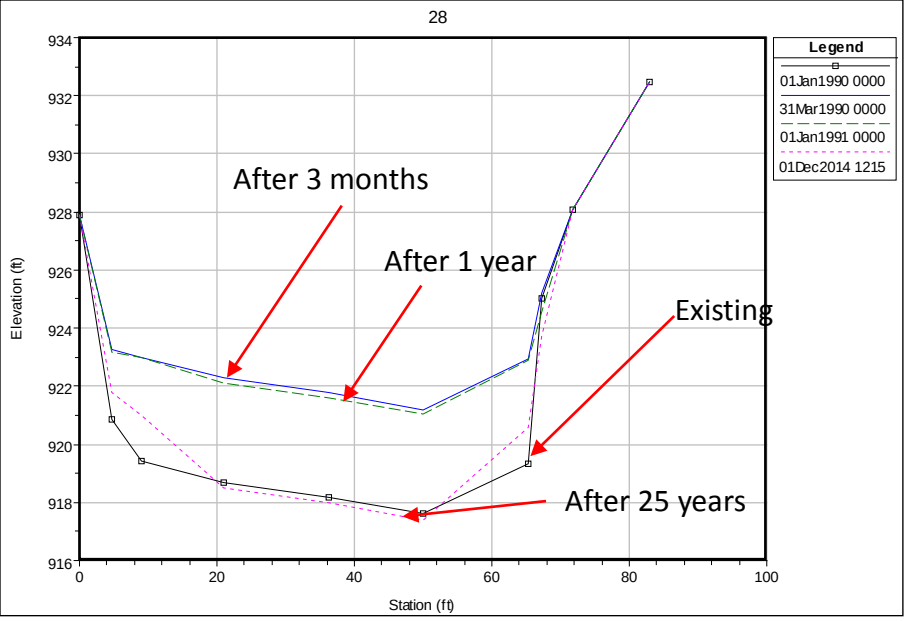

XS 34

XS 32

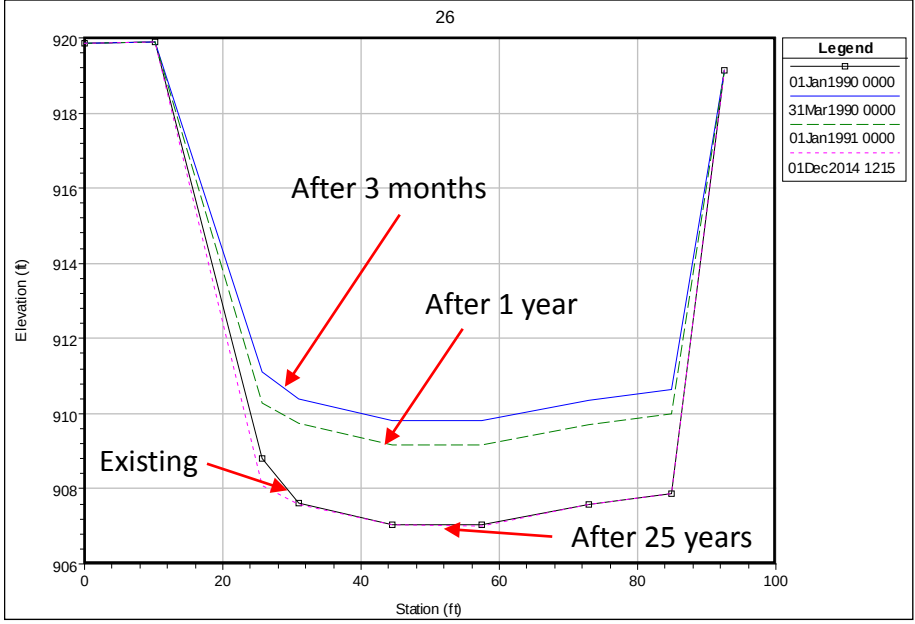



XS 30






XS 28

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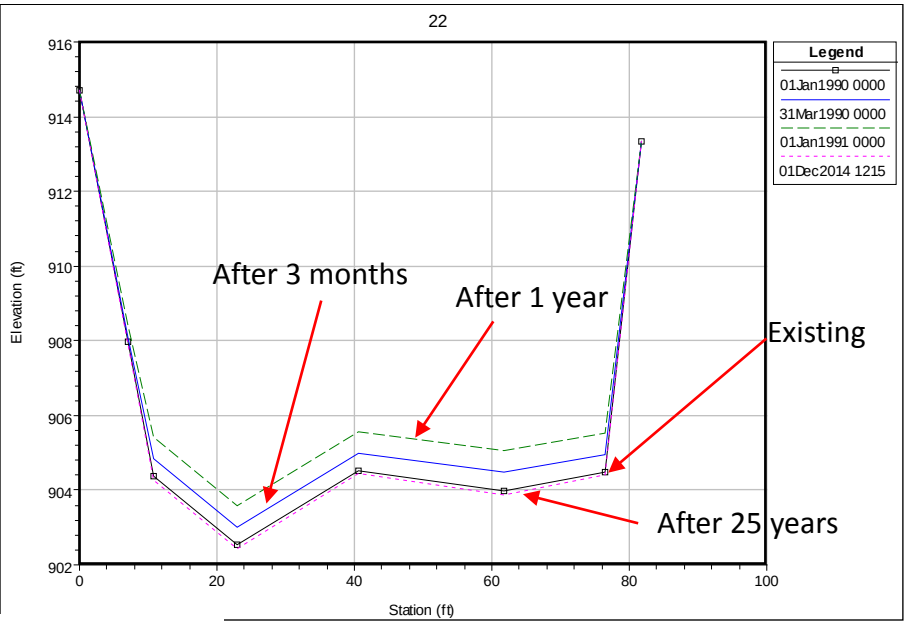


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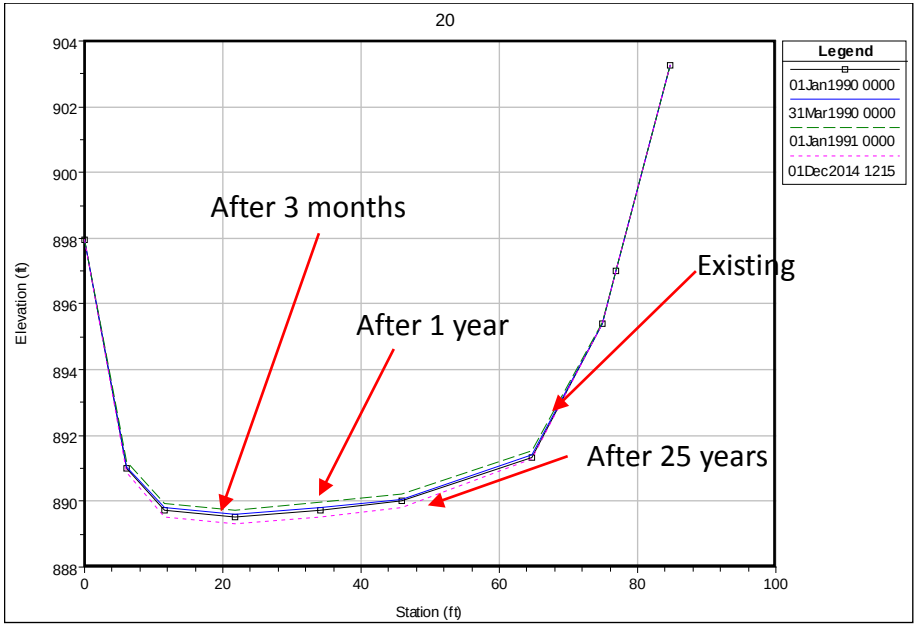

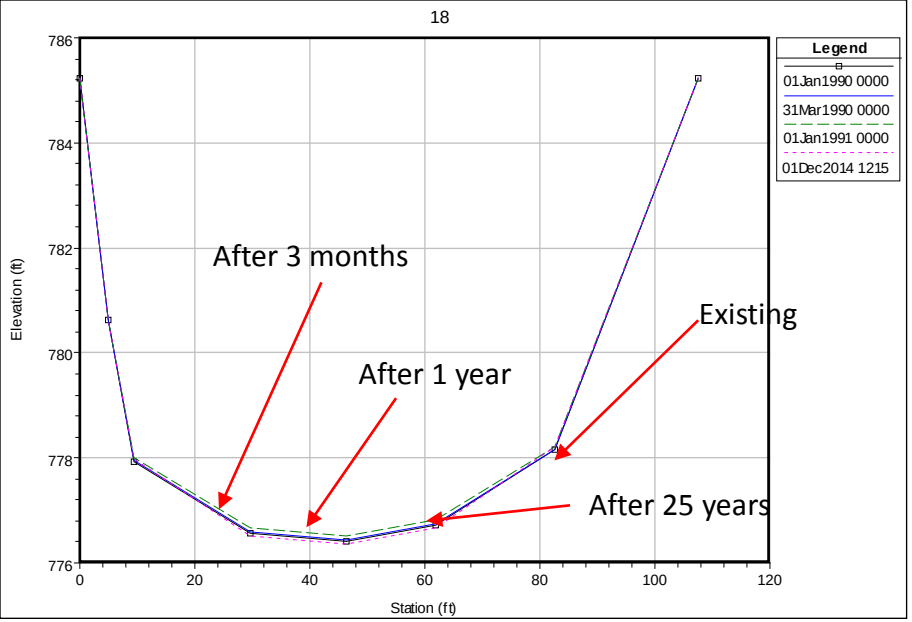


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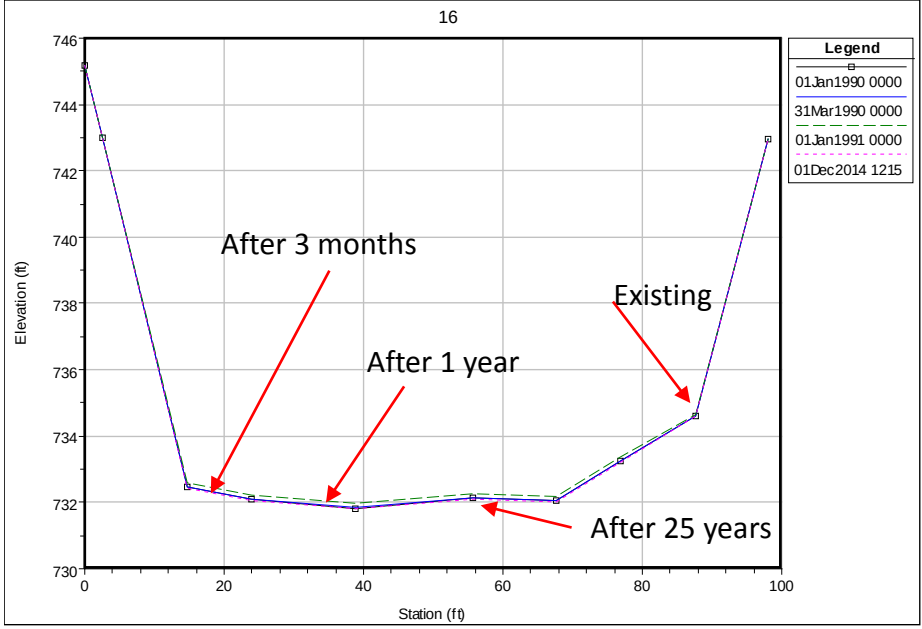


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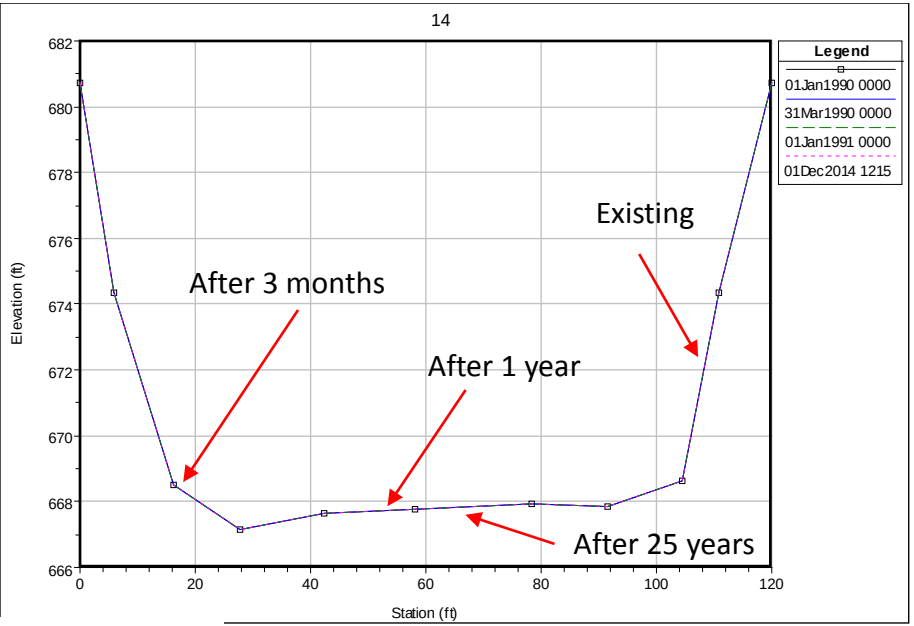
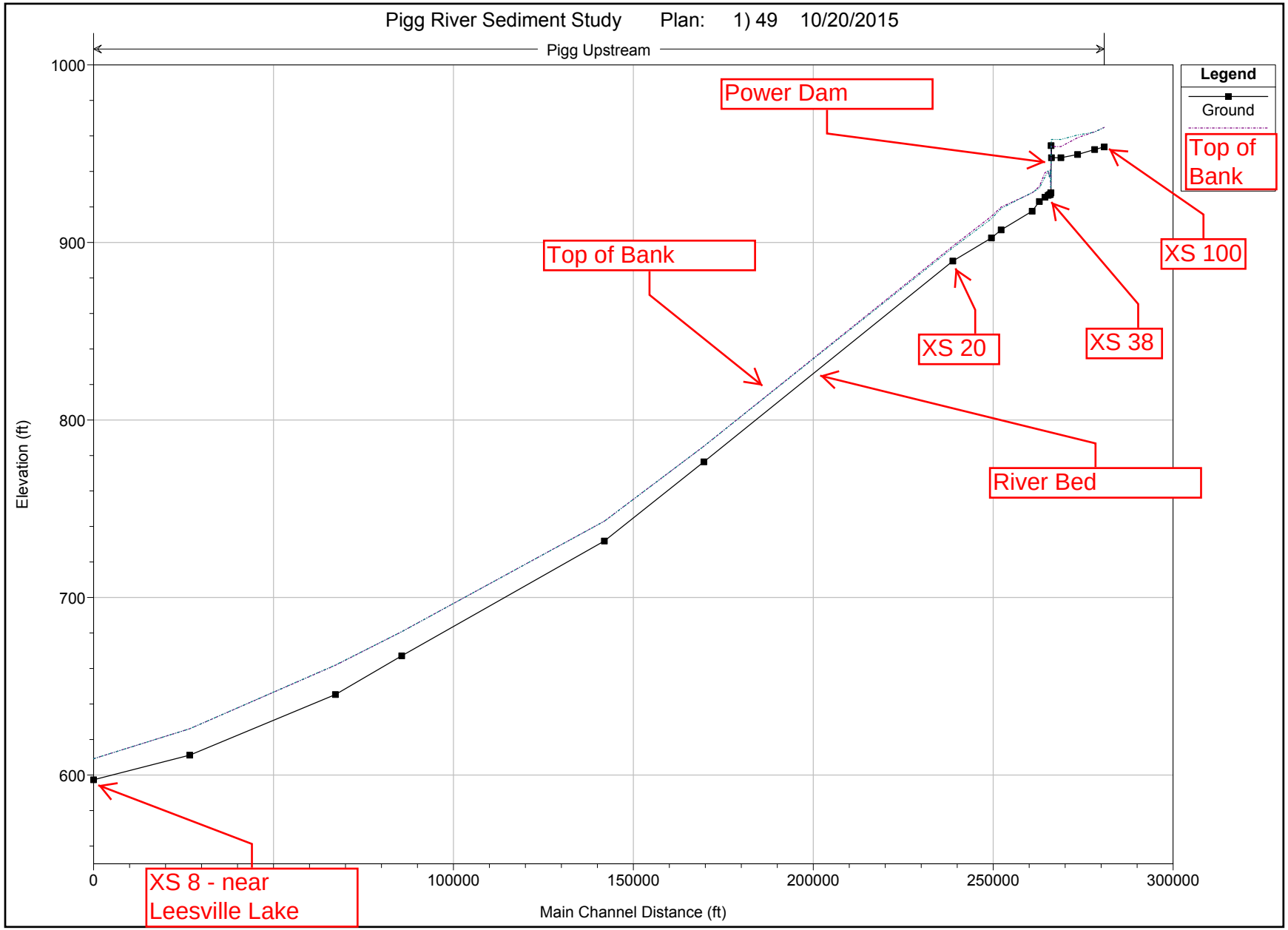
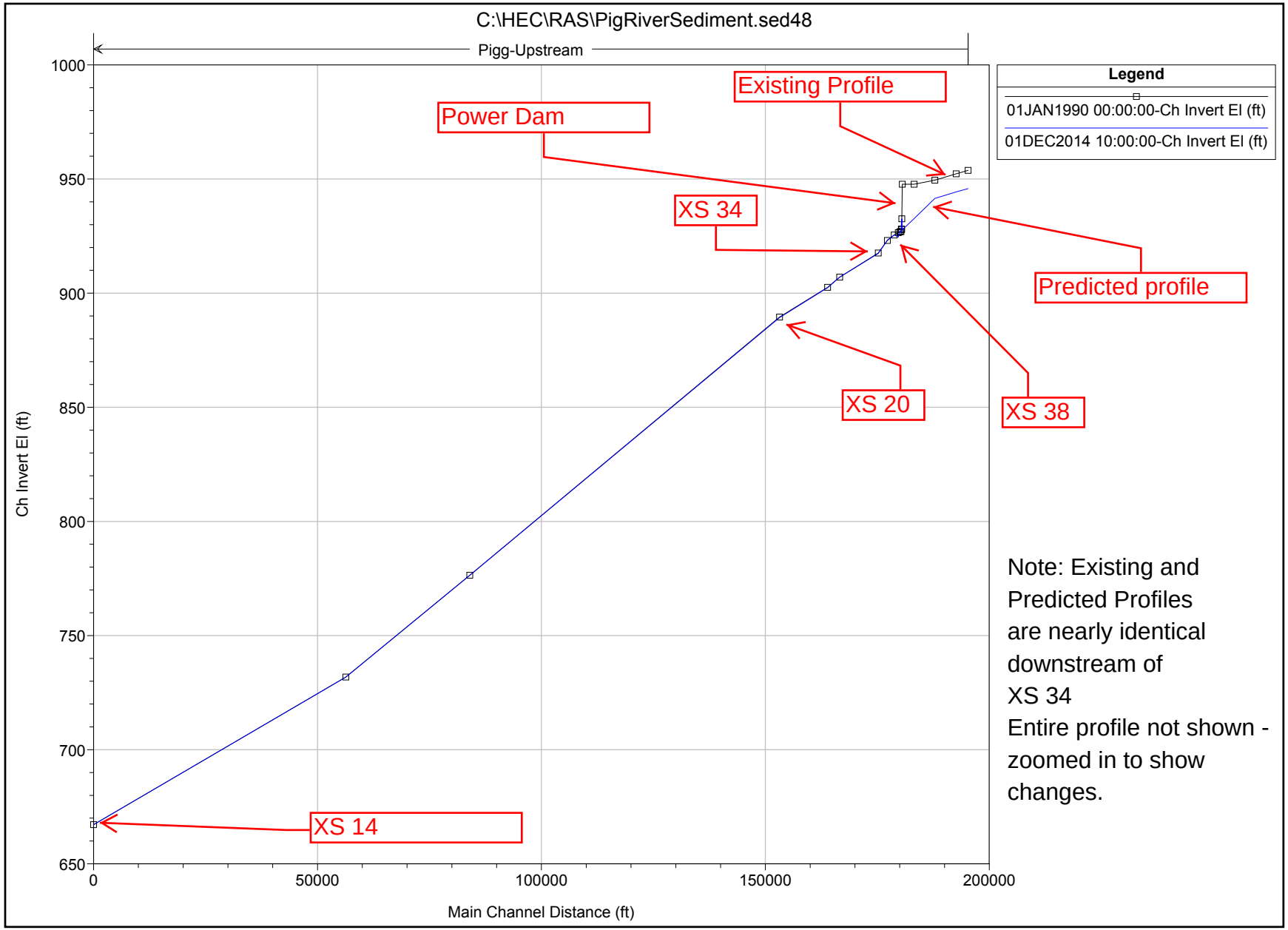


Pigg River - Existing River Profile



Pigg River - Predicted River Profile - 25 year simulation



# Appendix E - Stakeholder Questions

Specific questions were posed by regulatory agencies for investigation as a part of this study. This section lists each question and provides brief answers based on the analysis and interpretation of the results.

1. What is the recommended maximum interim dam notch size in order not to exceed the sediment transport capacity of the channel during the 1, 1.5, and 2 year runoff events?

**Answer:** There is no practical notch size that can limit the sediment transport below the capacity of the downstream channel during these storm events. The channel is too flat and wide to transport the volumes of sediment that are expected to be released with any realistic notching strategy. The enlargened channel means lower depths and velocities than are needed to move the expected sediment load. Larger storms, such as a 10 year storm, that could approach the top of bank in the downstream channel will have greater flushing capability.

2. What is the expected volume of sediment that will be released after each interim notching?

**Answer:** The estimate volume of sediment in the reservoir is approximately 325,000 CY (Froehling and Robertson). Another estimate created using the initial notching plan is presented below:

| | Volume released (CY) | Total Volume (CY) | Mass (tons) | Total (tons) |
|---|---|---|---|---|
| 60% dam removal | 86,820 | 86,820 | 91,422 | 91,422 |
| 80% dam removal | 77,356 | 164,176 | 81,456 | 172,878 |
| 100% dam removal | 106,855 | 271,031 | 112,519 | 285,397 |

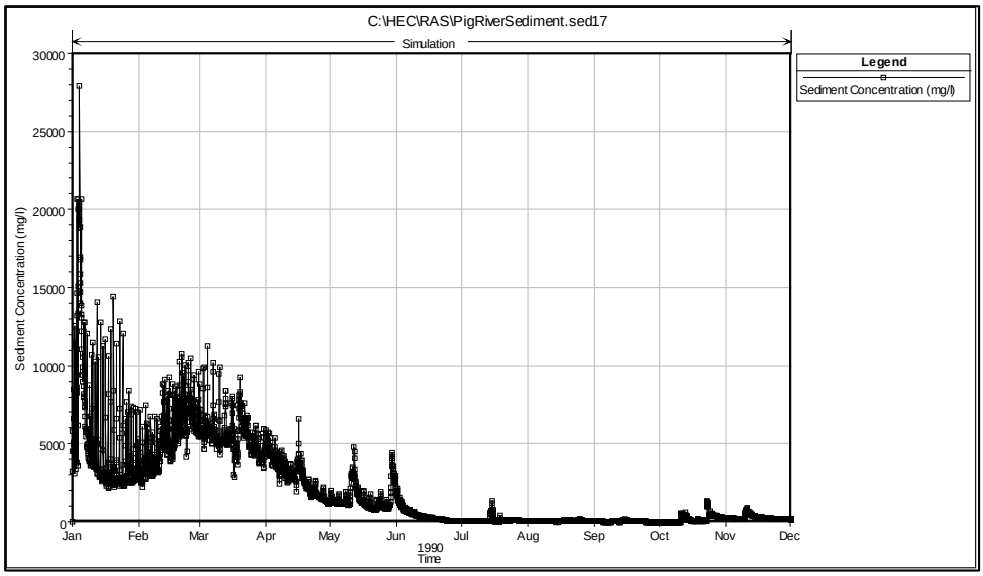
These two estimates are in decent agreement. However, all of this sediment may not be mobilized, as some may remain as terraces or streambanks in the new channel. Model simulations predict the following pattern of sediment transport.

| | Simulated Transport (tons) 4 months | Simulated Transport (tons) 12 months |
|---|---|---|
| 60% dam removal | 70,000 | 106,000 |
| 80% dam removal | 105,000 | 165,000 |
| 100% dam removal | 240,000 | 280,000 |

The simulated values are in close agreement with the table of available sediment. The simulated values also show the rapid rate of predicted movement, as a large precentage of the sediment can be evacuated in a few months time.

3. What distance with probabilities may sediment classes (silt/clay & sand) be expected to travel downstream for each event including the most probable locations sediment may reside based upon Rosgen channel types present between the dam and Leesville Reservoir?

**Answer:** Sediment may be expected to travel all the way to Leesville Lake during most storms, with deposits in the lake becoming more evident over the course of a year. The deepest deposits will be in the area just downstream of the dam and at the lake. It appears that 50-60% of the trapped sediment will be deposited near the dam, and redistributed over time. It does appear that there will be some accumulation in the Lake. However, it is difficult to separate whether the source of these deposits are from existing sediments that are already in-route or directly as the result of the dam removal. Sediment concentration increases are expected all the way to Leesville Lake. Concentrations should lessen once the majority of impoundment sediment has been evacuated. The graph below shows spikes in sediment after a notching event (daily averages), with a downward trend over a years time. It should be expected that storm related spikes in sediment concentration will last for several years.




**Appendix Figure 1.** Predicted sediment concentrations downstream of Power Dam after dam removal, Pigg River, Franklin County, Va.

4. What will be the expected impact (temporary and permanent) to riffles and pools from sediment release events for silt/clay and sand? Discuss in terms of depth of fill, residence time, permanency, and length of channel or area impacted.

**Answer:** In the initial months after a notching event, substantial redistribution of sediment will occur after rainfall events. It is likely that the few pools in the near downstream area will fill with sand, and that this deposition may last for several years. Pools that are in meander bends may benefit from complex hydraulics to help maintain the pool depth. It also appears that riffles near the dam will also have deposits of sand. Over time, any substantial deposits will persist as banks or terraces as an inner bankfull channel develops. This development could start in as soon as one year and develop more permanently over a few years. A large portion of the Pigg River will remain unchanged in this way compared to existing conditions. The redistribution of sediment in the near downstream areas of the dam will prevent substantial deposits in lower reaches. The additional flow provided by tributaries will also help transport any suspended material all the way down to the lake.

5. A request was made to calculate potential flow rates during removal of the dam and check for potential downstream flooding during the release of the stored water.

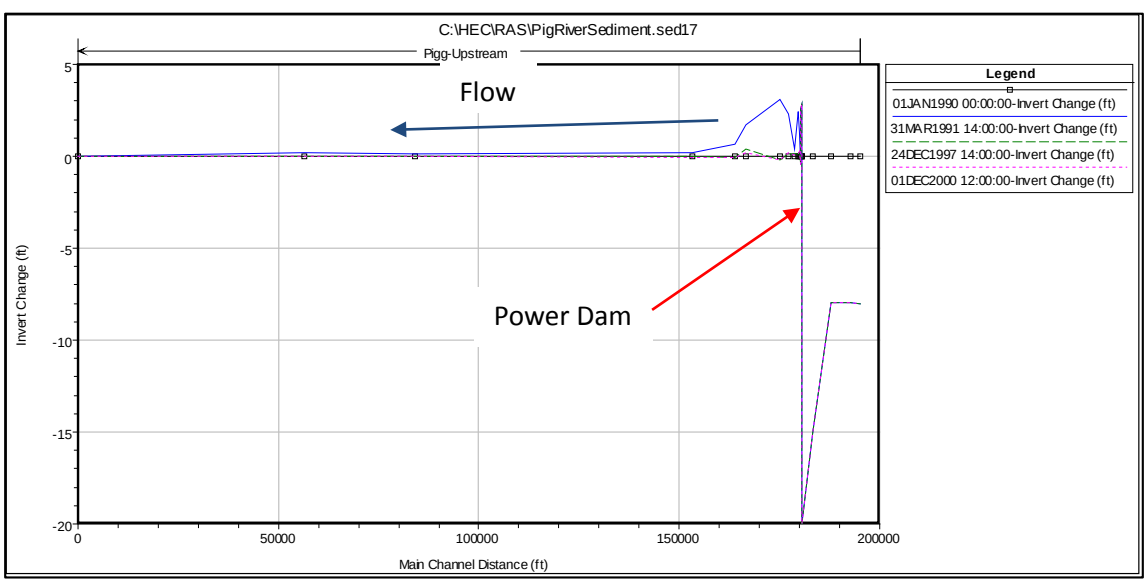
**Answer:** The current plan for dam removal includes an initial notching and impoundment drawdown. This drawdown can be accomplished by only notching the dam down a portion of its total height. During this notching, the outgoing flowrate will have to be managed to keep work crews safe. An instantaneous opening of over 100 feet wide and 5 feet tall would be needed to allow flows to threaten the top of bank downstream. It is likely that smaller openings will be made at a time, followed by a drawdown period. Even if an opening could be made of this size all at once, the impoundment would drain down in 10-20 minutes and flows would spread out downstream.

**6.** What are the potential flooding impacts due to downstream deposition?

**Answer:** Permanent deposition in downstream cross sections could potentially raise water surface elevations for storms. The more permanent changes are predicted in the area just downstream of the dam. This area has a current floodplain depth of nearly 15 feet during a 100 year storm. A quick simulation of this reach with an additional 3 feet of deposited sediment showed no change in the water surface elevation.

7. Please provide a graph of predicted depth changes along the Pigg River over time.

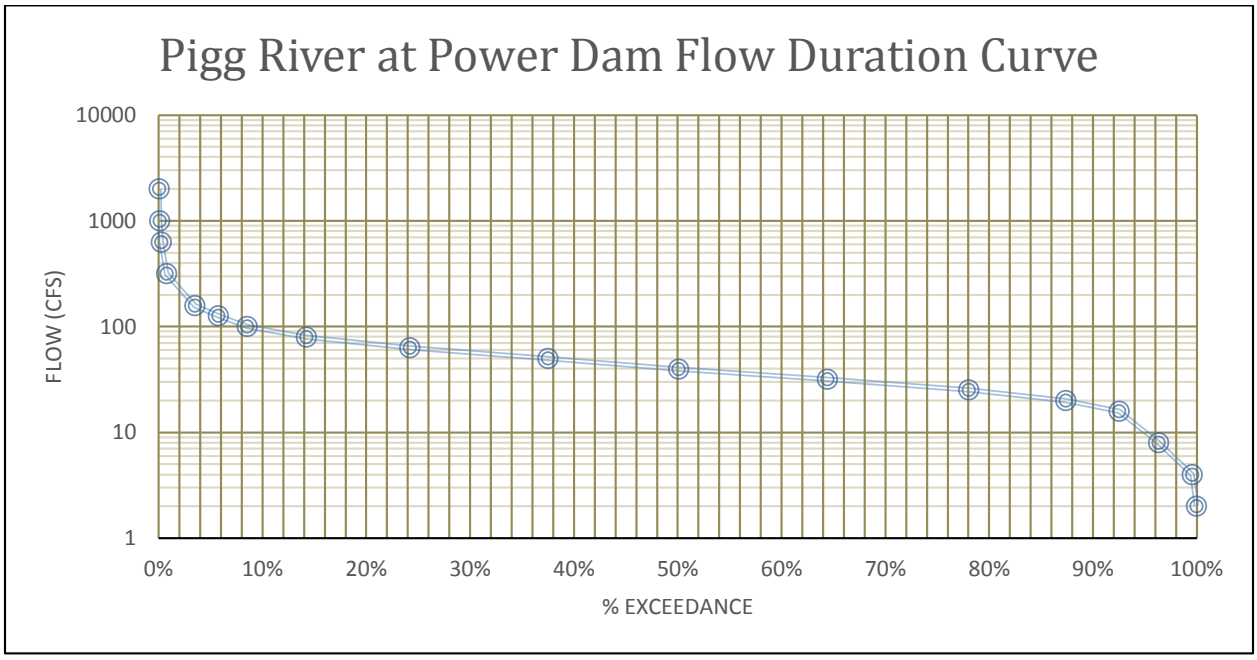
**Answer:** The graph below shows the longitudinal profile changes predicted over a 10 year period. The right side of the graph is the impoundment, and progresses downstream to the left. The impoundment invert drops as the sediments are evacuated during the first few months. An initial period of deposition is seen downstream that ranges from 1-4 feet. The profile then flattens as the initial deposits are redistributed over time and new channels develop. Channel invert changes reduce to almost nothing in the downstream direction.




**Appendix Figure 2.** Predicted depth changes above and below Power Dam after removal, Pigg River, Franklin County, Va.

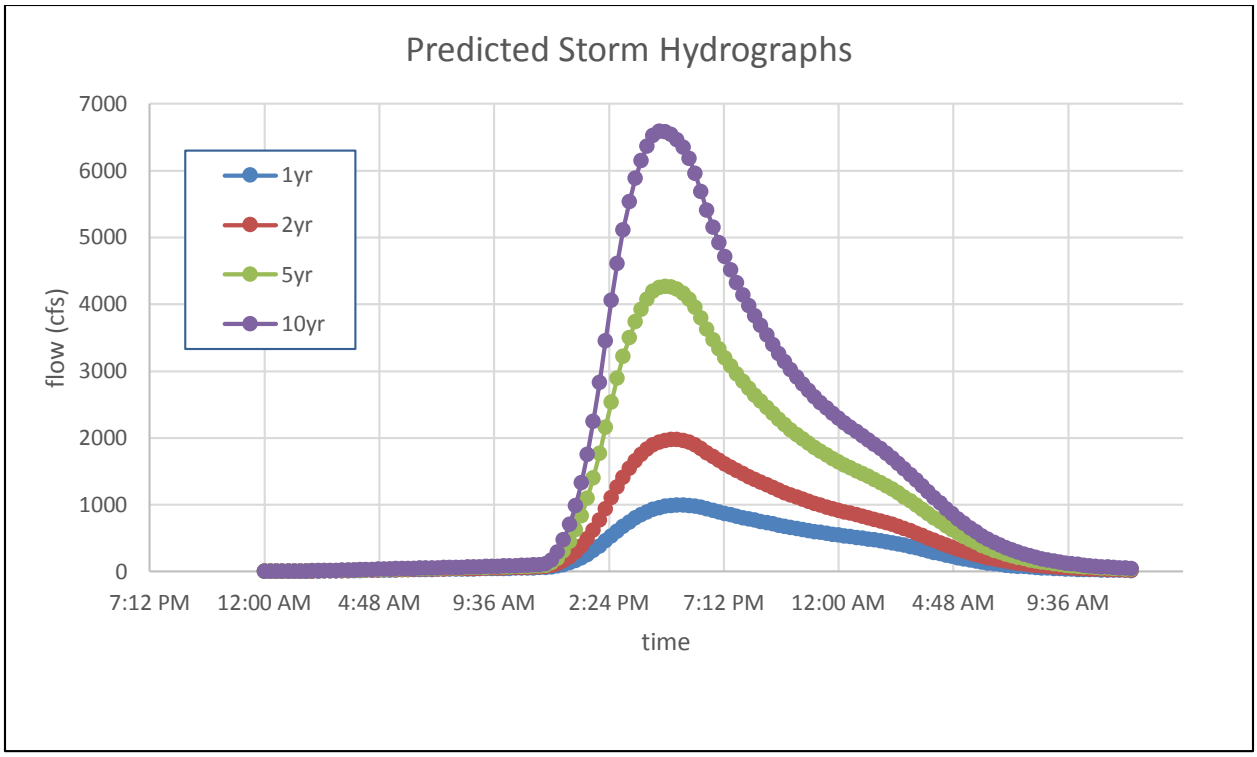
8. Please provide a flow duration curve of historic flow data and predict sediment transport for the 1, 2, and 10 year storm events, with the goal to be able to make predictions of how much sediment can be moved during these storms.

**Answer:** Flow data from the USGS stream gage for the Pigg River at Sandy Level was acquired and analyzed as part of this project. This data was proportioned by watershed size to make an estimate of flowrates at Power Dam. Daily average flowrates were used in all simulations completed for this study. A flow duration curve was generated and is provided below.

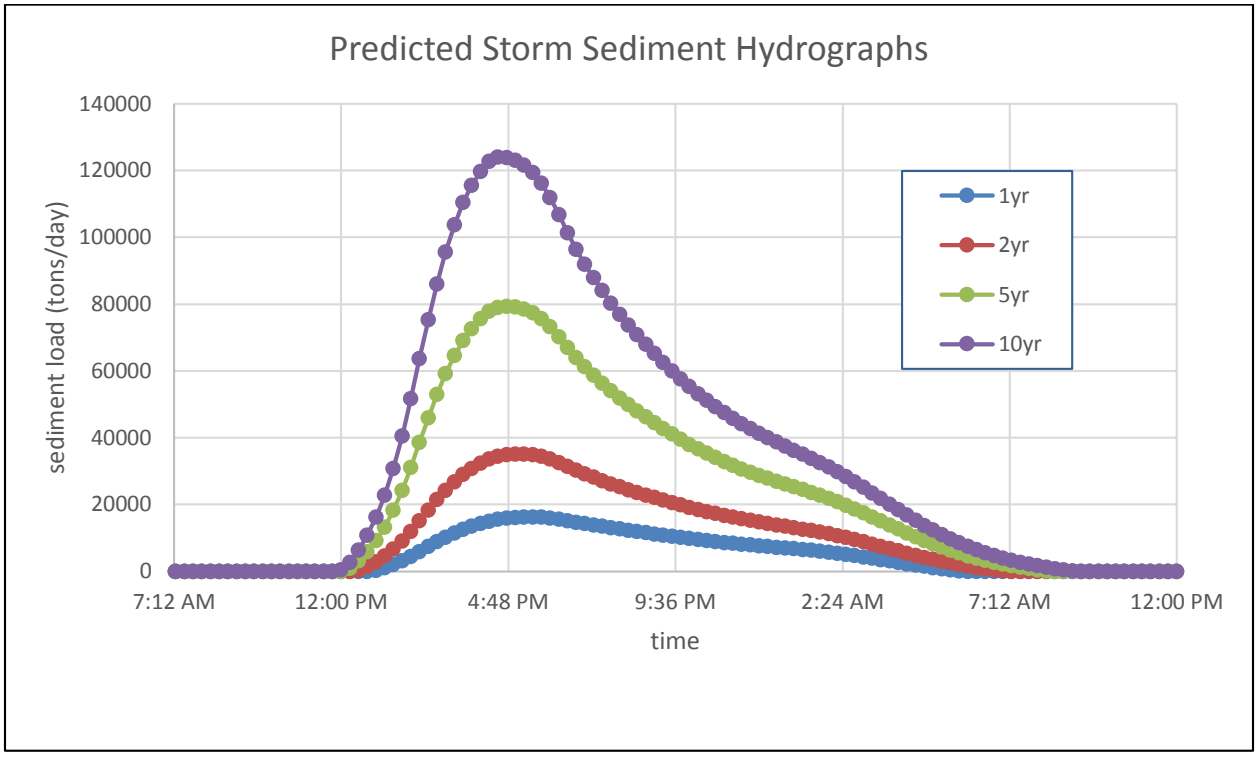



**Appendix Figure 3.** Flow duration curve at Power Dam, Franklin County, Va. Data generated from proportioned gage station data (Pigg River at Sandy Level).

Flow data at this gage station has been analyzed by USGS and peak flows for return interval storms are published information. The published peak flows were similarly proportioned by watershed size to estimate peak flows at the dam. A watershed runoff model was then developed using HEC-HMS. Runoff predictions were created with the SCS curve number method and calibrated to match the USGS runoff peaks. The predicted hydrographs are shown in Appendix Figure 4. The compiled hydrographs for the 1, 2, 5, and 10 year return interval (24 hr) storms were then combined with sediment transport capacity calculations to create predictions of downstream sediment transport during these storms. These predictions are best presented as a range of sediment loads due to the changes in capacities for different cross sections.




**Appendix Figure 4.** Predicted storm hydrographs at Power Dam.



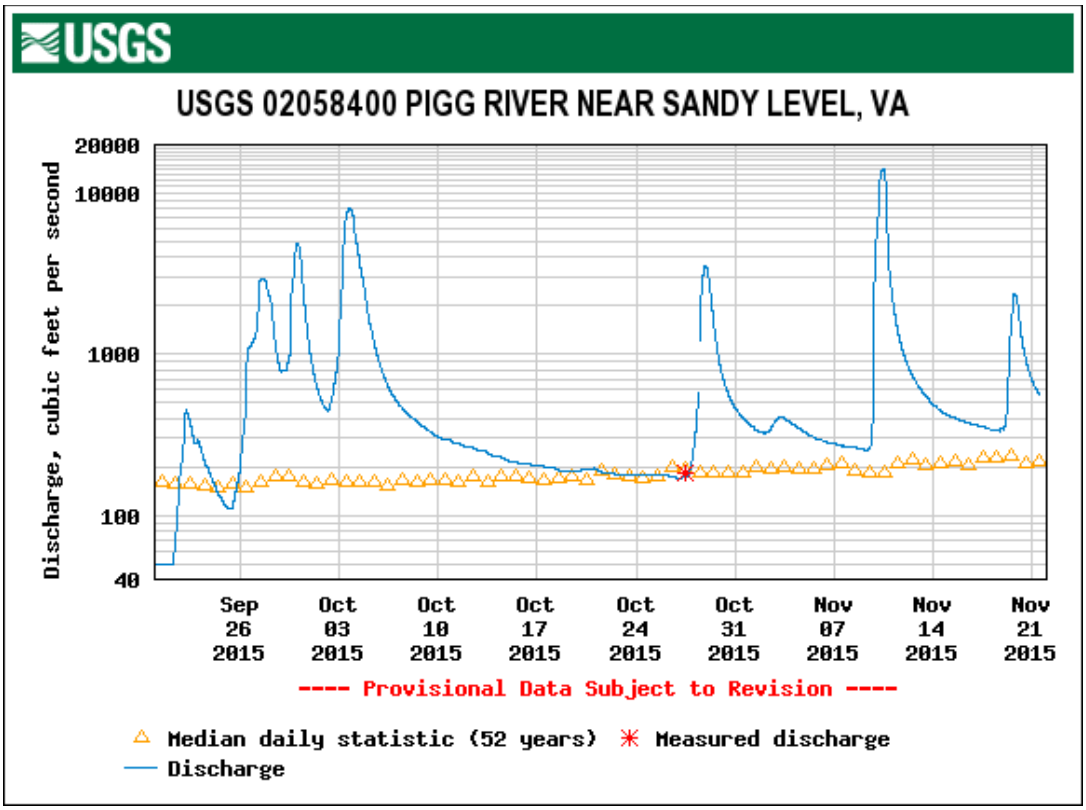

**Appendix Figure 5.** Predicted storm sediment hydrographs downstream of Power Dam.

The total volumes of sediment that can be flushed downstream are shown in the following table.

| Storm | Downstream Sediment Transport Capacity (tons) |
|---|---|
| 1 yr | 5,000-7,000 |
| 2 yr | 12,000-15,000 |
| 5 yr | 25,000-30,000 |
| 10 yr | 40,000-45,000 |

**Discussion:**
These predictions add perspective on the effects of larger storms to the patterns that might be seen downstream. The total amount of sediment predicted to be evacuated from behind the dam is approximately 285,000 tons (over a year). Approximately 50-60% of this sediment was predicted to be deposited in the first few miles from the dam (Question 3.). Although the sediment that can be moved during return interval storms is substantial, it is not a large percentage of the total. These comparisons further illustrate the difference in sand supply and downstream capacity that will occur until the upstream channel completely develops. This imbalance will a pattern of deposition and redistribution as described in the main body of the report. Once a stable upstream channel configuration is reached, storms will cause a greater redistribution response. These predictions may also point to the importance of daily flows and smaller, more frequent storms to the redistribution of sediments. Because of the ease of moving sand compared to coarser sized particles, these types of flows may more sediment over time in this system than less frequent, larger storms.

Predictions of single storm transport are limited in describing the complex process of dam removal and downstream response. These calculations are a simplified representation that is isolated in time and from other events. The timing of storms plays an important role in just how much sediment is deposited or flushed further downstream. Storms occurring in series or as part of a wetter cycle can quickly multiply sediment transport. If a large storm occurs during the first few months after dam removal, more of the sediment may be flushed. However, larger volumes of flushed sediment might simply shift predicted deposits further downstream. If a large storm occurs later in the year, it may accelerate the process of new feature development in deposition areas. If there are no storms in the year after removal, downstream development may be delayed. Single storm predictions are also limited because of their short duration. Due to the predictive procedure for return interval storms, the hydrographs developed only last 24 hours. Real storm cycles may create peaks that last longer or occur more frequently than these predictions. Storms may also result in elevated baseflow that adds to the real transport that would occur compared to predictions. A measured pattern of storm flows and the effect of storms in series is shown with some examination of recent USGS gage station data. This data was acquired from the USGS website for the gage station at Pigg River at Sandy Level, and shown in Figure 5.




**Appendix Figure 5**. Pigg River Flow Data in fall 2015.

The 1 yr storm peak is approximately 5,000 cfs at this gage on the Pigg River. During a two month time span, this flowrate was exceeded twice and approached 3 other times. This type of rainfall pattern would increase the amount of sediment that can be moved. In addition, baseflow jumps dramatically with the first storm and remains above the long term average for most of this period. This increased baseflow can also lead to increased transport because of the long period of time it covers.

The full modeling analysis described in the main body of this report is the best way to incorporate the effects of flow and dimensional variability on sedimentation processes over time. The results presented are an interpretation of what might happen based on different years of simulations that represent a variety of weather conditions. The average effects of larger storms are incorporated into these predictions. However, the full effect of all timing and peak possibilities cannot be completely captured. If the results of this storm analysis were extended to the long term study, it would likely lead to additional or accelerated redistribution of sediments in the downstream reaches. However, it is also likely that differences in the predictions would be minimal.
Even if a large storm occurs during the first year after dam removal, the predicted pattern of deposition would still occur, but the process of forming a newly developed river complex may be accelerated.