HARVELL DAM FISHWAY ALTERNATIVES ASSESSMENT

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Virginia Department of Game and Inland Fisheries
Harvell Dam Fishway Alternatives Assessment

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EXECUTIVE SUMMARY

Harvell Dam is located on the Appomattox River between the City of Petersburg and the City of Colonial Heights, Virginia. The original dam was reportedly constructed in 1856 and was used for hydropower generation as early as 1885. The current hydroelectric facilities, located at the right abutment of the dam, consist of a main powerhouse (capable of producing up to 600kW) and two smaller siphon turbines (capable of producing 180 kW). In 1998 a Denil fishway was constructed near the right abutment of the dam to satisfy a Federal Energy Regulatory Commission (FERC) requirement. Ownership of the dam was recently transferred from the Virginia Hydrogeneration and Historical Society to Mr. William Patton. Mr. Patton is the current owner of the dam.

The Denil fishway at Harvell Dam is a unique and complicated structure that contains two fish entrance locations at different elevations (one of which is influenced by tidal flow), has a dual attraction flow system, and is intended to operate in combination with hydropower generation under a wide range of river flow conditions. The complexity of the fishway requires continuous monitoring and careful adjustments in response to changing river flow conditions to ensure that all aspects of the facility function properly and optimal flow conditions for attracting upstream migrating fish into the fishway are constantly maintained.

Fish passage monitoring results from 1998, 1999 and 2001 (during hydropower generation) reported some fish movement through the Denil fishway, including a few American shad. However, hydropower generation ceased in 2004 at Harvell Dam with no plans for resuming generation. The performance of the Denil fishway is compromised without adequate attraction flow created by hydroelectric generation. Furthermore, the existing internal attraction flow system of the Denil fishway is undersized, supplying adequate attraction flow for only 60 percent of the time (i.e., river flows up to 1,400 cfs) during the spring migration season. Currently, no monitoring results are available to evaluate the performance of the fishway since hydropower generation has ceased at this site.

The complexity of the fishway, continuous monitoring requirements, inadequate attraction flow and the absence of hydropower generation all contribute to the reduced efficiency of the Denil fishway. It is believed that the performance of the Denil fishway can be improved during low and average river flow conditions by altering the fishway structure's design and simplifying the operational procedures required to maintain the facility at its maximum efficiency. The recommended modifications are described in greater detail in Section 10. The most significant modifications include the following:

- Eliminate the main (lower) fishway entrance and only use the secondary (upper) fishway entrance.

- Construct a rock weir barrier across the siphon tailrace channel to the main (lower) fishway entrance to prevent migrating fish from entering this channel.
- Reconstruct the secondary (upper) entrance and provide an automated gate system for continuous monitoring and adjustment of the entrance flow conditions.
- Construct an improved approach channel servicing the secondary entrance.
- Extend the spillway barrier on the dam crest and relocate the down migration chute.
- Provide continuous monitoring of the facility during the upstream migration season to document the effectiveness of the facility to pass the desired fish species.

The aforementioned modifications are intended to reduce operation and maintenance costs and enhance the performance and efficiency of the existing Denil fishway during low and average river flow conditions (up to 2,600 cfs). Based on historical river flow records, it is expected that river flows will exceed 2,600 cfs approximately 22 percent of the time during the spring migration season (March 1st through June 30th). As river flows exceed 2,600 cfs and approach the upper design range (7,500 cfs), elevated tailwater conditions reduce the effectiveness of the attraction flow system and the fishway will become less effective in attracting fish into the fishway. Improvements to the attraction flow system to allow it to function during high river flow conditions would require significant alterations to the structure or a complete replacement of the structure with a vertical slot fishway and may be impractical. The estimated construction cost to modify the existing Denil fishway to achieve satisfactory fish passage during low and average flow conditions are estimated to range between $350,000 and $500,000. Accounting for design and permitting, the total project costs are estimated to be between $400,000 and $600,000.

It should be noted that the physical limitations of the current structure, even if modified, will not support the projected ultimate numbers of target fish species. Should the target species populations increase over time to a point where they approach the physical limitation of the existing Denil fishway, additional fishway(s) and/or other types of fishways will be required at Harvell Dam to accommodate the target migration goals for the Appomattox River.

Should additional fish passage capacity be required, it is recommended that nature-like fishways, such as the rock ramp fishway, be considered. These types of facilities have an unlimited capacity, allow a wider variety of aquatic species to pass through the structure, provide aquatic habitat, and have minimal maintenance requirements. Alternatively, if the rock ramp solution is not practicable, a vertical slot fishway could be considered.

1. Purpose of the Study

Harvell Dam is located on the Appomattox River within the City of Petersburg, Virginia. The dam is equipped with two fish passage facilities; a pool and weir type fishway is located near the center of the dam, and a Denil-type fishway near the right abutment. The construction date of the pool and weir fishway is unknown; however, it is believed to have been in existence for many decades. The Denil-type fishway was constructed in 1998 to fulfill a FERC order requiring the Dam Owner to provide effective fish passage at the dam. The location and design of the Denil fishway was established to work in conjunction with the normal operations of the hydropower plant. However, Harvell Dam has ceased generating hydropower and there are no plans to resume generation of power in the future. Consequently, the Denil fishway no longer functions as originally intended and is currently not providing effective fish passage.

In 2008, the Virginia Department of Game and Inland Fisheries (VDGIF) performed a preliminary study to evaluate the feasibility of breaching Harvell Dam. The study performed by Froehling & Robertson, Inc. did not identify any obstacles that would prevent breaching the dam. Prior to advancing the breach concept through final design, the Virginia General Assembly directed the Virginia Department of Game and Inland Fisheries through House Bill 1855 (as provided below) to perform a fish passage study and determine if fish passage can be improved at this site without necessitating removal of the dam. The Bill was approved on March 16, 2011 and requires that said study be delivered to the Virginia General Assembly on or before November 30, 2011. Specifically, the study is to evaluate the performance of the existing fish passage facilities and make recommendations for improving fish passage for the target fish species of American shad (*Alosa sapidissima*), Hickory shad (*A. mediocris*), Blueback herring (*A. aestivalis*) and Alewife (*A. pseudoharengus*). For reference, House Bill 1855 is repeated below:

House Bill 1855
CHAPTER 215

An Act directing the Department of Game and Inland Fisheries to submit a report evaluating the alternatives to a proposed breach of the Harvell Dam.

[H 1855]

Approved March 16, 2011

Be it enacted by the General Assembly of Virginia:

1. *§ 1. That prior to any breach of the Harvell Dam, located on that part of the Appomattox River located within the City of Petersburg, the Department of Game and Inland Fisheries shall prepare and submit a report to the House Committee on Agriculture, Chesapeake and Natural Resources and the Senate Committee on Agriculture, Conservation and Natural Resources on or before November 30, 2011. The report shall evaluate the alternatives to the proposed breach of the dam, and include consideration of the adaptive reuse of the existing fishways, the costs for such adaptive reuse, and the availability of federal or state funding sources for such alternatives to the breach of such dam, and such other matters as the Department deems necessary and appropriate.*

2. History of Harvell Dam

Harvell Dam is located on the Appomattox River within the City of Petersburg, Virginia approximately 100 yards upstream of the tidal waters. The Harvell Dam is an existing concrete-buttress type run-of-river dam constructed on a rock ledge within the Appomattox River. The dam has blocked the upstream migration of fish and other aquatic species since its original construction reportedly in 1856. The dam is approximately 9 to 10 feet high, 390 feet long and has a storage volume of approximately 50 acre-feet. Historic documents indicate that the dam was used to generate electricity as early as 1885. Over the years, different power plant systems were installed including a stand-alone powerhouse on the right river bank (looking downstream) constructed circa 1930; and two siphon turbine units located between the headrace of the main powerhouse and the main dam constructed in 1998. The dam and hydropower facilities are currently owned by William Patton who recently purchased the property from the Virginia Hydrogeneration and Historical Society.

A Denil fishway was constructed in 1998 to fulfill a FERC requirement (License P-8657) and was designed to function in conjunction with the operation of the siphon hydropower units. The discharge from the siphons is an essential functional feature of the Denil fishway and is necessary to provide flow to attract fish to the main fishway entrance. Since Harvell Dam is no longer being used for hydropower generation this source of attraction flow no longer exists.

An abandoned pool and weir fishway is located near the center of the dam. A third fishway was reported to exist at the left abutment of the dam. Gannett Fleming reconnoitered the site on May 13, 2011 and again on October 27, 2011, and did not observe a fishway at the left dam abutment. Consequently, this study does not address or acknowledge the presence of a fishway at the left abutment of Harvell Dam.

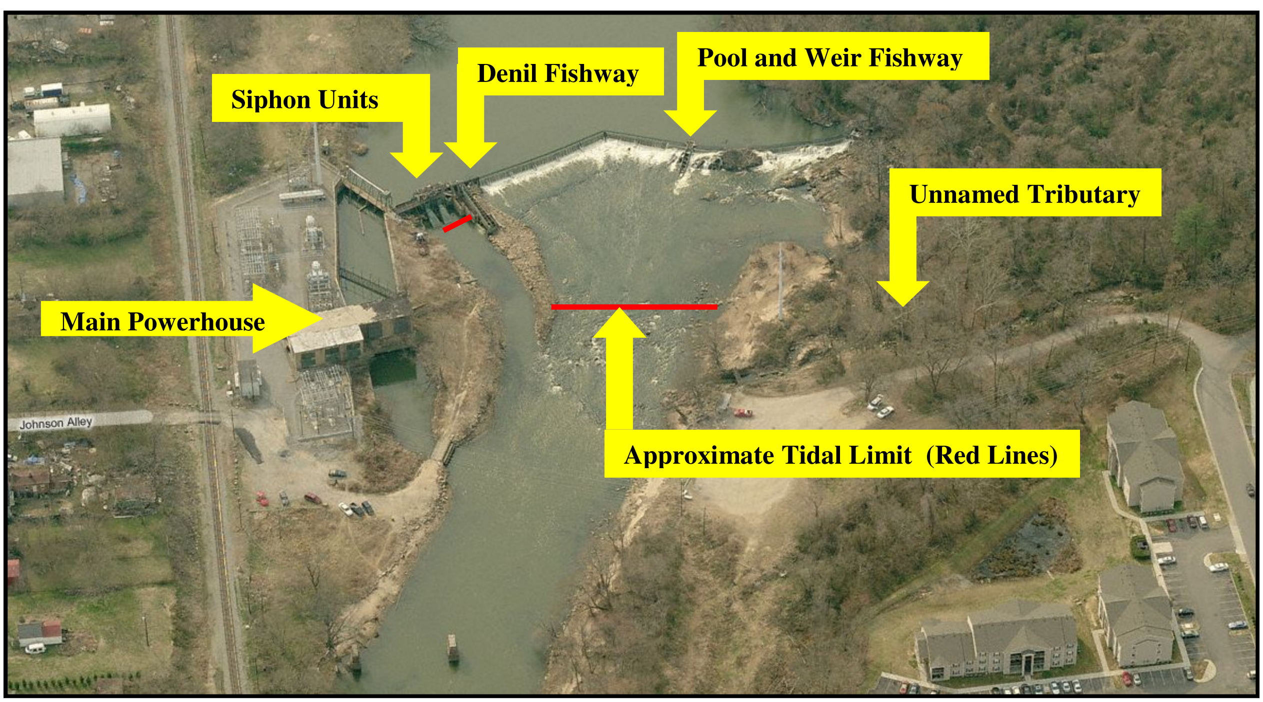

Figure 1. Aerial Photo of Harvell Dam on the Appomattox River

The Appomattox River has a drainage area of approximately 1,359 square miles at the dam site and approximately 127 river miles of the upper Appomattox would be accessible to anadromous fish with successful passage at Harvell Dam. The next upstream dam on the Appomattox River (Battersea Dam) has a natural breach. Abutment Dam and Brasfield Dam are located upstream of the Battersea Dam and both of these dams are equipped with fish passage facilities. The original design drawings for the Harvell Dam Denil fishway dated October 11, 1996 indicate that the fishway is intended to operate for river flows up to 7,500 cfs with the normal flow during the upstream migration season being approximately 2,300 cfs. These design flows assume that the hydropower plant is operational and able to pass up to 1,200 cfs around the dam. The design flows were established by the United States Fish and Wildlife Service and are typically based on the target species' swimming abilities and other behavioral factors that have been discovered through research.

Anadromous fish species which have historically been impacted by Harvell Dam include American shad (Alosa sapidissima), Hickory shad (A. mediocris), Blueback herring (A. aestivalis), Alewife (A. pseudoharengus) and Striped bass (Morone saxatilis). The target fish populations for the upper Appomattox River which have been identified by the Virginia Department of Game and Inland Fisheries are 70,000 Shad and 700,000 Herring per spring migration season.

3. Documents Reviewed *(SOW Task 1)*

The following information was reviewed and used to evaluate the effectiveness of the Harvell Dam Denil fishway:

- On-line FERC information for Project P-8657.
- Design drawings for the original Denil fishway as prepared by the original FERC licensee and owner Joshua Greenwood, dated October 11, 1996. It is understood that these drawings are design drawings and do not represent the as-built conditions.
- Dam Removal Feasibility Study by Froehling & Robertson, dated 2008.
- FEMA Flood Insurance Study for the City of Petersburg.
- 1998 & 1999 Harvell Hydro Project Fish Census prepared by Ingrid Greenwood.
- Efficiency of a Denil Fishway on a Low Head Dam on a Small Coastal River in Central Virginia, draft report dated 2001 prepared by Susan Schaefer, Virginia Commonwealth University.

The Harvell Dam Fishway Assessment study was prepared in the absence of a detailed topographic/bathymetric survey of the Harvell Dam and the surrounding area. Topographic mapping containing two-foot contours was obtained from the City of Petersburg for the purpose of evaluating existing site conditions and preparing concepts for alternate fish passage facilities.

4. Current State of the Denil Fishway *(SOW Task 1)*

The existing Denil fishway is a complicated structure that is intended to function under a variety of flow conditions. Exhibit 1 shows the configuration of the fishway as detailed on the original design drawings dated October 11, 1996. Additional photographs of the Denil fishway are provided in Appendix B. The structure contains attraction flow capabilities, two separate fish entrance locations, a four-foot-wide baffled fish ladder, and a fish counting window with crowder. Mr. Dick Quinn, P.E. of the United States Fish and Wildlife Service was responsible for developing the conceptual design concept for the Denil Fishway at Harvell Dam. Final construction drawings were prepared by Mr. Joshua Greenwood. It is reported that the final construction documents did not necessarily follow all of Mr. Quinn's recommendations. Mr. Quinn is a nationally recognized expert in the design of fishways and has been involved in the design and construction of over 200 modern fishways on rivers throughout the United States. The following describes each component of the fishway.

Fishway Entrances:

The Denil fishway has two separate fish entrance locations. The main (lower) entrance is located in the siphon turbines tailrace (refer to Figure 2). This entrance is intended to work in conjunction with the siphon turbines which can pass 300 cfs. The flow from the turbines is intended to attract upstream migrating fish into the siphon tailrace. The main fishway entrance is 2.5 feet wide and flow conditions immediately inside the entrance are controlled by manually adding or removing stop logs. This entrance is influenced by tidal flow.

Figure 2 Main (Lower) Fishway Entrance in Siphon Tailrace

The second (upper) fish entrance is located adjacent to the dam spillway and is intended to operate when the river flows exceed 370 cfs. This entrance is also 2.5 feet wide. Flow conditions immediately inside the entrance are controlled by manually adding or removing stoplogs. This entrance is higher in elevation than the main entrance and is not influenced by tidal flow. A steel spillway barrier structure is present on top of the dam spillway immediately upstream of the second fish entrance. The purpose of the steel barrier is to create a calm black-water area immediately in front of the second fish entrance. Figure 3 provides a photograph of the secondary spillway entrance. The photo on the left shows the secondary entrance and the steel spillway barrier on top of the dam. The right photo (taken on May 11, 2011) shows a close-up of the secondary entrance. The vertical stop log slot is visible immediately inside the entrance and several wooden stop logs which have been removed from the slot are sitting on top of the structure.

Figure 3 Secondary (Upper) Fishway Entrance at Right Abutment of Spillway

Attraction Flow System:

The Denil fishway includes a supplemental attraction flow system to attract fish into both the lower and upper fishway entrances. This system is also used for downstream migration of juvenile fish. The attraction flow system consists of two four-foot-wide stop log bays (refer to Figure 4) that allow water from the reservoir to pass over a wedgewire screen. Water passing through the wedgewire screen drops into a three-foot-wide channel where the flow can be distributed to Attraction Flow Chamber Nos. 1 and 2. Flow to each chamber can be controlled by one of two gates (refer to Figure 5). Attraction Flow Chamber No. 1 supplies flow to the main entrance in the siphon tailrace and Attraction Flow Chamber No. 2 supplies flow to the secondary entrance adjacent to the dam spillway.

Figure 4 Photo of Attraction Flow Inlet from Reservoir

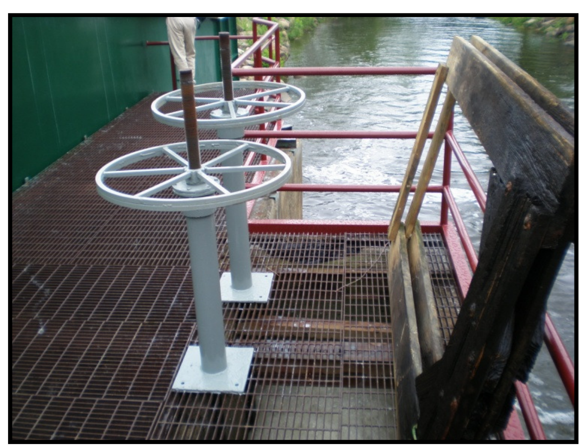

Figure 5 Photo of Gate Valves to Attraction Flow Chambers

Baffled Chutes:

Baffle chutes are located between the fishway entrances and the fishway exit into the upstream reservoir. All of the baffled chute sections are 4 feet wide. Fish entering the main entrance from the siphon tailrace swim over Attraction Flow Chamber No. 1 and then negotiate a 180 degree turn where they pass adjacent to the secondary entrance and Attraction Flow Chamber No. 2 before entering the lower baffled section of the fishway. The upper level of the fishway consists of two baffle runs (a 12 baffle run followed by a 16 baffle run), both of which are constructed with bottom slopes of 8H:1V. The two baffle runs are separated by a turning/resting pool. At the top of the 16 baffle run, the fish are directed by a crowder to pass in front of a counting window before they leave the structure and enter the upstream reservoir. The baffles placed in the chute are fabricated of wood (refer to Figure 6). A photo of the baffled chutes is presented on Figure 7.

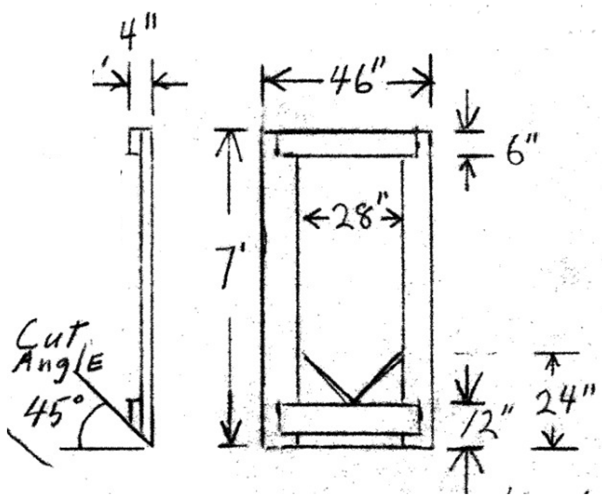

Figure 6 Typical Wood Baffle Per 1996 Design Drawings

Figure 7 Photo of Baffled Chutes

Fish Counting Window:

A crowder and viewing window are located at the upper end of the fishway near the fishway exit for the purpose of counting fish and evaluating the performance of the fishway. The crowder consists of a metal frame with vertical bars which forces the fish to swim close to the window. Numerous modifications to the crowder are apparent in the form of dissimilar screen materials. The viewing window is made of Plexiglas which allows for viewing of the fish passing through the facility. Photos of the crowder and counting window are presented in Figures 8 and 9, respectively.

Figure 8 Photo of Crowder

Figure 9 Photo of Counting Window

Fishway Exit:

The exit or upstream end of the fishway is connected to the reservoir pool at the upstream face of the existing dam immediately adjacent to the siphon turbines. The 4 foot wide exit channel is equipped with a steel trashrack to prevent large floating debris from entering the fishway. A photo of the fishway exit is presented in Figure 10.

Figure 10 Photos of Denil Fishway Exit Into the Reservoir

5. Denil Fishway Operating Procedures *(SOW Task 1)*

The Denil fishway at Harvell Dam is a unique and complicated structure. It is unusual for a Denil fishway to have two fish entrance locations, have a dual attraction flow system, operate in conjunction with hydropower generation, and be influenced by tidal flow. To further complicate the operation of the fishway, river flows at the Harvell Dam can be dramatically influenced on a daily/hourly basis by the upstream hydropower generation at Brasfield Dam.

The original fishway design provides a creative solution to deal with all of these variables over a wide range of river flow conditions (up to 7,500 cfs). However, as a result of the complexity of the fishway, the facility requires continuous monitoring and adjustments to ensure that all aspects of the facility are functioning as intended. Furthermore, the generation of hydropower by the siphon turbines is an important component of the operating procedures in order to attract upstream migrating fish into the siphon tailrace.

Operation of the Denil fishway was discussed with Mr. Joshua Greenwood, who designed and constructed the Denil fishway in 1998. Operation procedures include monitoring the upstream reservoir and downstream tailwater elevations, adjusting flows into the fishway exit and attraction flow system through the manual addition or removal of wooden stop logs, adjusting the attraction flow to both fishway entrances through two adjustable gates, adjusting the wooden baffles at the main fishway entrance and at the fishway exit as need to fit flow conditions, and adjusting flow conditions at the main and secondary fishway entrances through the addition or removal of wooden stoplogs. All of these adjustments must be taken into consideration for the river flow conditions at that moment in order to create ideal flow conditions for attracting fish into each fishway entrance. As the river flow conditions change, the adjustment process must be repeated.

For passage of anadromous fish, the Denil fishway needs to be operated during the upstream migration period from March 1st to June 30th. The fishway is operated from June 1st through November 30th for downstream migration. The original design drawings dated October 11, 1996 indicate that the Denil fishway has two modes of operation depending on the flow in the Appomattox River. Both operating modes rely on the Harvell Dam hydropower facility to be operational in order to create the necessary hydraulic environment for the fish to find the lower fishway entrance. Each operating mode is described below.

Operating Mode 1: Low River Flow Conditions (0 to 380 cfs)

For low flow conditions in the Appomattox River (river flows less than 380 cfs), the secondary (upper) fishway entrance adjacent to the dam spillway (see Figure 3) is closed, leaving the main (lower) fishway entrance in the siphon tailrace (see Figure 2) as the only active entrance under these flow conditions. One or both of the siphon turbines will be in operation (each siphon turbine having the capability to pass 150 cfs) and the main powerhouse will remain closed. Approximately 15 cfs will enter the Denil fishway through the fishway exit channel. Excess flow will pass through either the downstream migration flow opening, which also serves as the attraction flow intake, or over the dam crest (a minimum flow of 10 cfs is to pass over the dam crest at all times). The attraction flow system is capable of adding up to 15 cfs to the fishway outflows. From June 1st

through June 30th at least 15 cfs must be allowed to pass over the wedgewire attraction flow intake for downstream migration. Figure 11 provides a schematic diagram of the minimum flow operations.

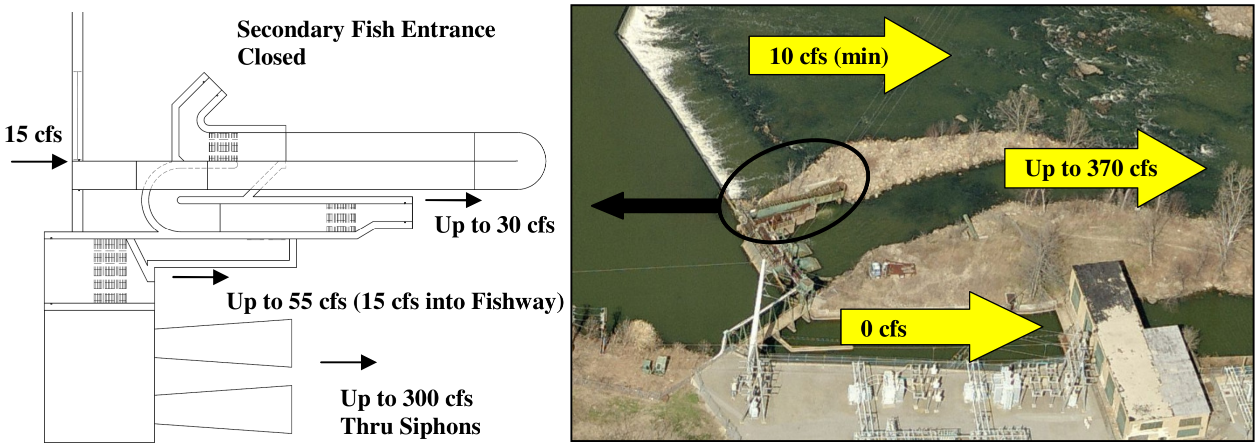

Figure 11 Denil Fishway Operation (with Hydropower) Under Low River Flow Conditions

Figure 11 shows that under minimum flow conditions, nearly all of the flow in the river (approximately 97%) is directed through the siphon tailrace. This condition is expected to provide sufficient attraction flow to direct upstream migrating fish into the siphon tailrace towards the main fishway entrance.

Operating Mode 2: Low to High River Flow Conditions (380 to 7,500 cfs)

For river flows between 380 cfs and 7,500 cfs, both the main (lower) fishway entrance within the siphon tailrace and the secondary (upper) fish entrance located adjacent to the dam spillway are to be opened. The siphon turbines are activated first as flows increase and are to be taken offline last as flows recede. Once river flows exceed 380 cfs, the main powerhouse is activated which can pass up to 880 cfs. During high flow events, up to 35 cfs will enter the Denil fishway through the fishway exit. The attraction flow system is capable of adding up to 25 cfs to the main fishway. During the operation of the main powerhouse, a 24-inch diameter conduit is activated to pass down-migrating juveniles from the main powerhouse headrace back into the siphon tailrace to avoid the main powerhouse turbine. This 24-inch diameter conduit is capable of adding up to 25 cfs to the siphon tailrace. Figure 12 provides a schematic diagram of the flow conditions for when the river flows exceed 380 cfs.

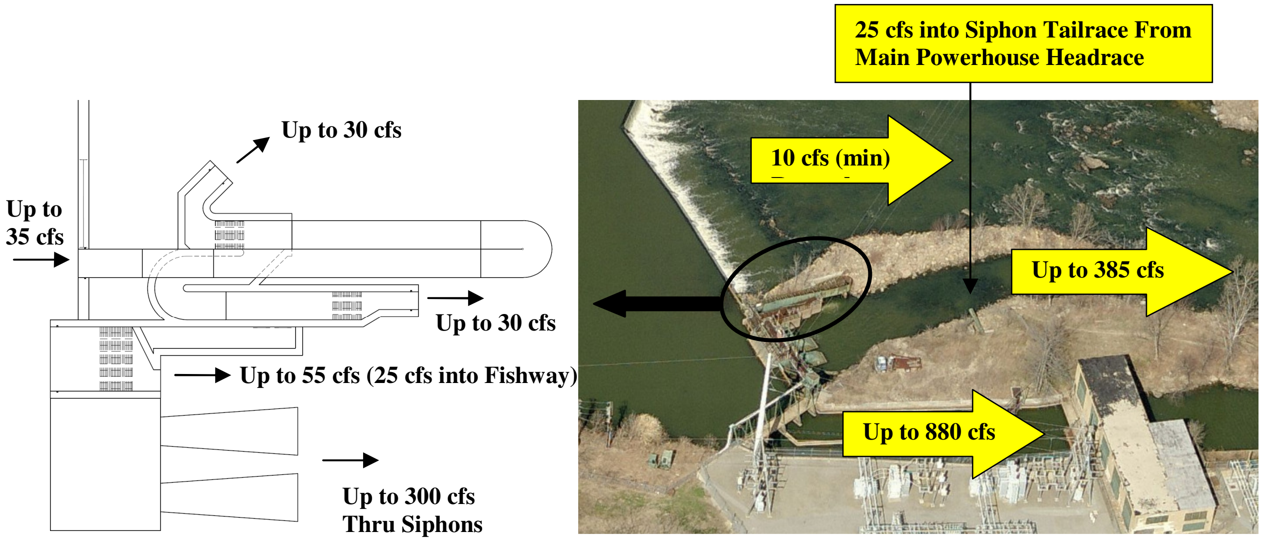

Figure 12 Denil Fishway Operation (with Hydropower) for High River Flow Conditions

Figure 12 shows that for river flows up to 1,275 cfs, nearly all of the flow in the river (approximately 99%) is directed through either the siphon tailrace (385 cfs) or the main powerhouse tailrace (880 cfs) which is expected to draw fish towards the south bank of the river and into the main (lower) fishway entrance. As river flows approach the maximum design flow of 7,500 cfs, the percentage of the total flow passing through the tailrace systems is reduced to approximately 17% of the total river flow. It is expected that the effectiveness of the main (lower) fishway entrance will diminish as river flows rise above 1,275 cfs since upstream migrating fish will be drawn past the siphon tailrace towards the dam spillway.

6. Historic Performance of the Harvell Dam Denil Fishway

After the fishway was constructed and placed in operation, and while the hydropower facility was still in use, Mr. Dick Quinn was reported to have visited the site to evaluate the fishway and make adjustments to the flows in the fishway. At that time, fish were observed using the fishway, indicating that it had a measure of initial success for the river flow conditions at that time. The 1998 & 1999 Harvell Hydro Project Fish Census prepared by Ingrid Greenwood and as submitted to FERC under cover letter dated October 22, 1999, indicated that fish were observed using the Denil fishway during the 1998 and 1999 migration seasons. This census indicated that the fishway was monitored sporadically throughout the 1998 migration season. During the period from May 5 through May 31, 1998, approximately 1,600 fish were observed passing through the fishway on five separate days. Blueback herring, American shad, Hickory shad and Gizzard shad, were reported to have been observed using the fishway. During the 1999 migration season (March 1st through June 30th), the fishway was monitored for a total of one-half hour a day at varying times between the hours of 8:00 am and 8:00 pm. Fish were observed using the fishway with the majority of the fish movement occurring on four to five separate days during the month of May. Approximately 440 fish were observed passing through the fishway on a single day during the middle of May 1999. Monitoring activities during the 1998 and 1999 migration seasons were performed in the absence of a fish biologist and without video backup. Consequently, the fish passage results from 1998 and 1999 cannot be verified.

Research performed by Ms. Susan Schaefer in 2001 as part of a Master's thesis from the Virginia Commonwealth University also documented fish movement through the facility. This study monitored the performance of the Harvell Dam Denil fishway from mid April through the end of June, 2001. Monitoring was performed by a combination of manual observation (44 hours) and video recording (184 hours). During this monitoring period, 5,371 fish were observed using the fishway. The majority (73 percent) of the fish movement occurred on five separate days. Most Alosine fish movement occurred on two separate days with the majority of these fish being Blueback herring. Table 1 provides a summary of all the fish observed using the fishway during the 2001 migration season.

Table 1
Summary of Fish Observed Using the Harvell Dam Denil Fishway
During the 2001 Migration Season

Species	Total	Percent of Total	Maximum Day
Alewife (*Alosa pseudoharengus*)	15	0.3%	10
Hickory shad (*Alosa mediocris*)	27	0.5%	19
American shad (*Alosa sapidissima*)	2	<0.1%	2
Blueback herring (*Alosa aestivalis*)	1126	21.0%	475
Gizzard shad (*Dorosoma cepedianum*)	4095	76.1%	1,328
Channel catfish (*Ictalurus punctatus*)	2	<0.1%	1
Largemouth bass (*Micropterus salmoides*)	8	0.2%	2
Green sunfish (*Lepomis cyanellus*)	20	0.4%	8
Bluegill (*Lepomis macrochirus*)	24	0.4%	8
Sea lamprey (*Petromyzon marinus*)	1	<0.1%	1
Threadfin shad (*Dorosoma petenense*)	43	0.8%	21
Common carp (*Cyprinus carpio*)	5	<0.1%	3
Fallfish (*Semotilus corporalis*)	1	<0.1%	1
Unidentified Clupeid	2	<0.1%	2

The monitoring results from 1998, 1999 and 2001 indicate that the fishway was successful in passing fish with hydropower generation in place. Beyond these accounts, no official fish counting records have been located to document the historical performance of the fishway without hydropower generation in place.

It should be noted that these historic accounts were all consistent in showing that upstream migration numbers are not evenly distributed throughout the migration period. The bulk of the annual upstream migration occurred on five to six separate days. Consequently, it is extremely important that the fishway be operational and working at peak efficiency at all times in order to be ready for these concentrated upstream migration periods.

7. Current Condition of the Denil Fishway *(SOW Task 1)*

During site visits performed on May 13, 2011 and October 28, 2011, the existing Denil fishway was observed to be operational and the overall general condition of the facility appeared to be fair to good. Portions of the fishways steel exterior were recently painted. The exposed steel surfaces within the fishway are showing signs of rusting. The concrete portions of the structure appeared to be in fair condition. Valve stems and operators appeared to be in good condition and functional. The valves were reported to be operational. The crowder at the viewing window was found to be operational; however, numerous repairs were evident and the surface paint was observed to be flaking. No signs of debris accumulation or sedimentation were observed within the fishway.

Several discrepancies were noted between the design drawings dated October 11, 1996 and the conditions observed on May 13, 2011. These discrepancies are as follows:

- The design drawings call for a stone wall to be in place immediately below the main fishway entrance within the siphon tailrace. The purpose of the wall is to prevent fish from entering the space under the fish ladder and help guide fish to the main entrance of the fishway. This stone wall was not observed.

- The design drawings call for the steel spillway barrier located at the crest of the dam immediately upstream of the secondary fishway entrance to extend at least five feet beyond the fishway entrance. The observed conditions found this steel diversion to be inadequate in length to provide a calm black-water area immediately in front of the fishway entrance.

- Several staff gages are identified on the design drawings. No staff gages were observed.

8. Pool and Weir Fishway Evaluation *(SOW Task 1)*

An abandoned pool and weir fishway is located near the center of the dam. A photo of the pool and weir fishway is presented in Figure 13. The original construction date of this fishway is unknown. The pool and weir fishway was observed during a site visit on October 28, 2011. The fishway is located on the downstream face of the dam and is formed by two sloping concrete walls. These concrete walls are spaced approximately four feet apart, are four feet in height and are aligned parallel to the river. Perpendicular concrete walls within the pool and weir fishway (spaced approximately 4.5 feet apart, three feet in height and two inches thick) divide the structure into a series of six pools. Each perpendicular wall contains a square orifice (approximately 13 inches by 13 inches) at the base of the wall. The orifice locations alternate from the bottom left to the bottom right side of each adjacent wall. These orifices are intended to allow upward fish movement. A U-shaped concrete structure was visible at the exit (upstream end) of the pool and weir fishway. The majority of this upstream structure was submerged by the reservoir pool and unable to be viewed.

The perpendicular walls within the pool and weir fishway were observed to be deteriorating. Several of the walls were missing the top six to nine inches of concrete and the steel reinforcement bars were exposed in many areas. Woody debris was observed within the fishway and the square orifice in the upper pool appeared to be sealed shut with a steel plate. Consequently, the pool and weir fishway was not operational at the time of this inspection.

Figure 13 Pool and Weir Fishway near Center of Dam

Based on visual observations, the pool and weir fishway contains several deficiencies that prevent this structure from effectively passing the target species of fish. These deficiencies include the following:

- The location of the pool and weir fishway and the absence of an attraction flow system make the entrance of this structure very difficult to find by fish attempting to migrate upstream.

- The capacity of each pool is only a fraction of the required volume needed to pass the number of target fish species (*Quinn, 1998*) and the inability to adjust flows within the fishway severely limits the effectiveness of this facility (refer to Appendix C).

- The high velocities through each orifice create a highly turbulent condition within each pool. These conditions are not favorable for passing American shad (*Mudre, Ney & Neves, 1985*).

- The pool and weir fishway, situated near the center of the river, is subject to river flows transporting floating debris. With no upstream deflection devices, the fishway is at risk of siltation and debris accumulation. Furthermore, with no access to the fishway, providing maintenance to this structure is very difficult, especially during normal to high river flows.

- There are no provisions for monitoring the performance of the fishway.

The pool and weir fishway is believed to be ineffective for passing the target species and volumes of fish.

9. Feasibility of the Current Denil Fishway to Provide the Desired Fish Passage *(SOW Task 2)*

As previously stated, hydroelectric power is no longer being generated at the Harvell Dam with no plans for future generation. The elimination of flows through the siphon turbines significantly alters the operation and viability of the Denil fishway which relied on this flow to attract fish into the siphon tailrace and ultimately into the main fishway entrance. Figure 14 depicts the anticipated flow conditions without hydropower generation in place.

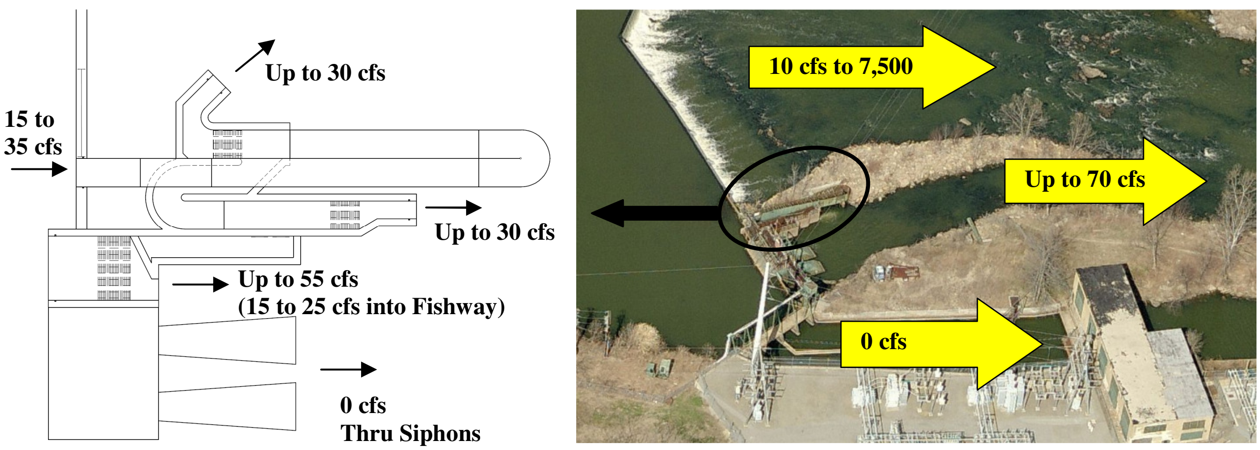

Figure 14 Denil Fishway Operation without Hydropower Generation

Figure 14 shows that with no hydroelectric generation in place the majority of the river flow is passed over the spillway section of the concrete dam. This condition results in very little flow in the siphon tailrace to attract fish to the main fishway entrance. To further compound the difficulty of attracting fish into the siphon tailrace, the Appomattox River contains a slight bend from left to right (looking downstream) and a tributary enters the north side of the river below the Harvell Dam. These conditions concentrate river flows along the north side of the river and draw upstream migrating fish away from the Denil Fishway. Consequently, the performance of the Denil fishway is compromised without hydroelectric generation due to the inability of upstream migrating fish to locate the main fishway entrance.

The ability of fish to locate the entrance of a structural fishway is one of the most significant factors (if not the greatest factor) in determining whether or not the fishway will be successful in passing fish. However, the physical features of the structural fishway also play an important part in determining the success of the fishway in passing the target species. The following observations have been made regarding the Harvell Dam Denil fishway.

- The optimal floor slope of the fishway should be between 6H:1V and 8H:1V for passing the target species of Herring and American shad. The Harvell Dam fishway contains a floor slope of 8H:1V which is acceptable for the target species.

- Resting pools should be provided for every 6 to 8 feet of vertical rise through the fishway. The Harvell Dam fishway contains one turning pool which also serves as a resting pool. The maximum rise which must be navigated by fish using this structure is approximately 4.7 feet, which is well within the acceptable range.

- The length of the turning pool should be between 2.5 and 3 times the width of the fishway (i.e., 10 to 12 feet long for the Harvell Dam fishway). The Harvell Dam fishway contains a 10 foot long turning pool length which is within the acceptable range.

- The baffle spacing within the sloped portions of the fishway is dependent upon the width of the fishway. The Harvell Dam fishway contains a 2.5 foot long baffle spacing which is acceptable for a four foot wide fishway.

- The physical dimensions and configuration of the wood baffles appear to be appropriate for the fishway width.

- The fishway contains an area of complicated hydraulics immediately inside the secondary (upper) fishway entrance adjacent to the dam spillway. At this location the flow passing through the body of the fishway splits. Half of the flow is intended to proceed to the main (lower) fishway entrance in the siphon tailrace and the remaining flow is intended to proceed to the secondary (upper) fishway entrance adjacent to the dam spillway. Additional turbulence is introduced at this location by the flow leaving Attraction Flow Chamber No. 2. This turbulence has the potential to disorient fish, preventing them from moving up the fishway. Furthermore, the close proximity of the attraction flow to this split could potentially cause a fish which has entered the main fishway entrance to leave the facility through the secondary fishway entrance.

- Upon entering the main fishway entrance, the fish must swim under the overhead baffled chutes which cast a shadow over the approach channel. Shadows and unlit or dark sections within the fishway are generally discouraged as they tend to discourage fish from moving through the fishway.

- The Steel Spillway Barrier located on the crest of the dam does not appear to be long enough to create a calm black-water area immediately in front of the secondary (upper) fishway entrance.

- No training walls were observed at each fishway entrance. The addition of a training wall along the shoreline immediately downstream of each fishway entrance would help to guide fish into the entrance.

- Varying river flows and the tidal influence at the main fishway entrance within the siphon tailrace require the flow conditions at each fishway entrance to be continuously monitored and adjusted to provide optimal conditions for attracting fish into the fishway. The current design requires flow conditions at each entrance to be manually adjusted by adding or removing stop logs. This configuration requires a physical presence at the dam several times a day to monitor and adjust the stop logs as needed.

- The design drawings appear to indicate that a two foot deep channel should be excavated into bedrock at the secondary (upper) fishway entrance below the dam spillway. This channel is intended to provide a flow path containing an adequate depth of water to allow upstream migrating fish to physically swim towards the fishway entrance. Due to river flows, the presence of this excavated channel could not be verified. However, a line of rocks was observed within the river bed downstream of the secondary fishway entrance. These rocks appeared to be creating an increased water depth at the secondary fishway entrance. It should be noted that under lower flow conditions, this line of rocks could become a barrier to upstream fish movement, preventing fish from finding the secondary fishway entrance. Furthermore, these rocks cannot be relied upon to provide a continuous tailwater effect as they are subject to river flows and can potentially be moved during large storm events.

- A viewing window is provided at the upstream end of the fishway for monitoring the performance of the fishway. However, all monitoring operations must be performed manually. No provisions were observed for continuous monitoring operations.

- The capacity of the attraction flow system appears to be marginal. The industry standard is to provide an attraction flow that is three (3) percent of the river flow. As river flows exceed 1,100 cfs, the rising tailwater conditions reduce the attraction flow to the secondary entrance below 3 percent. Based on historic data, a river flow of 1,100 cfs is expected to be exceeded 50 percent of the time during the spring migration season (refer to Appendix D). At the upper end of the operating range (7,500 cfs), the tailwater below the dam is expected to significantly reduce the amount of flow which the attraction flow system can provide. The reduced attraction flow will make it difficult for fish to locate the entrances of the fishway.

The original fishway was designed to operate for flows up to 7,500 cfs. A percentage of this design flow (up to 1,205 cfs) was intended to pass around the dam as part of the hydropower operations through either the main powerhouse or through the siphon turbines. With the elimination of hydropower, most of the river flow now passes over the dam. Consequently, with additional flows passing over the dam, it is expected that the headwater elevation for a given river flow will also increase.

Table 2 compares the design headwater elevations (i.e., with hydropower in place) with the estimated headwater elevations assuming no hydropower generation is in place. It is estimated that the water surface elevations within the upstream reservoir will increase by six to seven inches for both the average flow event (2,300 cfs) and the high flow event (7,500 cfs).

Table 2
Comparison of Headwater Elevations With and Without Hydropower Operation

Design River Flow (cfs)	Per Original Design Drawings dated October 11, 1996			Without Hydropower	
	Flow In Turbines[(1)] (cfs)	Flow In River (cfs)	Headwater El. (ft)	Flow In River (cfs)	Headwater El.[(2)] (ft)
0-380 (Low Flow)	0-300	0-160	12.8	0-300	12.8
2,300 (Avg. Flow)	1,205	1,095	**13.6**	2,300	**14.1**
7,500 (High Flow)	1,205	6,295	**15.5**	7,500	**16.2**

Table Notes:
1. "Flow Through Turbines" includes flow through the siphon turbines, main powerhouse and the 2 foot diameter pipe in the main powerhouse headrace.
2. The "Without Hydropower Headwater El." have been interpolated from the stage-discharge information provided on the original design drawings. A detailed and independent analysis of river flows and corresponding headwater elevations was not performed as part of this study.

To accommodate the increased headwater elevations, the last four baffles in the fishway (i.e., the most upstream baffles closest to the fishway exit) may require adjustment in order to maintain a 31 inch to 34 inch flow depth in the top baffle run. If necessary, the fishway exit may need to be extended into the reservoir to allow for additional baffles to be added.

While the majority of the interior components of the fishway appear to be adequate for passing the target species, the inability of the fishway to attract and guide fish to the fishway entrances severely reduces the effectiveness of the fishway. Poor hydraulic conditions at several key areas within the fishway along with the need for continuous monitoring and adjustment of the entrance flow conditions further reduces the performance and efficiency of the fishway. For these reasons, it is our opinion that the Harvell Dam Denil fishway, as currently configured and operated, does not provide effective passage for the target species.

10. Potential Alterations to the Denil Fishway to Improve Fish Passage *(SOW Task 3)*

As currently configured and operated, the Harvell Dam Denil fishway does not appear to provide effective fish passage. Various alterations can be made to the fishway to improve its performance; however, it should be noted that a typical Denil fishway (when operating at optimum efficiency) can pass only approximately 25,000 shad (*Quinn, Fish Passage Facilities for Alosa*) and 200,000 Alewife/Blueback per spring migration season. These numbers fall short of the target populations that the upstream habitat can support. The carrying capacity of spawing American shad is approximately 50 shad per acre based on studies done on the Connecticut and Columbia rivers. This has become the standard for estimating potential run size of shad populations in Chesapeake Bay tributaries (*CBP website:* http://www.chesapeakebay.net/status_shad.aspx?menuitem=19689). Fish passage at Harvell Dam would provide access to 127 miles of the Appomattox River, equating to approximately

1,400 acres of potential spawing habitat. At 50 shad per acre, the population target for American shad upstream of Harvell Dam is 70,000. The conservative approach to estimating herring population is to multiply the shad estimate by a factor of 10. Therefore, the herring target for the habitat upstream of Harvell Dam is 700,000. Even if the Harvell Dam Denil fishway could be modified to provide optimal fish passage conditions, the structure would not be able to pass the target populations due to the physical limitations of the structure.

As previously discussed, the Harvell Dam Denil fishway is a complicated structure that requires a continuous physical presence at the site to monitor and adjust the fishway. These adjustments are complicated, and if performed by someone without a detailed knowledge of the fishway, are unlikely to result in flow conditions that will encourage fish to enter the fishway. Consequently, all recommendations for improving the performance of the fishway should also attempt to simplify the operation of the structure in order to provide a greater chance for successful fish passage and also to minimize the required operational costs of the fishway.

To accomplish these goals, it is recommended that the dual entrance configuration be converted to a single entrance condition. The main (lower) fish entrance can be closed (filled with stoplogs) and the secondary (upper) fish entrance can become the main and only operating fishway entrance. Fish access to the siphon tailrace can be blocked by placing a boulder weir across the entrance to the tailrace. Both attraction flow chambers may remain active; however, Attraction Flow Chamber No. 1 could be used to provide attraction flow by providing reverse flow through the lower part of the fishway to the point where the flow currently splits at the base of the baffled chute. A removable grate or screen would need to be provided at this confluence to prevent fish from traveling towards the lower entrance.

This configuration significantly simplifies the structure and eliminates several of the current deficiencies associated with the fishway such as the need for fish to swim into a shaded or unlit area and the need to constantly adjust the flow conditions at the lower entrance to accommodate tidal flows. The following provides a list of alterations required to make this conversion. Exhibit 2 provides a plan view of the fishway showing the physical location of each alteration.

- Close the main (i.e., lower) fishway entrance by installing stoplogs. The stoplogs would extend to the top of the existing stoplog slot.

- Restrict fish movement up the siphon tailrace by installing large boulders at the downstream end of the siphon tailrace near the location where the siphon tailrace meets the Appomattox River. This boulder barrier could be equipped with a screen or stop logs to allow the siphon tailrace to drain after a high water event, freeing any fish which may become trapped behind the boulder barrier and preventing stagnate water. An alternative to this would be to open the main (i.e., lower) fishway entrance, allowing any fish trapped within the siphon tailrace to enter the Denil fishway.

- Install a removable screen or grating at the location where the flow in the baffled chute splits between the main and secondary fish entrance. The grating system would need to completely cover the opening that directs flow to the main fishway entrance. This modification would allow flow from Attraction Flow Chamber No. 1 to back up through the lower part of the fishway and supplement the attraction flow to the Secondary entrance. This condition is not ideal in that the flow from Attraction Flow Chamber No. 1 may introduce turbulence into the baffled chute where the flows combine. However, the alternative to this option is to completely rebuild the attraction flow system which may be impractical. This condition is expected to provide adequate attraction flow during low and average river flow conditions. During higher flow conditions (up to 7,500 cfs) the effectiveness of the attraction flow will be reduced by the downstream tailwater. Significant alterations to the fishway would be required in order to provide adequate attraction flow during high river flow conditions (raising of entrance channel walls, increasing the size of the attraction flow tunnels, replacing entrance gates, etc.).

- Close off the down migration opening just downstream of the wedgewire grating. This modification would continue to allow attraction flow to enter the fishway but would prevent flows from entering the siphon tailrace.

- Reconstruct the secondary fish entrance and relocate Attraction Flow Chamber No. 2. These modifications are intended to improve the turbulent flow conditions immediately inside the secondary fishway entrance and provide a rounder, smoother transition for the fish to navigate immediately after entering the fishway.

- Add a vertical wall immediately downstream of the relocated secondary fishway entrance along the river bank. This wall would help guide upstream migrating fish into the fishway entrance.

- Add an automated gate system at the relocated secondary fishway entrance to provide continuous monitoring and adjustment of the entrance flow conditions. A leaf gate that rises from the floor of the fishway appears to be appropriate for this situation. The gate would be controlled by an operator mounted above the gate that receives information from two transducers (one located within the fishway and one located outside the fishway). The information provided by the transducers would allow the gate to automatically adjust up or down to provide continuous optimal flow conditions at the fishway entrance.

- Extend the existing steel spillway barrier located on the crest of the dam beyond the secondary fishway entrance to provide a calm black-water area immediately in front of the fishway entrance.

- Excavate the area immediately in front of the secondary fishway entrance several feet into bedrock to provide a pool area that will provide adequate depth and help fish to navigate their way towards the fishway entrance.

- Provide attraction flow to the secondary entrance by notching the crest of the existing concrete dam immediately to the left of the extended steel spillway barrier. The notch would be equipped with stop logs to allow for flow adjustments. Stoplogs would be removed from the notch during upstream and downstream migration periods. Recommend providing a catwalk to access the notch to facilitate stoplog removal and installation.

- Move the downstream migration chute to the dam crest and consider incorporating this facility into the attraction flow notch described above.

- Provide additional catwalk areas along the north side of the Denil fishway to provide safe maintenance access to the baffled chute section of the fishway.

- Provide adjustments to the fishway exit in order to accommodate the higher reservoir elevations now that hydropower is no longer being generated. These adjustments may involve providing additional baffles or modifications to the existing baffles at the fishway exit or physically extending the fishway exit into the reservoir so that additional baffles can be added to the structure.

- Replace the existing crowder.

- Provide continuous monitoring of the fishway during the upstream migration season to verify the performance of the facility.

It is anticipated that the above-referenced alterations will simplify the daily operating procedures, improve the ability of the fishway to pass the target species of fish and make the Denil fishway more effective during low and average river flow conditions. The recommended attraction flow (three percent of the river flow) is expected to be provided for river flows up to 2,600 cfs. Once river flows exceed 2,600 cfs, the tailwater elevations below the dam will begin to reduce the attraction flow capacity. Based on historical data, river flows of 2,600 cfs are expected to be exceeded 22 percent of the time during the spring migration season. Significant alterations to the attraction flow system are expected to be required in order to create effective flow conditions at the fishway entrance during periods of high flow. These modifications would require significant reconstruction of the fishway and may be impractical.

The automated gate system and the elimination of the tidal conditions at the lower entrance would simplify the tedious task of adjusting attraction flows. However, these recommendations will not completely eliminate the need for regular monitoring and maintenance of the fishway. Daily observation of the fishway is still recommended to ensure that the facility is functioning as intended and that no debris, vandalism or other damage has occurred.

The estimated construction costs for the above-referenced improvements (not including the reconstruction of the attraction flow system) are expected to be in the range of \$350,000 to \$500,000. A detailed breakdown of the estimated construction cost is provided in Appendix E.

The proposed improvements to the Denil fishway will involve work within the Waters of the United States and modifications to the existing Harvell Dam. Consequently, it is expected that various permitting activities will be required. Section 12 identifies potential permits that may be required to perform the proposed improvements listed herein.

It is estimated that final design and permitting costs (not including bidding and construction phase services) may be in the range of \$50,000 to \$100,000 for the above-referenced improvements, depending on the features selected for final design. These engineering and permitting costs are provided for budgetary purposes only. The scope and associated design costs would need to be refined should some or all of the proposed modifications be advanced to final design.

It is believed that the aforementioned improvements will simplify the structure, reduce operation and maintenance costs, and improve the performance and efficiency of the existing Denil fishway under low and average river flow conditions. It should be noted that the physical limitations of the current structure will not support the ultimate numbers of target fish species. Should the target species' populations approach the physical limitation of the existing Denil fishway, additional fishway(s) and/or other types of fishways will be needed in the future to meet the target goals for the Appomattox River.

Consideration should be given to alternative fishway designs that have unlimited capacity to not only pass the target fish species, but be able to pass a wide variety of aquatic species under variable river flow conditions with minimal maintenance. Section 11 discusses opportunities for alternate fish passage facilities.

11. Fish Passage Alternatives at Harvell Dam *(SOW Task 4)*

Numerous types of fish passage facilities have been used along the east coast of the United States for passing American shad, Hickory shad, Herring and Alewife. The type of facility to be used is dependent upon factors such as topography, flow conditions, height of the structure to be passed, target species, and the desired population of fish to be passed through the facility. Table 3 lists the types of fishways that have been used along the east coast of the United States for passing the same target species that have been identified for the Harvell Dam.

Table 3
Types of Fish Passage Facilities

Fishway Type	Example	Comments
Chute Type	Denil Fishway	~25,000 American shad
Pool Type	Vertical Slot Fishway Pool and Weir Fishway	~500,000 American shad
Mechanical Devices	Fish Lifts	Capacity depends on hours of operation and size of facility
Nature-Like	By-Pass Channels Rock Ramps	Capacity depends on width of by-pass Unlimited for full width rock ramp
Breaches	Notches Partial or Complete Breaches	Breached dam can have unlimited capacity with complete dam removal

As previously discussed, the physical limitations (i.e., maximum capacity of 25,000 American shad) of the existing Denil fishway at the Harvell Dam will prevent this structure, even after modifications are made to improve its efficiency, from passing the target population of migratory fish (i.e., 70,000 American shad and 700,000 Herring) which the upper Appomattox River can support. Consequently, additional and/or alternative fish passage facilities may ultimately be needed. All of the fish passage facilities listed in Table 3 are feasible for increasing fish passage at this dam. However, some of these options have capacity limitations.

A second Denil fishway could be added at the left abutment of the dam. The original design drawings dated October 11, 1996 identify this area as a potential location for a second fishway. However, even with two Denil fishways in place, the combined capacity would still fall short of the target population of 70,000 American shad.

Fish lifts, or elevators, are typically used to transport fish over larger structures. Lifts have been successfully used at several hydroelectric power plants throughout the northeast United States, including Conowingo Dam, Safe Harbor Dam and Holtwood Dam on the Susquehanna River. A fish lift was installed at Brasfield Dam on the Appomattox River, approximately 6.6 miles upstream of Harvell Dam. A fish lift typically involves an entrance channel with attraction flow, a fish trap and crowder, a lifting container with hoisting mechanism, and an exit channel which typically contains a fish counting facility. These facilities are typically only used for large dams and are not economical or necessary for low head dams. Consequently, the use of a fish lift is dismissed as a practical means of fish passage at Harvell Dam.

Breaching Harvell Dam is the most effective option for providing fish passage. The Virginia Department of Game and Inland Fisheries investigated this option as part of a previous study prepared by Froehling & Robertson, dated 2008. Other than acknowledging the past study by Froehling & Robertson, this fish passage assessment does not investigate breaching of the dam as a fish passage option.

The vertical slot fishway is a common pool-type fishway for passing high volumes of fish and are typically used on large rivers like the Appomattox River. The vertical slot fishway at Easton Dam shown in Figure 15 is one of two vertical slot fishways constructed on the Lehigh River in Pennsylvania. The drainage area of the Lehigh River at Easton Dam is 1,345 square miles which is similar to the 1,359 square mile drainage area at Harvell Dam.

Like the Denil fishway, the vertical slot fishway contains a fish entrance with a supplemental attraction flow system. The body of the fishway consists of pools which are sized to accommodate the design fish population. Each pool is essentially a resting pool that contains a vertical slot that controls water flow between pools. Each pool generally rises 7 to 10 inches in elevation from the pool below and the pools continue until the required elevation difference between the downstream tailwater and the upstream reservoir has been overcome.

Figure 15 Vertical Slot Fishway at Easton Dam on the Lehigh River, PA

For Harvell Dam, a single vertical slot fishway is a viable option for passing the target population of fish species provided adequate attraction flow can be obtained to attract fish into the fishway. The vertical slot fishway could be located on the left abutment of the dam to work in combination with the existing Denil fishway or the vertical slot fishway could replace the existing Denil fishway. The Virginia Department of Game and Inland Fisheries reports that the existing vertical slot fishway at Boshers Dam on the James River has a properly designed attraction flow system and that the fishway has been successful in passing a wide range of fish. At least 23 species of fish, including American shad, have been reported passing through the Boshers Dam vertical slot fishway.

It should be noted that the same concerns that are associated with the ability of upstream migrating fish to find the entrance of the Denil fishway also apply to the vertical slot fishway. The ideal fish passage option should provide effective entrance conditions and unlimited capacity. Based on similar recent projects, the cost for a vertical slot fishway at Harvell dam could range between $3 and $6 million, depending on the features and degree of automation.

Historical poor performance of vertical slot fishways on the Lehigh, Schuylkill and Susquehanna Rivers has recently led the Pennsylvania Fish and Boat Commission to discourage construction of this type of fishway at low head dams in Pennsylvania in favor of other fishway types. The poor performance of some of the vertical slot fishways in Pennsylvania may be attributed to their design and to poor attraction flow configurations.

A new state-of-the-art fishway type that is gaining popularity are nature-like fishways. As the name implies, nature-like fishways closely resemble a natural river feature such as a stream channel or series of pools and riffles. These types of facilities are designed to provide a varying range of flow depths and velocities, and as such, pass a wider range of fish species. The use of natural materials also introduces habitat and allows the fishway to become a living part of the river system. Nature-like fishways are generally divided into two subcategories: (1) by-pass channels, and (2) rock ramps.

The bypass channel fishway involves the construction of a channel through or around the dam embankment that connects the reservoir to the immediate tailwater below the dam. These channels emulate naturally occurring streams within the surrounding watershed and provide a means for up migrating fish to bypass a manmade impediment such as a dam. This fishway requires sufficient land to be available immediately adjacent to the reservoir for locating the by-pass channel. Consequently, space limitations and topography often prohibit the use of a by-pass channel, especially in developed areas.

The rock ramp fishway involves placing a wedge of rock fill material immediately below the dam to create a passable slope over the dam. This facility is well suited for low head dams and is typically contained within the bed and banks of the watercourse. As a result, land acquisition is typically not required. The infill material is typically large field stones or quarried rock infilled with gravel which provides habitat and over time becomes a living part of the river bed (*Aadland, 2010*). In addition to providing fish passage, the rock ramp fishway also effectively eliminates downstream scour and the dangerous hydraulic roller which is associated with drowning at many low head dams.

Figure 16 Nature-Like Bypass Channel (Photo courtesy of Dr. Luther Aadland)

Figure 17 Before and after Photos of Rock Ramp Fishway Constructed at Riverside Dam (Photos courtesy of Dr. Luther Aadland).

The rock ramp fishway appears to be a viable option for providing fish passage at the Harvell Dam. A conceptual layout and associated details of this facility are shown on Exhibits 3 and 4, respectively. The area below the dam would be infilled with large diameter boulders and graded to a flat slope (three percent slope is recommended). This slope would extend from the top of dam downstream until this slope intersects the existing river bed. The infill material would be graded such that the finished grade at the center of the river is slightly lower than at the edges of the river. This configuration would channelize flows towards the center of the river, creating variable flow regimes across the width of the rock ramp. Large weir stones would be placed on the contour to create a series of pools across the full width of the river. The weir stones would be strategically placed to create localized openings that allow migrating fish to pass through each weir. In the center of the river, the pools provided by each weir would be supplemented with small localized depressions that provide additional resting pools for migrating fish. The entire surface of the rock ramp fishway would be chinked with smaller diameter rock to form a smoother and less permeable surface.

As previously discussed, the efficiency of the Denil and Vertical Slot fishways are driven by the ability of the migrating fish to find the entrance of the fishway. This concern is eliminated with the rock ramp fishway which essentially converts the entire dam into a single set of rapids. The chinking stone and the natural sediment infill that would occur over time would form a natural channel bottom that provides habitat for small aquatic species.

At this location, a rock ramp fishway would provide an efficient means for passing target species since the fishway would essentially become part of the river. A rock ramp fishway would have abundant capacity for passing the target population of fish. Furthermore, the design of the rock ramp provides a wide range of flow conditions so that nearly all species of resident fish would be able to use the structure. Another positive aspect of the rock ramp fishway is that there is minimal maintenance required to keep the facility functional. Operation and maintenance costs are discussed in Section 13.

The estimated construction cost of the rock ramp concept as shown on Exhibits 3 and 4 is estimated to range between $2 and $3.5 million. Refer to Appendix F for supporting cost information.

The rock ramp design shown on Exhibits 3 and 4 has been reviewed by Dr. Aadland of the Minnesota Department of Natural Resources. Dr. Aadland is the nation's leading expert in the design of nature-like fishways. Recommendations from Dr. Aadland include flattening the slope of the rock ramp fishway from five percent to three percent. This will lengthen the rock ramp and subsequently increase construction costs beyond the costs identified within this report. Should this option be considered for providing fish passage at the Harvell Dam, variations of the full height rock ramp may be entertained for the purpose of reducing construction costs. For example, to shorten the length of the rock ramp fishway, the top portion of the dam could be removed, reducing the vertical height of the dam. This option would still maintain a permanent pool behind the dam; however, the reduced dam height would shorten the length of the rock ramp fishway and subsequently reduce the cost of the fishway.

Table 4 provides a summary of construction costs associated with several recent fish passage projects (i.e., within the past five years) and provides a feel for the magnitude of the investment needed to construct a new fish passage facility.

Table 4
Recent Construction Costs for Fish Passage Facilities

Fishway Type	Location	Dam Height (Feet)	Drainage Area (Square Miles)	Approximate Construction Cost (Million)
Denil	Norristown Dam, Schuylkill River, PA	16	1,761	$3.2
Denil	Black Rock Dam, Schuylkill River, PA	12	1,213	$3.5
Vertical Slot	Sunbury Inflatable Dam, Susquehanna River, PA	9	18,300	$7
Rock Ramp	Shenango Intake Dam, Shenango River, PA	6	607	$1
Rock Ramp	Riverside Rapids Dam, MN	13	-	$4.7
Rock Ramp	Crookston Rapids Dam, MN	11	-	$1.3

12. Permitting *(SOW Tasks 3 & 4)*

The suggested modifications to the Denil fishway and the rock ramp fishway option both involve modifications to the existing Harvell Dam and both include the placement of fill within the Appomattox River either in the form of riprap, boulders, concrete or other types of building materials. The modification of the Denil fishway also involves excavation of the river bed immediately adjacent to the secondary fishway entrance. All of these activities represent work within Waters of the United States, and as such, are expected to require some form of permitting approval from local, state and/or federal agencies. Permit approvals from the following agencies will likely be required for the Denil fishway improvements and/or the rock ramp fishway option.

United States Army Corps of Engineers

The in-stream work activities will likely require permits pursuant to Section 404 of the Clean Water Act (33 U.S. Code §1344(a)) and Section 401 of the Clean Water Act (33 U.S. Code § 1341(1)). The proposed work activities constitute work within Waters of the United States as defined in the U.S. Army Corps of Engineers (COE) regulations. Section 401 Certification is required to insure that the proposed discharges and activities will not violate specified water quality standards.

Virginia Department of Environmental Quality

The in-stream work activities will likely require permits pursuant to the 1989 Water Protection Permit law (VA Code § 62.1-44.15:5). The Virginia Department of Environmental Quality (VADEQ) Water Division and the State Water Control Board implement Section 401 of the Clean Water Act on behalf of the COE. A joint permit application (JPA) is anticipated to be required. Submission of the JPA is made to the Virginia Marine Resources Commission (VMRC) who in turn forwards the permit application to the COE, VADEQ, local wetlands boards and various other state agencies as appropriate.

In addition, pursuant to the Clean Water Act and the 1989 Water Protection Permit law, the VADEQ Water Division may require a Virginia Pollution Discharge Elimination System (VPDES) permit for the discharge of stormwater from construction sites. This includes erosion control plan approval from the appropriate Soil and Water Conservation District.

Virginia Department of Conservation and Recreation

Pursuant to the Virginia Dam Safety Act (VA Code § 10.1-604), the Virginia Soil and Water Board, under the authority of the Virginia Department of Conservation and Recreation (VDCR) must issue dam construction permits to provide for the proper and safe design, construction, operation and maintenance of impounding structures, to protect public safety.

Municipal Coordination

Coordination and approvals from the local governing bodies (i.e., Petersburg and/or City of Colonial Heights) may be required as needed to obtain state/federal permits, building permits, etc.

Should the proposed improvements to the Denil fishway or the rock ramp option be considered, it is recommended that a pre-application meeting be held with all of the potential reviewing agencies so that all of the permit requirements can be established early in the design process.

13. Down Migration Evaluation *(SOW Task 5)*

The downstream migration period on the Appomattox River occurs from June 1st through November 30th. Harvell Dam currently contains three facilities for passing downstream migrating fish. The following provides a brief description of each down migration facility.

24" Diameter Conduit at Main Powerhouse: During operation of the Main Powerhouse, the potential exists for fish to be drawn through the main turbines, increasing the risk of fish mortality. To prevent fish from entering the Main Powerhouse, a fish screen located immediately upstream of the powerhouse directs fish which have entered the headrace into a 24-inch diameter conduit. This conduit discharges into the siphon turbine tailrace. This downstream migration system may have been effective during hydropower generation activities; however, the 24-inch diameter conduit is no longer in use now that hydropower generation has ceased. It is believed that the use of this 24-inch diameter conduit without hydropower generation will not provide effective downstream migration. Without the draw of water (up to 880 cfs) through the Main Powerhouse headrace, there is no flow which will direct down migrating fish towards this conduit entrance.

Attraction Flow Entrance of the Denil Fishway: The Denil fishway contains two four foot wide stop log bays for allowing flow to enter the attraction flow system (refer to Figure 3.A). These bays also allow for downstream migration. The original design drawings dated October 11, 1996 call for a log boom to be placed upstream and to the right of the attraction flow entrance. In addition to providing debris deflection, the log boom also helped to guide down migrating fish towards the attraction flow entrance. This log boom was not observed during the site visit performed on May 15, 2011. With hydropower generation, the Main Powerhouse and the Siphon Turbines helped to draw water to the right abutment of the dam, which in turn helped to improve the efficiency of this down migration facility. Without hydropower generation, the Denil fishway attraction flow entrance is still capable of passing down migrating fish. However, its efficiency is reduced without the turbine units drawing river flows towards the right abutment.

Spillway Crest: The Harvell Dam is a run of the river dam. Consequently, in the absence of hydropower generation, all river flows will pass over the dam. This situation allows for down migrating fish to pass over the dam. The drop over the dam is estimated to be up to 9 feet in height. This drop height is expected to result in some fish mortality.

Without modification to limit the drop height, the existing spillway crest is considered to be ineffective for down migrating fish.

Should the modification to the Denil fishway (as discussed in Section 10) be implemented, we recommend that the attraction flow entrance be moved to the left and incorporated into the existing dam immediately to the left of the secondary fishway entrance. The drop on the downstream side of the dam could be reduced by constructing a stepped pool system immediately below the down migration chute. The efficiency of the down migration facility could be improved by installing a floating barrier within the reservoir that would help to guide fish to the entrance.

Should the recommended rock ramp fishway option be implemented, all down migrating fish will simply pass over the dam through the rock ramp structure. This configuration also eliminates the potential health concerns associated with fish passing over the dam (i.e., free fall condition). During low flow periods, the shallow flow depths over the dam crest could discourage downstream migration of larger fish. This situation can be resolved by cutting a shallow notch near the center of the dam, providing an increased flow depth over the dam at this location.

14. Operation and Maintenance Procedures and Costs *(SOW Task 6)*

Long term operation and maintenance is critical to the success of a fishway to pass the target populations and species of fish. Operation and maintenance activities can include items such as annual start-up and shut down operations, general upkeep of the facility, daily observation and adjustment of the flow conditions within the facility, removal of debris and sediment deposits, repair due to vandalism, and repair following flood events. The type of fishway and design features of the fishway can make a significant difference in the effort and costs needed to keep the facility functional and operating as intended. The following compares the operation and maintenance requirements for both the Denil fishway and the rock ramp fishway.

Denil Fishway

The Denil fishway at Harvell Dam currently contains two fish entrance locations (i.e., a lower and upper entrance). As discussed in Section 10, it is recommended that the fishway be simplified by eliminating the lower fishway entrance. The fishway also contains an attraction flow system (consisting of concrete channels, gates and grating), a steel chute with wooden baffles, a crowder, fish counting window and a grated exit into the upstream reservoir. The following provides a typical operation and maintenance procedure that should be considered the minimum requirements for the Harvell Dam Denil fishway.

Annual Start-Up Operations

- If open, close the attraction flow opening, the secondary fish entrance and the fish exit location by installing wooden stop logs. Note that the main fish entrance is to remain closed at all times as discussed in Section 10.
- Dewater interior of the fishway so that a thorough inspection can be made.
- Review the entire structure for damage and acts of vandalism. Repair/replace items found to be in damaged.
- Operate attraction flow gates to ensure full range of operation. Operate automated leaf gate (if installed) at the secondary fish entrance to ensure full range of operation. Check gate seating areas for sediment deposits, debris or other material that will prevent the proper operation of the gates.
- Remove all debris and sediment deposits from within the fishway and outside of the fishway at the secondary entrance location.
- Replace or repair all damaged wooden baffles.
- Clean viewing window (inside and out) and the fish counting backboard on the crowder.
- Touch-up paint on the fish counting backboard as necessary.
- Remove stop logs from the fishway entrance locations.
- Remove stop logs from the fishway exit and attraction flow opening.
- Open attraction flow valves, adjust flows and activate leaf gate system to provide a 6" to 9" elevation difference between the water surface within the secondary entrance and the tailwater along with a flow velocity of 5 to 6 feet per second leaving the secondary fish entrance.
- Perform all needed maintenance to the surrounding site including riprap slopes, gravel access roads/bridges, eroded areas, vegetation control, etc.
- Secure site.

Routine (i.e., Daily) Operations During Upstream Migration Period

- Monitor the performance of the automated gate system at the secondary fish entrance.
- Adjust the attraction flow as needed to maintain flow velocities of 5 to 6 feet per second at the secondary fishway entrance.
- Remove all debris and sediment accumulations from within the fishway.
- Adjust removable baffles in the top baffle run to maintain a 31 to 34 inch flow depth at the top of the fishway and a 30" depth at the turning pool under average flow conditions.
- Monitor performance of the fish passage facility (currently no provisions are in place for continuous monitoring of the viewing window).

Routine (i.e. weekly) Operations During Downstream Migration period

- Monitor the downstream migration chute for debris accumulation.
- Remove all debris and sediment accumulations that may impact the performance of the downstream migration facilities.
- Monitor the Denil fishway for damage or acts of vandalism.

Annual Shut-Down Operations

- The fishway may be shut down at the completion of the upstream migration season with the exception of the attraction flow opening which shall provide downstream migration flow through November 30th.
- Install stop logs in the attraction flow opening within the dam crest. Close the attraction flow gates to Attraction Flow Chamber Nos. 1 and 2.
- Place stop logs in the fishway exit and at the secondary fish entrance locations.
- Remove wooden baffles (optional).
- Place stop logs in attraction flow opening at the completion of the down migration season.
- Evaluate the condition of the fishway and perform major maintenance repairs during the non-migration season and prior to initiating the annual start-up operations.

Table 5 provides a recommended operation and maintenance schedule for the Harvell Dam Denil fishway (in its proposed condition as described in Section 10).

Table 5
Operation and Maintenance Schedule for the Harvell Dam Denil Fishway

Activity		Daily	Weekly	Annual Start-Up	Annual Shut-Down	During Varying Flow Conditions	After Flood Event
Operation	Monitor/Adjust Flow Conditions at Fish Entrance	X		X			
	Add/Remove Upstream Baffles					X	
	Monitor Downstream Migration Facility		X				
Maintenance	Remove Debris and Sediment	X		X			X
	Repair/Replace Wooden Baffles			X			
	Repairs to Fishway Structure				X		
	General Site Maintenance			X	X		X

The annual operation of the Denil fishway requires physical monitoring of the structure on a daily basis (assume one hour per day) during the upstream migration period (122 days) and on a weekly basis (assume one hour per week) during the remaining downstream migration period. This effort, along with the annual start-up and shut-down operations, is estimated to require over 160 manhours resulting in an annual operating cost of approximately $15,000 to 20,000 per year (assuming that the improvements discussed in Section 10 are implemented). In the current condition, the Denil fishway requires a nearly continuous presence to ensure that the facility is performing at its optimal efficiency. Annual manpower efforts under this condition could easily exceed 400 hours resulting in operational costs exceeding $40,000 per year.

Rock Ramp Fishway

The rock ramp fishway emulates the natural river. There are no moving parts or maintenance activities required to regulate flow through the fishway. There is the potential for floating debris such as tree trunks to become lodged within the fishway which may need to be removed. If properly designed, the rock ramp should remain stable during flood events and not require repair. Consequently, the annual operation and maintenance costs associated with a rock ramp fishway are estimated to be negligible.

15. Summary

The Denil fishway at Harvell Dam is a unique and complicated structure that contains two fish entrance locations at different elevations (one of which is influenced by tidal flow), has a dual attraction flow system, and is intended to operate in combination with hydropower generation under a wide range of river flow conditions. The complexity of the fishway requires continuous monitoring and adjustments in response to changing river flow conditions to ensure that all aspects of the facility function properly and optimal flow conditions for attracting upstream migrating fish into the fishway are maintained.

Fish passage monitoring results from 1998, 1999 and 2001 (during hydropower generation) indicate that the fishway was successful in passing fish, including a few American shad. However, hydropower generation ceased in 2004 at Harvell Dam with no plans for resuming generation. The performance of the Denil fishway is compromised without adequate attraction flow created by hydroelectric generation. Currently, no monitoring results are available to evaluate the performance of the fishway since hydropower generation has ceased at this site.

It is believed that the performance of the Denil fishway can be improved during low and average river flow conditions by altering the fishway structure's design and simplifying the operational procedures required to maintain the facility at its maximum efficiency. The recommended modifications are described in greater detail in Section 10. The most significant modifications include the following:

- Eliminate the main (lower) fishway entrance and only use the secondary (upper) fishway entrance.
- Construct a rock weir barrier across the siphon tailrace channel to the main (lower) fishway entrance to prevent migrating fish from entering this channel.
- Reconstruct the secondary (upper) entrance and provide an automated gate system for continuous monitoring and adjustment of the entrance flow conditions.
- Construct an improved approach channel servicing the secondary entrance.
- Extend the spillway barrier on the dam crest and relocate the down migration chute.

- Provide continuous monitoring of the facility during the upstream migration season to document the effectiveness of the facility to pass the desired fish species.

The aforementioned modifications are intended to reduce operation and maintenance costs and enhance the performance and efficiency of the existing Denil fishway during low and average river flow conditions. However, as river flows approach the upper design range, elevated tailwater conditions reduce the effectiveness of the attraction flow system. As river flows increase the fishway will become less effective in attracting fish into the fishway. Improvements to the attraction flow system to allow it to function during high river flow conditions would require significant alterations such as raising all of the walls of the attraction flow system, increasing the size of the attraction flow tunnels and increasing the size of the operating gates that supply flow to the attraction flow chambers. These improvements would require significant reconstruction of the fishway and may be impractical. The estimated construction costs to modify the existing Denil fishway to achieve satisfactory fish passage during low and average flow conditions are estimated to range between $350,000 and $500,000. Accounting for design and permitting, the total project costs are estimated to be between $400,000 and $600,000.

It should be noted that the physical limitations of the Denil fishway, even if modified, will not support the ultimate numbers of target fish species. Should the target species populations approach the physical limitation of the existing Denil fishway, additional fishway(s) and/or other types of fishways will be required at Harvell Dam to meet the target goals for the Appomattox River.

Existing Funding for Harvell Dam Fish Passage

The current federal grant from National Oceanic and Atmospheric Administration’s (NOAA) Open Rivers Initiative (NA10NMF4630188) to the Virginia Department of Game and Inland Fisheries for funding the removal of Harvell Dam was granted explicitly for a removal project only and cannot be used for fishway construction or modification. Additional funding from the United States Fish and Wildlife Service (USFWS) grant agreement (52330-A-6002) with the Virginia Department of Game and Inland Fisheries for the removal of Harvell Dam is explicitly for a removal project and cannot be used for fishway construction or modification.

Potential Fish Passage (fishway) Funding Sources

Virginia Fish Passage Grant and Revolving Loan Fund: If funding is available in the Fund, dam owners may seek dam removal or fishway construction financing assistance from this program. Source: Code of Virginia §29.1-101.2 through §29.1-101.9

Virginia General Assembly Appropriation: The Virginia General Assembly has directly funded portions of fish passage projects in Virginia in the past.

Congressional Appropriation: The U.S. Congress has directly funded portions of fish passage projects in the U.S. in the past via explicit earmarks.

USFWS National Fish Passage Program: The USFWS Fish Passage Program is a voluntary, non-regulatory program that provides funding and technical assistance toward removing or bypassing barriers to fish movement. Fish passage project proposals may be initiated by any individual, organization, or agency, in cooperation with the Service's Fish and Wildlife Management Assistance Offices. Grant agreements are preferably made between the USFWS and either a non-federal government agency or an environmental non-government organization. Dam removal applications are favored over fishway projects. Source: http://www.fws.gov/fisheries/fwco/fishpassage/ (site last updated 2-4-2009) and email communication from USFWS on 11/28/2011.

American Rivers: American Rivers and NOAA have a community-based river restoration grant partnership for fish passage projects. In the past, this partnership has funded many dam removal projects and some fishway projects. However, it is the current policy of the American Rivers-NOAA grant partnership that fishway construction projects are not eligible for funding. Only dam removal design and implementation projects are being considered under this funding mechanism. Source: http://www.americanrivers.org/assets/pdfs/dam-removal-docs/final-funding-guidelines-dec-11.pdf

FishAmerica Foundation: FishAmerica is the conservation and research foundation of the American Sportfishing Association. FishAmerica, in partnership with the NOAA Restoration Center, awards grants to local communities (e.g., non-profit organizations) and government agencies to restore habitat for marine and anadromous fish species. Fishway construction/improvement projects are eligible for funding under this program. Because this is a partnership with NOAA, it is likely that only removal projects will be considered or score favorably. The next application cycle will be announced in March 2012 for 2013 projects. A non-profit or governmental entity would need to apply for and receive the grant and pass it through to the actual dam owner, if the owner does not meet this qualification. Source: http://www.fishamerica.org/grants/

National Fish and Wildlife Foundation (NFWF), Chesapeake Bay Small Watershed Grants Program: The NFWF awards grants in partnership with the Chesapeake Bay Program, Environmental Protection Agency, U.S. Forest Service and Altria, with additional funding support from FedEx. Grants will be awarded to organizations and local governments working on a local level to protect and improve watersheds in the Chesapeake Bay basin, while building citizen-based resource stewardship. Fishway projects are eligible under this mechanism. Source: http://www.nfwf.org/AM/Template.cfm?Section=Chesapeake_Bay_Stewardship_Fund&Template=/CM/HTMLDisplay.cfm&ContentID=22003

Natural Resources Conservation Service (NRCS): NRCS has funded fish passage projects in Virginia in the past. The current fish passage funding program details were not available in time for this report. Source: email communication from NRCS on 11/23/2011.

Owners of dams: In Virginia, dam owners (e.g. municipalities) have paid for fish passage projects either in whole or as part of a partnership with non-government, state and/or federal agencies.

16. References

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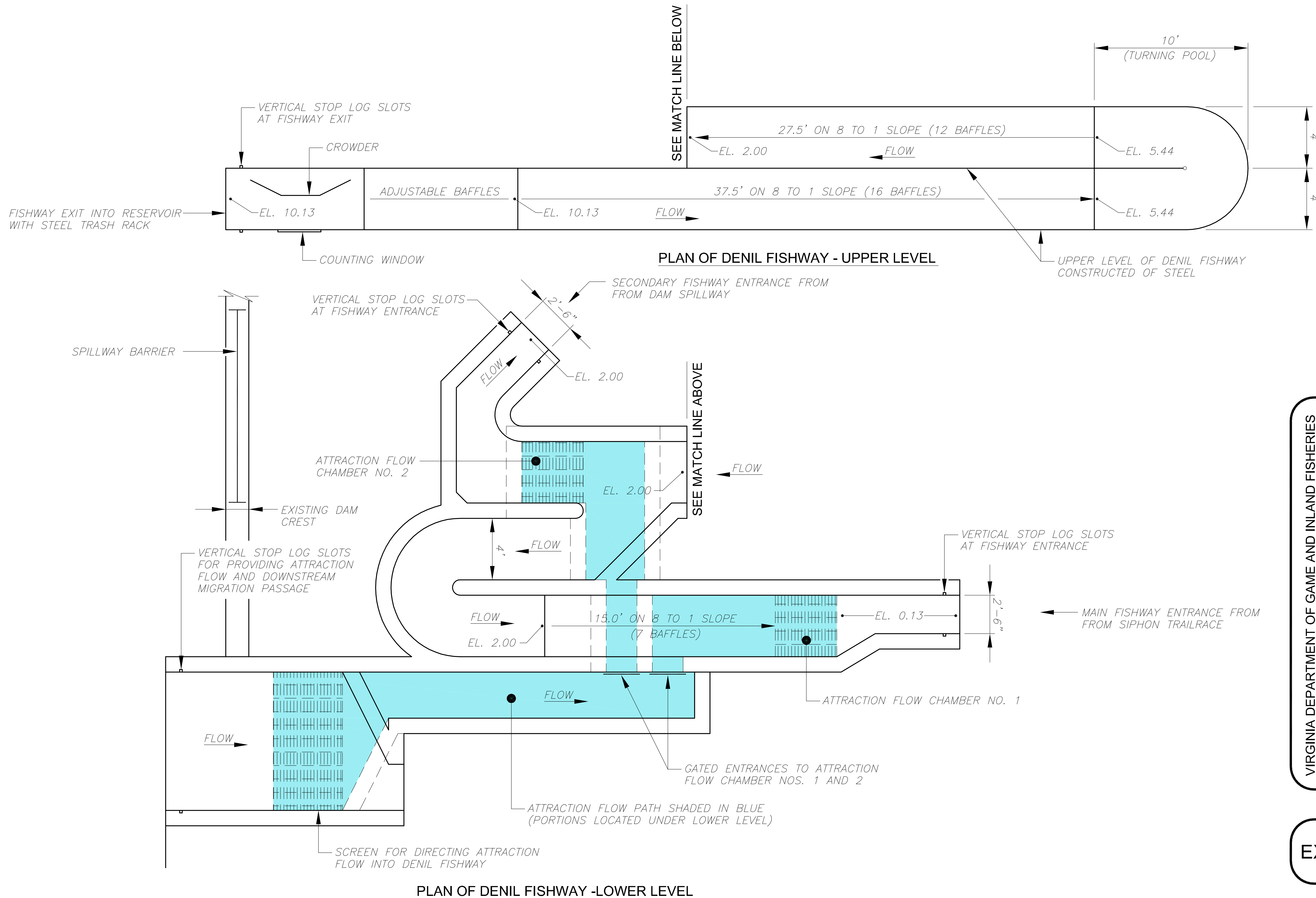
VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ALTERNATIVES ASSESSMENT

EXHIBITS

EXHIBITS

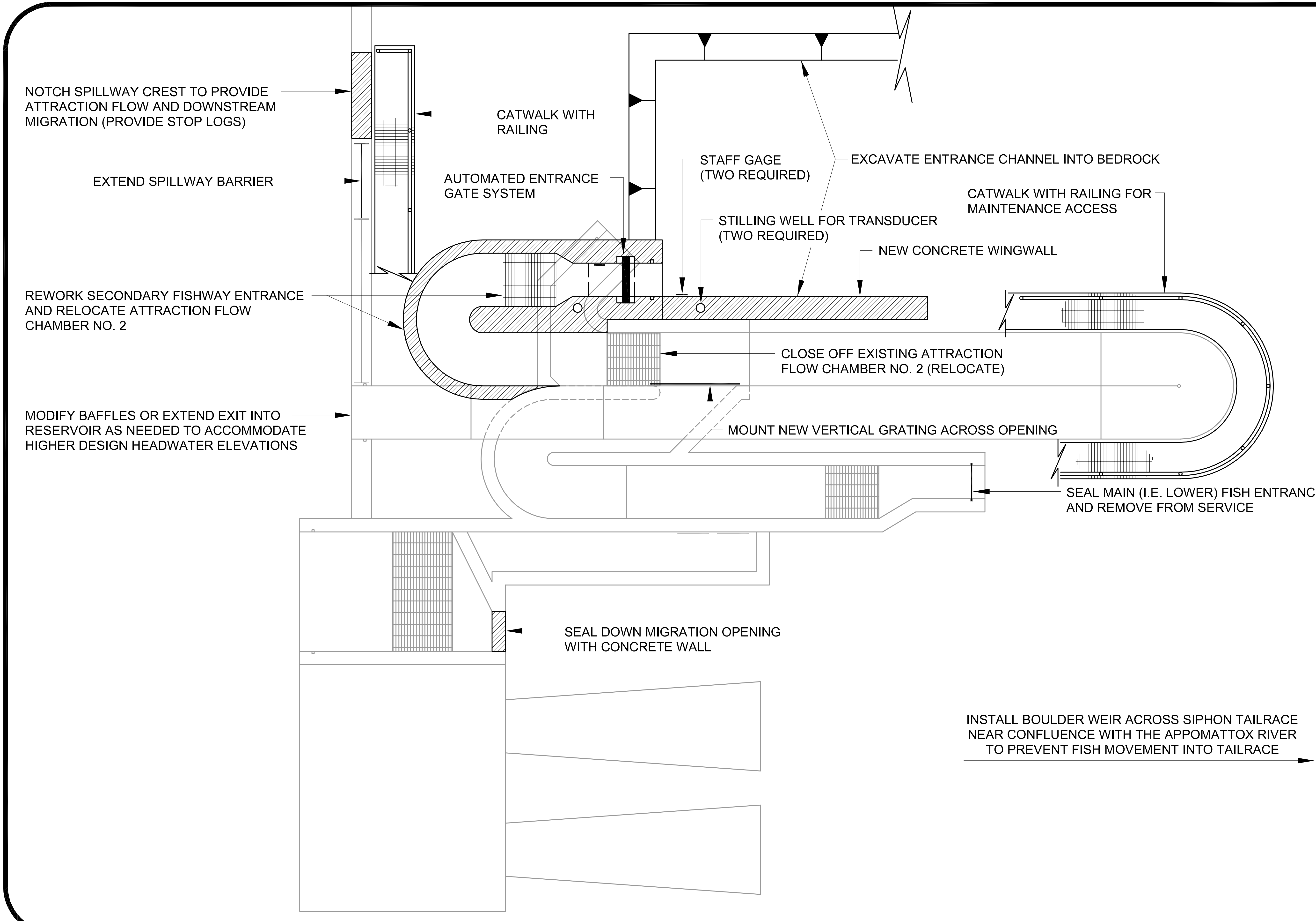
The Exhibits section includes schematic drawings showing the configuration of the existing Denil fishway, suggested improvements to the fishway and an alternate fish passage concept, with a total of five exhibits. Source: Gannett Fleming, Inc, Harrisburg PA; contact: Gannett Fleming, Inc., 717-763-7212.



VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ASSESSMENT

EXISTING DENIL FISHWAY CONFIGURATION

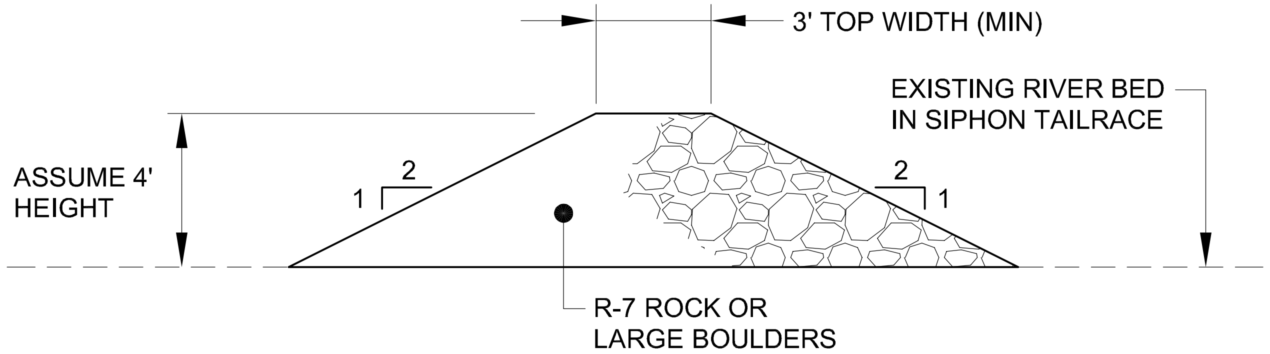
EXHIBIT 1



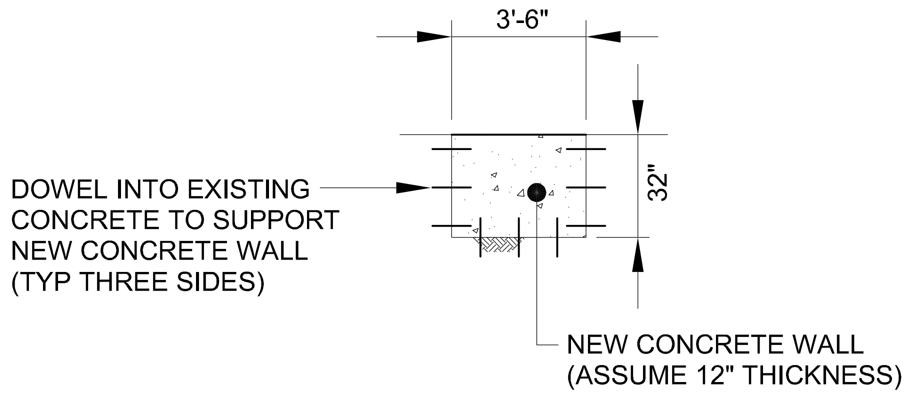
VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ASSESSMENT

SUGGESTED MODIFICATIONS TO THE DENIL FISHWAY

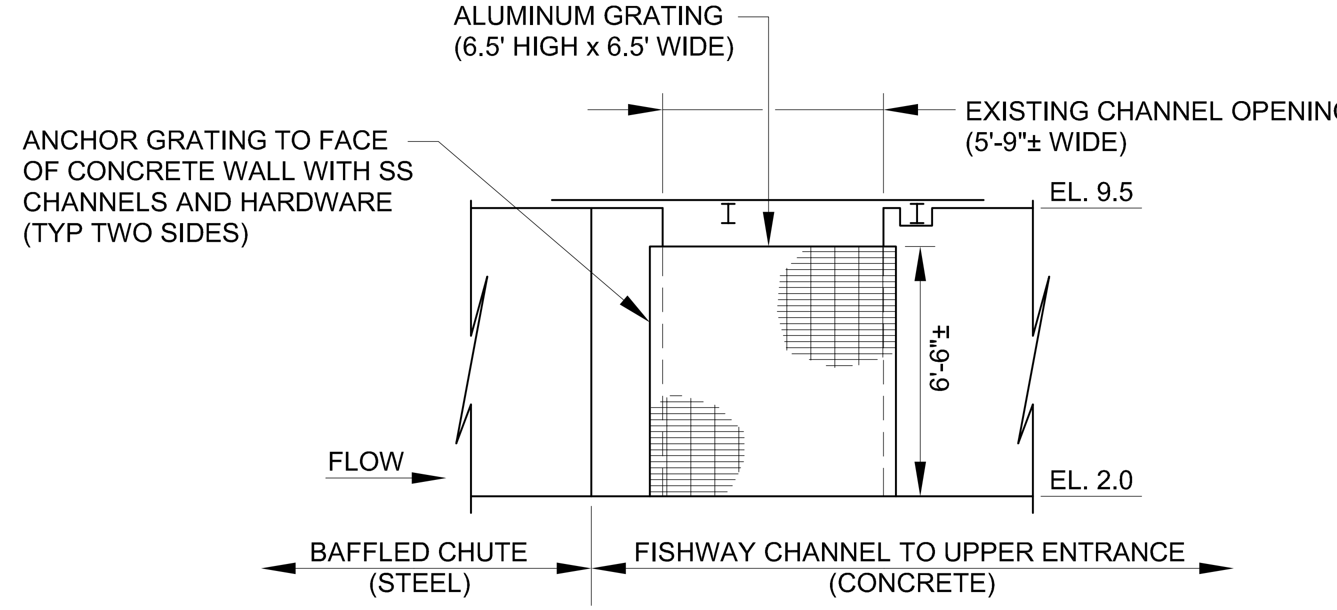
EXHIBIT 2



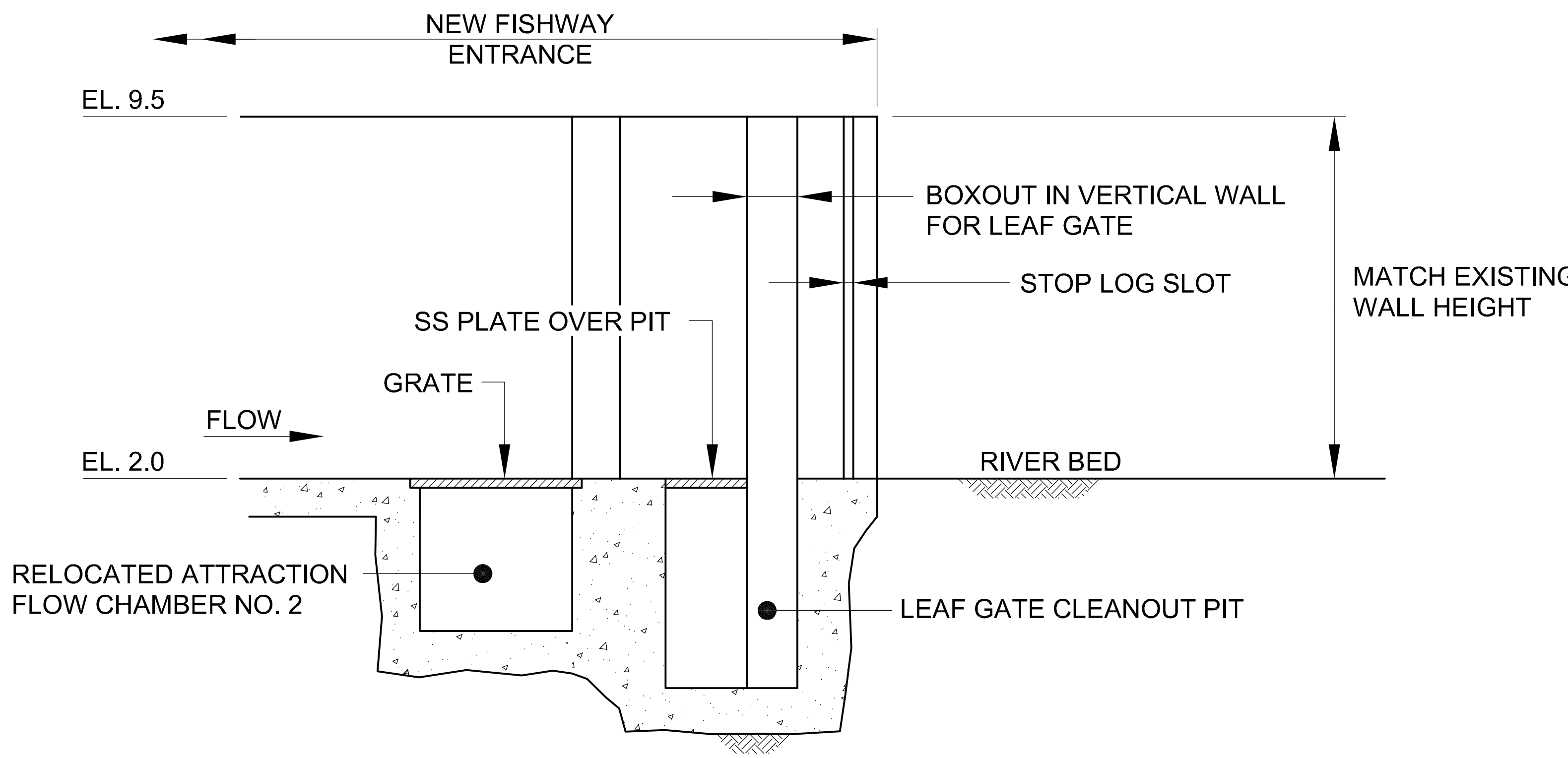
BOULDER WEIR IN SIPHON TAILRACE



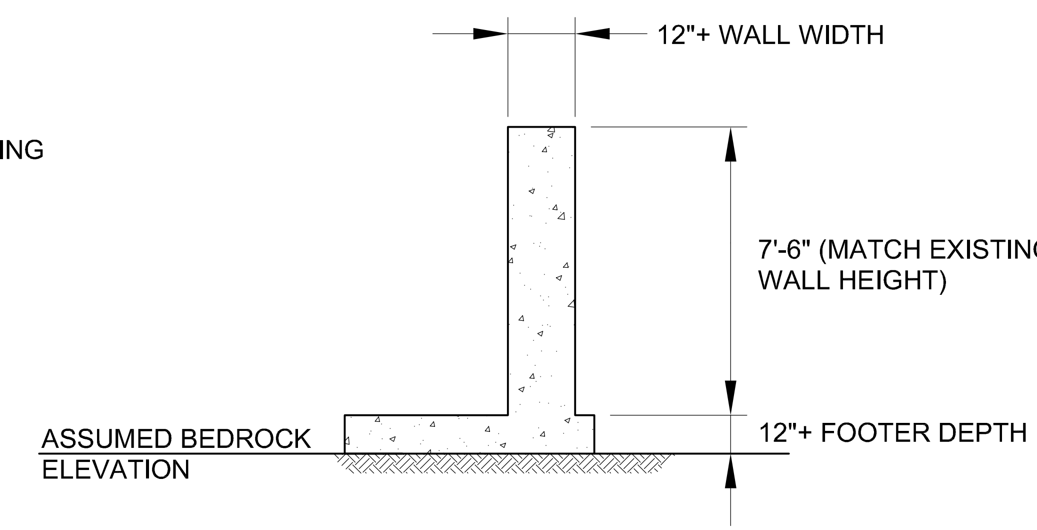
SEALING OF EXISTING DOWN MIGRATION OPENING



ELEVATION VIEW OF PROPOSED GRATING
OVER CHANNEL OPENING TO LOWER FISHWAY ENTRANCE



TYPICAL FISHWAY ENTRANCE GATE CONFIGURATION
(MAIN FISHWAY ENTRANCE SHOWN)

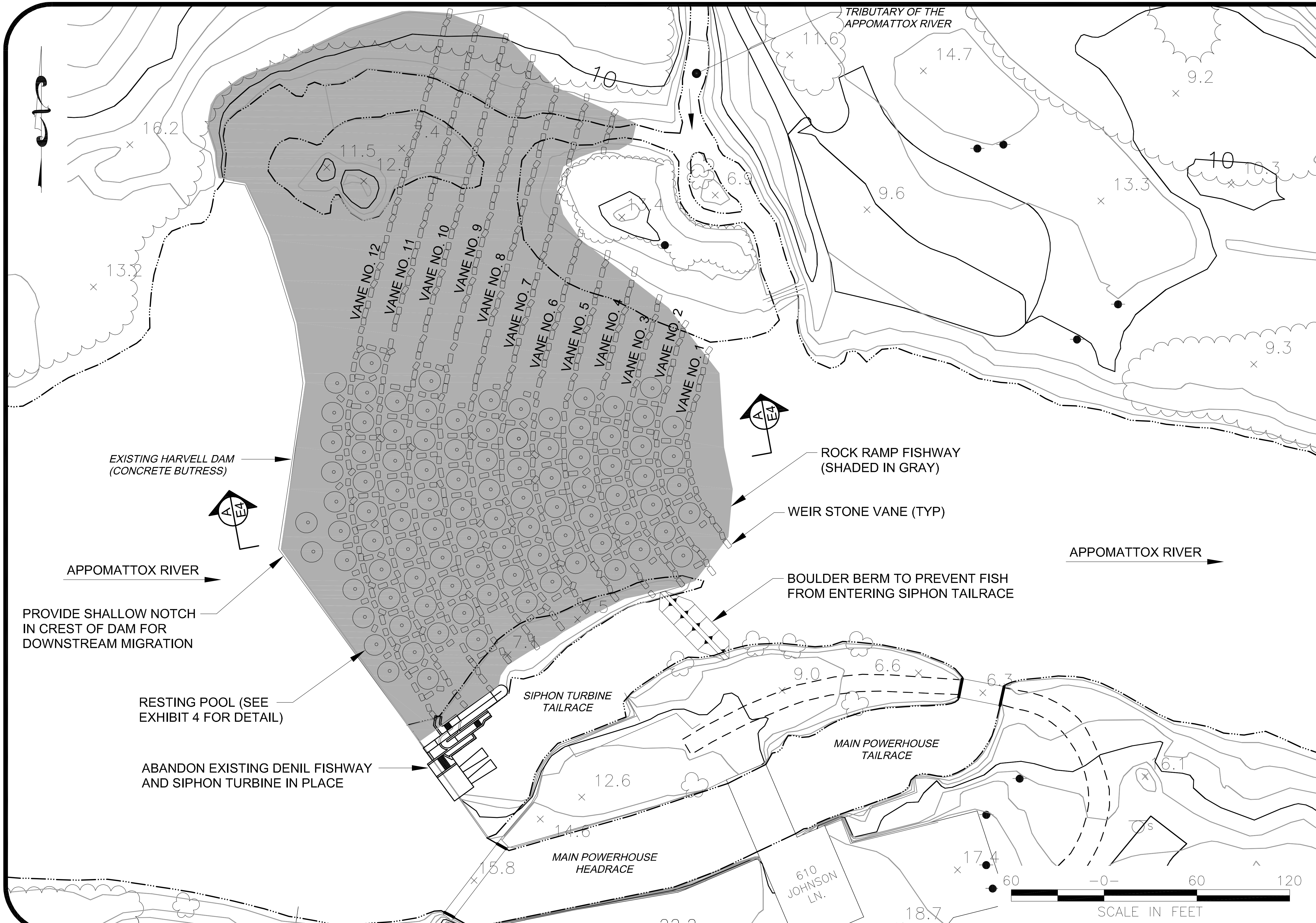


NEW CONCRETE WINGWALL AT
SECONDARY FISHWAY ENTRANCE

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ASSESSMENT

SUGGESTED MODIFICATIONS TO THE DENIL FISHWAY

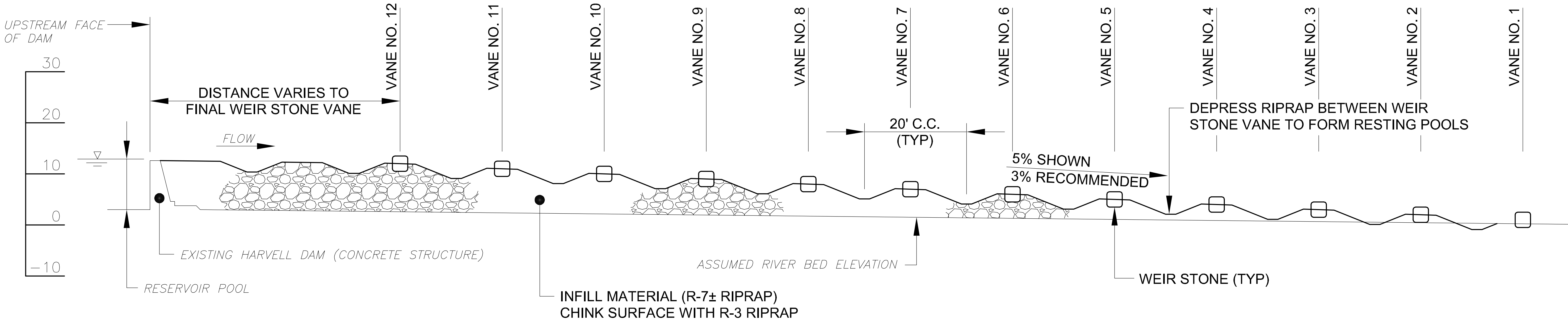
EXHIBIT 2A



VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ASSESSMENT

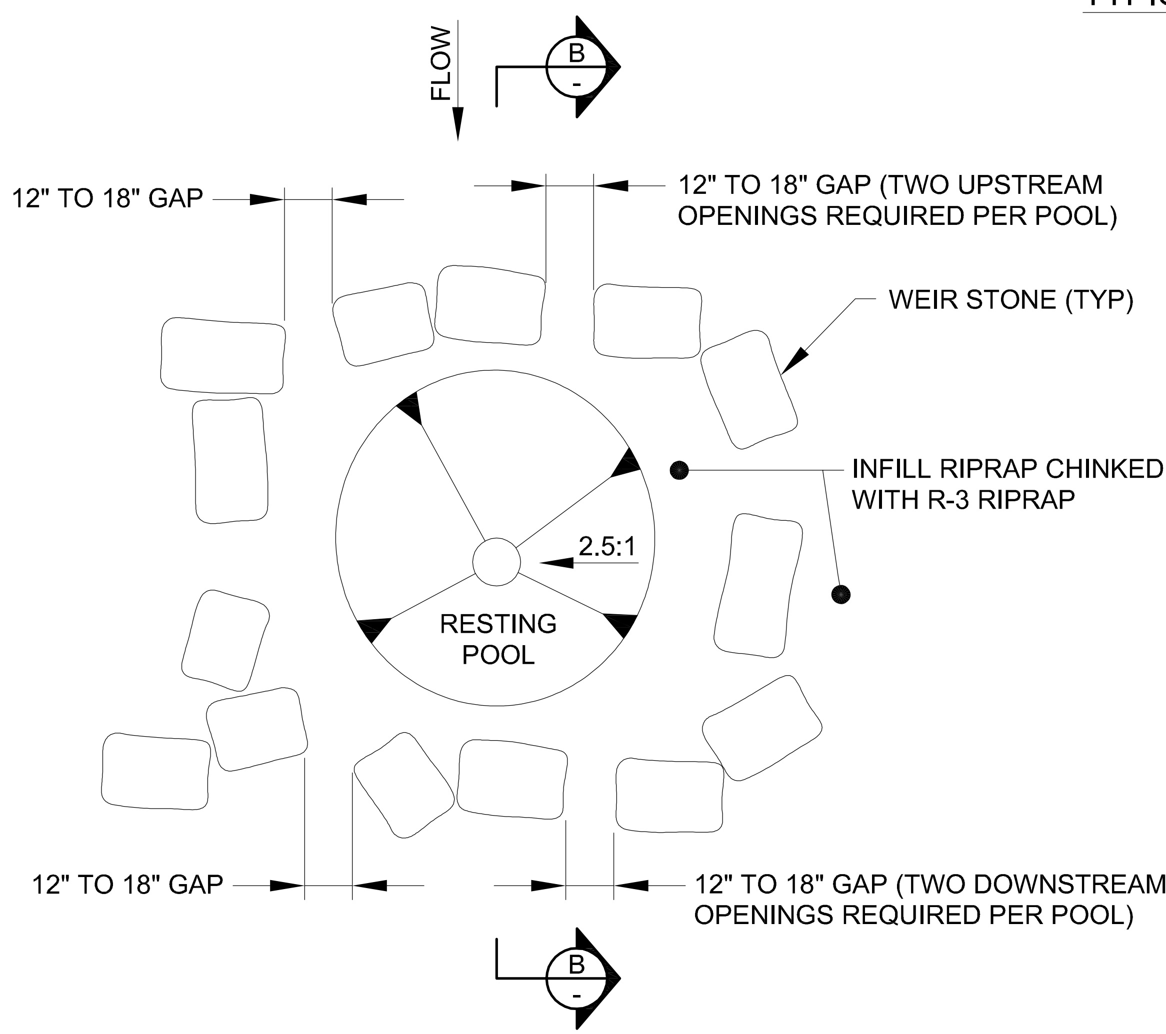
ALTERNATIVE FISH PASSAGE FACILITIES
ROCK RAMP OPTION - PLAN VIEW

EXHIBIT 3



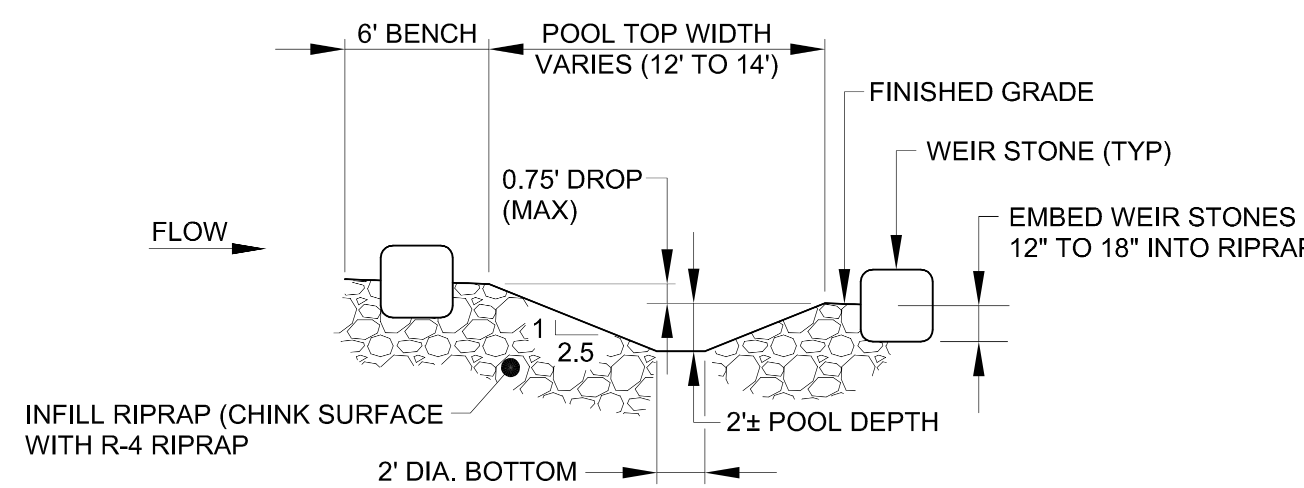
SECTION A-A

TYPICAL SECTION THROUGH ROCK RAMP FISHWAY



TYPICAL RESTING POOL PLAN VIEW

NOT TO SCALE



SECTION B-B

TYPICAL CROSS SECTION THROUGH RESTING POOL

NOT TO SCALE

NOTES:

1. A TOPOGRAPHIC/BATHYMETRIC SURVEY OF THE APPOMATTOX RIVER HAS NOT BEEN PERFORMED AS PART OF THIS STUDY. THE RIVER BOTTOM ELEVATIONS SHOWN ON THE CROSS SECTION AND DETAILS ARE BASED ON THE BEST AVAILABLE INFORMATION.

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ASSESSMENT

ALTERNATIVE FISH PASSAGE FACILITIES
ROCK RAMP OPTION - SECTIONS AND DETAILS

EXHIBIT 4

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ALTERNATIVES ASSESSMENT

APPENDIX A

LEGISLATIVE MANDATE

APPENDIX A

Appendix A provides the legislative mandate for completing the fishway alternatives assessment at the Harvell Dam. Source: Virginia General Assembly; contact: Division of Automated Legislative Systems.

House Bill 1855

CHAPTER 215

An Act directing the Department of Game and Inland Fisheries to submit a report evaluating the alternatives to a proposed breach of the Harvell Dam.

[H 1855]

Approved March 16, 2011

Be it enacted by the General Assembly of Virginia:

1. *§ 1. That prior to any breach of the Harvell Dam, located on that part of the Appomattox River located within the City of Petersburg, the Department of Game and Inland Fisheries shall prepare and submit a report to the House Committee on Agriculture, Chesapeake and Natural Resources and the Senate Committee on Agriculture, Conservation and Natural Resources on or before November 30, 2011. The report shall evaluate the alternatives to the proposed breach of the dam, and include consideration of the adaptive reuse of the existing fishways, the costs for such adaptive reuse, and the availability of federal or state funding sources for such alternatives to the breach of such dam, and such other matters as the Department deems necessary and appropriate.*

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ALTERNATIVES ASSESSMENT

APPENDIX B

PHOTOGRAPHS OF THE HARVELL DAM

APPENDIX B

Appendix B includes photographs of the Harvell Dam in its current state, including close-up photographs of the existing Denil fishway, with a total of nine images. Source: Gannett Fleming, Inc., Harrisburg, PA; contact: Gannett Fleming, Inc., 717-763-7211.

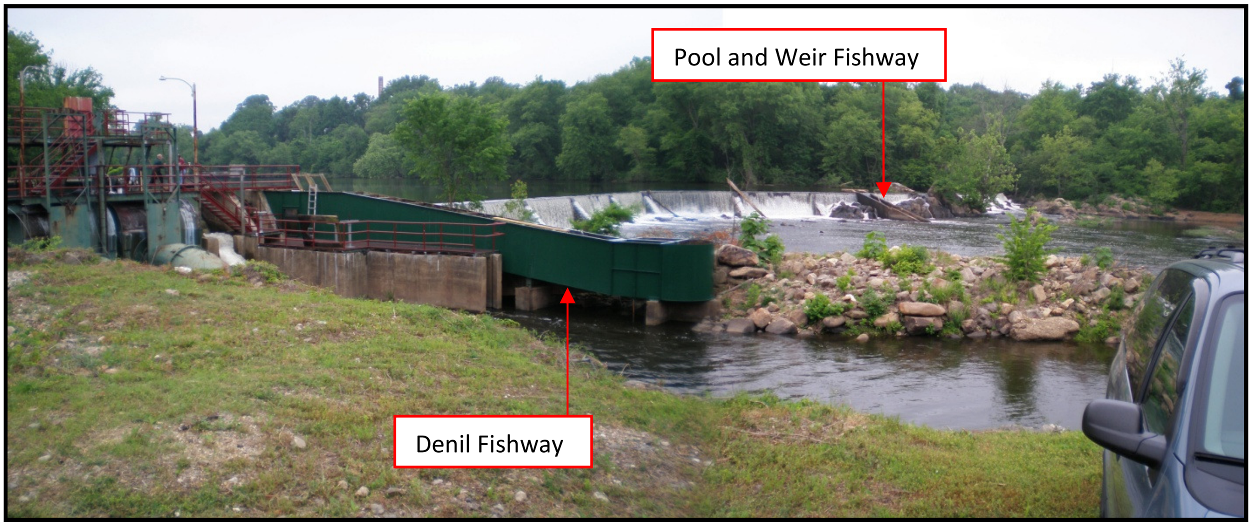


Photo 1
Standing downstream of the Harvell Dam between the Main Powerhouse headrace and the Siphon Turbine tailrace looking upstream at the Denil Fishway

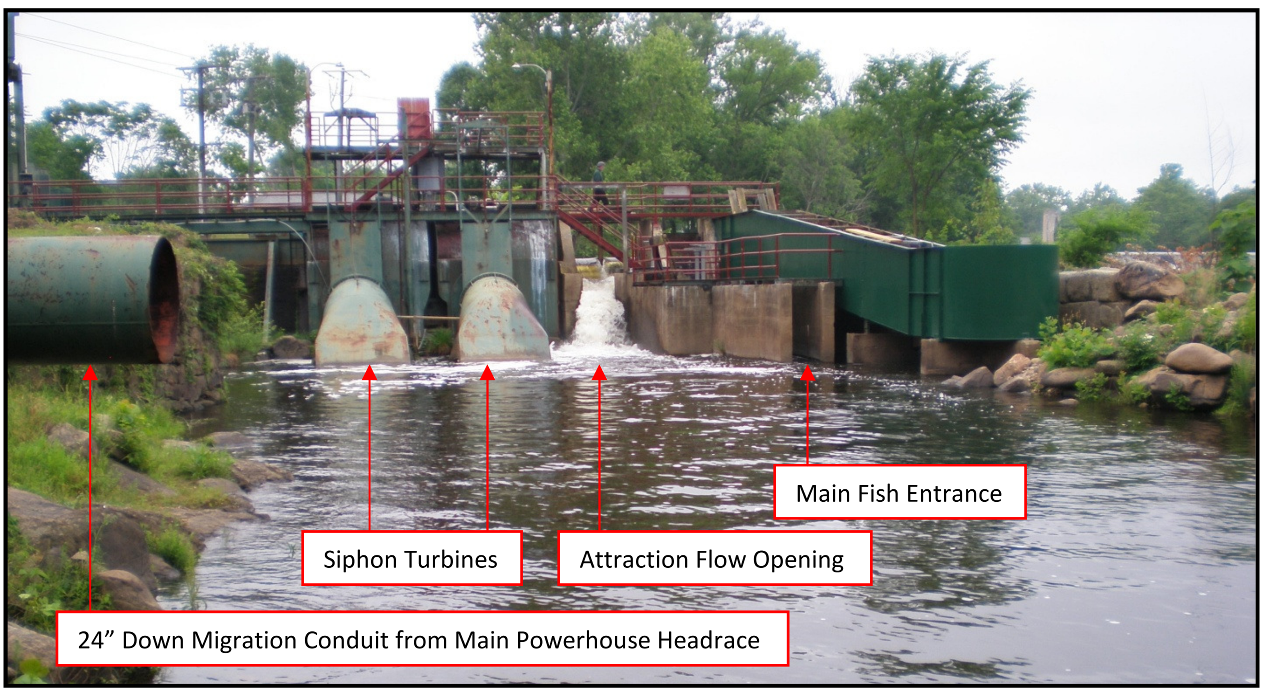


Photo 2
Standing downstream of the Harvell Dam looking upstream at the Siphon Turbine tailrace

Photo 3
Standing at upper end of the Main Powerhouse headrace looking north across river

Photo 4
Standing on top of Denil fishway looking downstream at baffled chutes

Photo 5
Standing at Secondary Fish Entrance looking downstream at baffled chute

Photo 6
View of Spillway Barrier located on crest of dam above the Secondary Fish Entrance

Photo 7
Standing near turning pool of Denil fishway looking upstream at baffled chute

Photo 8
Standing at upper end of Denil fishway looking downstream at Siphon Turbine tailrace

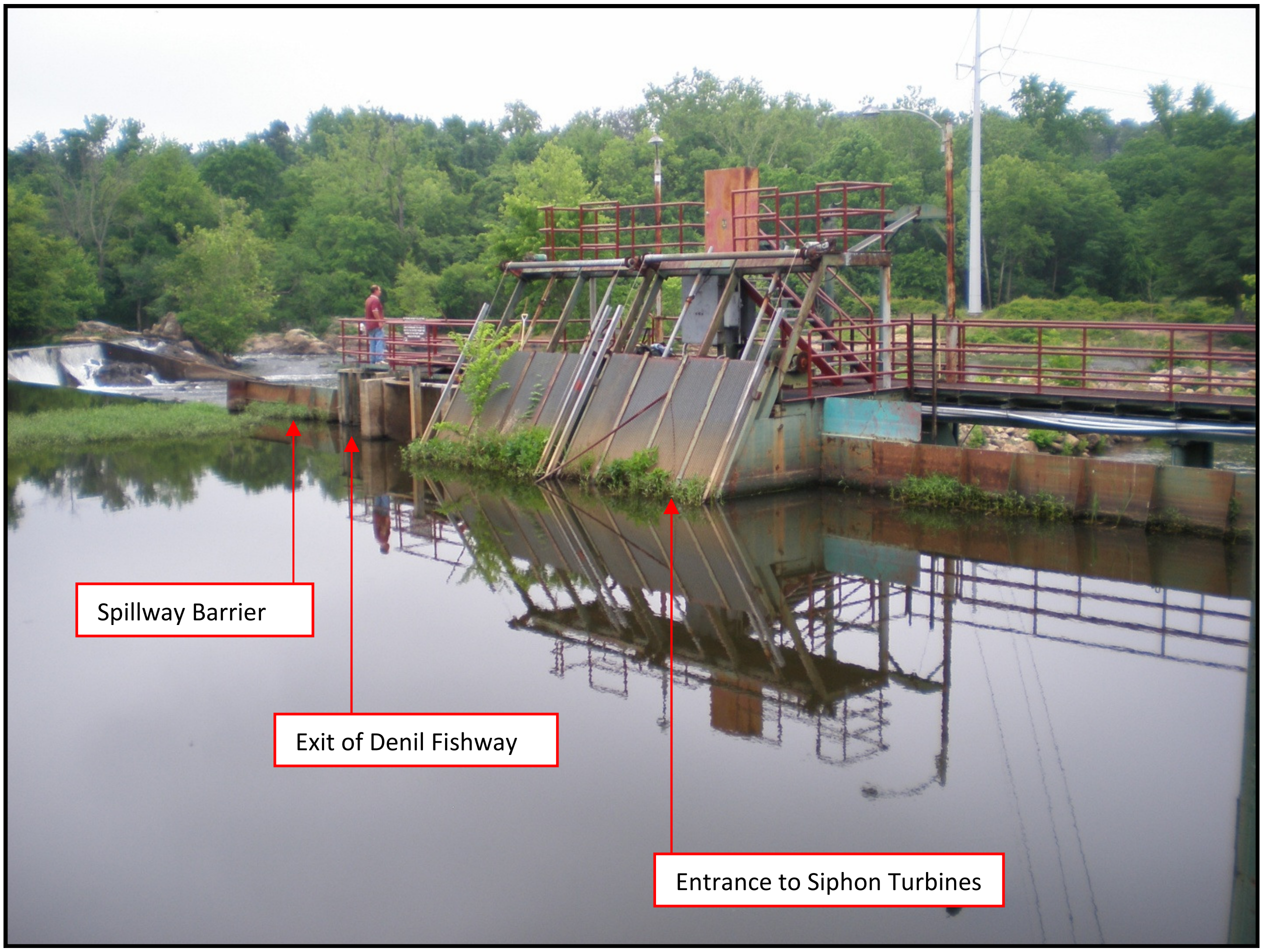


Photo 9
Standing along south river bank looking downstream at Siphon Turbine System

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ALTERNATIVES ASSESSMENT

APPENDIX C

POOL VOLUME REQUIREMENTS FOR POOL AND WEIR FISHWAY

APPENDIX C

Appendix C evaluates the design of the existing pool and weir fishway located near the center of the Harvell Dam and provides recommended pool volumes based on current accepted standards. Source: Gannett Fleming, Inc., Harrisburg, PA; contact; Gannett Fleming, Inc., 717-763-7212.

Virginia Department of Game and Inland Fisheries
Harvell Dam Fishway Alternatives Assessment

Evaluation of Existing Pool and Weir Fishway Near Center of Harvell Dam

A pool and weir fishway exists near the center of the Harvell Dam. The fishway is formed by two sloping concrete walls parallel to the river. These concrete walls are spaced approximately four apart and are four feet in height. Perpendicular concrete walls within the pool and weir fishway (spaced approximately 4.5 feet apart, three feet in height and two inches thick) divide the structure into a series of six pools. Each perpendicular wall contains a square orifice (approximately 13 inches by 13 inches) at the base of the wall. The orifice locations alternate from the bottom left to the bottom right side of each adjacent wall.

The upper-most square orifice was observed to be sealed shut at the time of the site visit on October 28, 2011. Consequently, the pool and weir fishway was not in operation.

Pool and Weir Fishway near Center of Harvell Dam

The required pool volume is driven by the target volumes of fish to be passed by the facility and can be estimated by the following equation (per presentation by Dick Quinn entitled Fish Passage Design as presented at the Northampton Inn in Northampton MA on November 2-6, 1998):

Pool Volume = (Fish/Minute) x (Minutes/Pool) x (Pool Volume/Fish) + C

Where Fish/Minute is a percentage of the target population:

Target Species	Target Volume	Peak Day (10% of Target Vol)	Peak Hour (15% of Peak Day)	Resulting Fish/Min
American shad	70,000	7,000	1,050	17
Herring	700,000	70,000	10,500	175

For American shad and Herring a typical value of 3 to 5 Minutes per Pool is acceptable
(Use 3 Min/Pool).

Pool Volume per Fish is based on the size of the fish that are anticipated to use the facility (0.5 cubic feet per pound of fish). Typical values are 2 cf/fish for American shad and 0.25 cf/fish for Herring.

"C" is an allowance for non target species and unusable space within the pools and is typically 10 to 15 percent of the calculated pool volume.

Pool Volume for American shad:	(17 fish/min) x (3 min/pool) x (2 cf/fish) = 102 cf/pool	
Pool Volume for Herring:	(175 fish/min) x (3 min/pool) x (0.25 cf/fish) = 131 cf/pool	
Volume Required (without 15% contingency):		233 cf/pool
Plus 15% for non-target species and lost space ("C"):		35 cf/pool
Total Volume Required:		268 cf/pool

The existing pools are approximately 4 feet in width, 4.5 feet in length and approximately 3 feet in depth. Consequently, the existing pool volume is estimated to be in the range of 50 to 60 cubic feet. This is well short of the target volume of 268 cubic feet per pool.

Refer to Section 8 of the report for additional discussion on the effectiveness of the existing pool and weir fishway.

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ALTERNATIVES ASSESSMENT

APPENDIX D

EVALUATION OF ATTRACTION FLOWS

APPENDIX D

Appendix D includes historic river flow information for the Appomattox River and evaluates the ability of the Denil fishway attraction flow system to provide effective attraction flow volumes under both the current condition and with the proposed modifications in place. Source: Gannett Fleming, Inc., Harrisburg, PA; contact; Gannett Fleming, Inc., 717-763-7212.

Virginia Department of Game and Inland Fisheries
Harvell Dam Fishway Alternatives Assessment

Evaluation of Attraction Flows

The Harvell Dam Denil fishway contains an attraction flow system that is capable of providing supplemental flow to one or both of the two fishway entrances (i.e., the main entrance and the secondary entrance). The attraction flow system consists of two four-foot-wide stop log bays (refer to Figure 4) that allow water from the reservoir to pass over a wedgewire screen. Water passing through the wedgewire screen drops into a three-foot-wide concrete channel. From this channel, gates are used to distribute the flow into two tunnels, each of which are two-foot square. It is reported that the interior of each tunnel was formed with steel duct work that was left in place following concrete placement. Each tunnel discharges into an attraction flow chamber where the flow rises through a grate on the floor of the fishway. Each attraction flow chamber is reported to have a baffle system which is intended to create a uniform flow distribution pattern through the floor of the fishway. Refer to Exhibit 1 for the attraction flow path (shaded in blue). This study was unable to verify the constructed condition of the attraction flow tunnels and chambers as these facilities were submerged at the time of each field visit.

Under the proposed conditions, the main (i.e., lower) fishway entrance is to be closed. Attraction Flow Chamber No. 2 will continue to be used; however, flow from this chamber will back up through the fishway and supplement the attraction flow to the Secondary (i.e., upper) fishway entrance. Under this condition the attraction flow to the secondary entrance can be approximately doubled, increasing the efficiency of this entrance over a wider range of river flows.

Attraction flow rates which are three (3) percent of the river flow rate are recommended to effectively attract fish into the fishway. This attraction flow is a combination of the flow in the baffled chute plus the flow from the attraction flow system. Table D-1 summarizes the approximate attraction flow rates which the Denil fishway is expected to be able to provide under the current condition and with the proposed improvements in place.

Table D-1
Approximate Attraction Flow Rates to the Secondary Fishway Entrance

River Flow Condition	Existing Conditions (cfs)			Proposed Conditions (cfs)		
	Chute Flow[1]	Attraction Flow[3]	Total Flow	Chute Flow[2]	Attraction Flow[4]	Total Flow
Low Flow (400 cfs)	7	36	**43cfs (10.8%)**	15	70	**85 cfs (21.2%)**
Average Flow (2,300 cfs)	12	26	**38 cfs (1.6%)**	25	50	**75 cfs (3.3%)**
High Flow (7,500 cfs)	17	6	**23 cfs (<0.5%)**	35	10	**45 cfs (<1.0%)**

Table Notes:

1. Chute flow under existing conditions is assumed to be one-half of the total chute flow as the chute flow is intended to split between the two fishway entrances.
2. All chute flow under the proposed conditions is allowed to pass through the secondary fishway entrance with the closure of the main (lower) fishway entrance.

3. Attraction flow under the existing conditions is only that flow which can be supplied by Attraction Flow Chamber No. 2.
4. Attraction flow under the proposed conditions is the sum of the flow which can be supplied by both Attraction Flow Chamber Nos. 1 and 2.

Table D-1 shows that the attraction flow to the secondary entrance under existing conditions is adequate for low flow conditions but falls below the target 3% rate under average and high river flow conditions. With the proposed modifications in place, the secondary entrance will be able to provide adequate attraction flow under low and average flow conditions but will fall short of the target 3% rate under high river flow conditions. Figure D-1 provides a graphical representation of the relationship between the attraction flow which can be provided by the fishway (under existing and proposed conditions) and the target attraction flow rate. The target 3% attraction flow rate at the secondary entrance is obtainable for river flows up to 1,400 cfs under existing conditions and for river flows up to 2,600 cfs under the proposed conditions.

To determine how often these flow rates (i.e., 1,400 cfs and 2,600 cfs) will be exceeded, historic river flows of the Appomattox River were evaluated. Forty-two years of daily flow data (October 1969 through November 2011) was obtained from the U.S. Geological Survey database for a river gage at Matoaca (USGS Gage 02041650) on the Appomattox River located approximately 3.7 miles upstream of the Harvell Dam. Figure D-2 summarizes the historical data and presents the results in the form of river flow versus the percent of time that a given flow is exceeded.

The secondary fishway entrance is capable of providing attraction flow equal to or exceeding three percent of the river flow for river flows up to 1,400 cfs as currently configured. It is estimated that this flow will be exceeded approximately 40 percent of the time during the spring migration season (March 1^{st} through June 30^{th}).

With the proposed modification in place, it is expected that the secondary fishway entrance will be capable of providing attraction flow equal to or exceeding three percent of the river flow for river flows up to 2,600 cfs. It is estimated that this flow will be exceeded approximately 22 percent of the time during the spring migration season (March 1^{st} through June 30^{th}). As river flows exceed 2,600 cfs, the fishway will still be capable of passing fish; however, the efficiency of the fishway will diminish as a result of the reduced attraction flow.

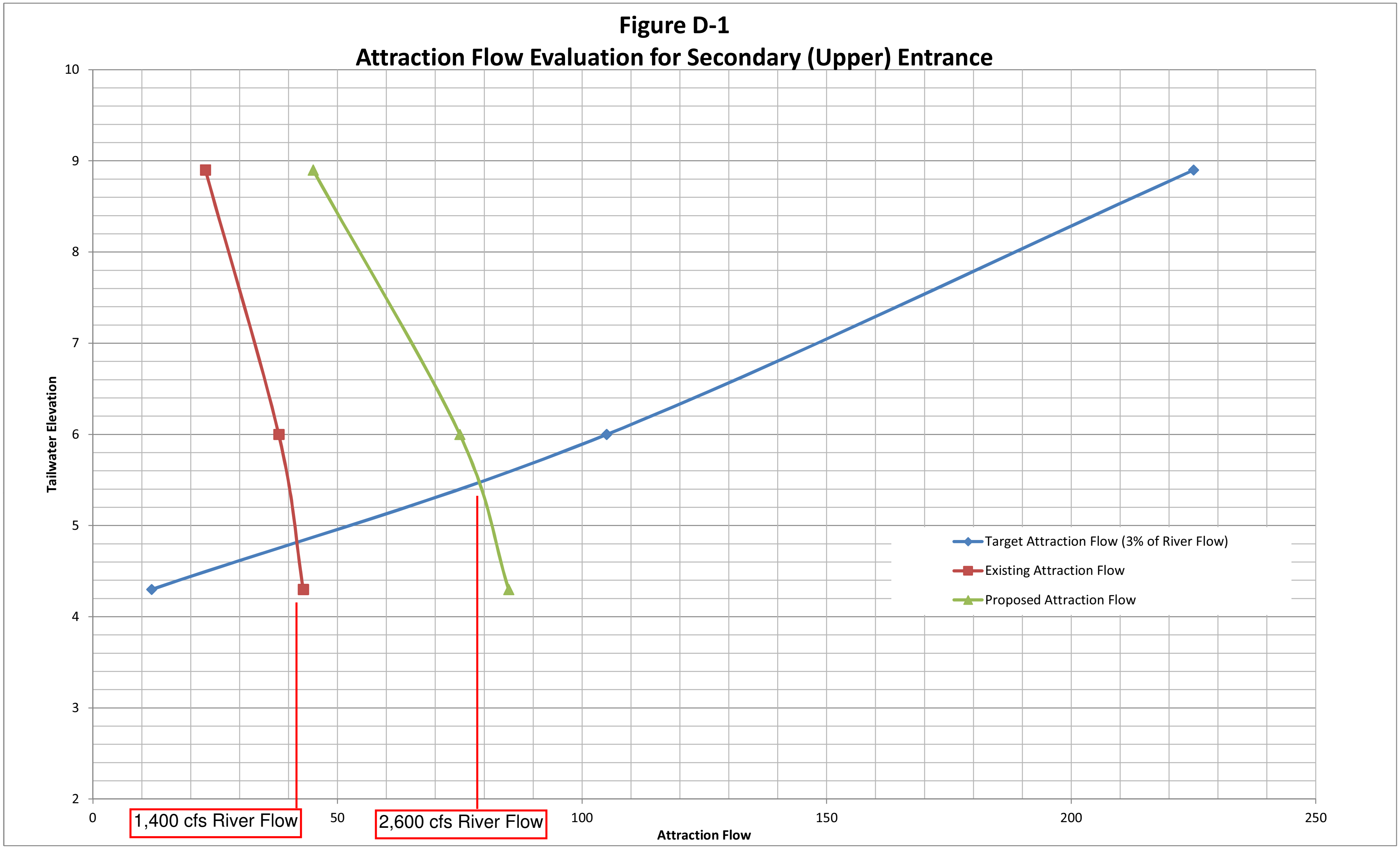


Figure D-1
Attraction Flow Evaluation for Secondary (Upper) Entrance
Tailwater Elevation
10
9
8
7
6
5
4
3
2
0
50
100
150
200
250
Attraction Flow
Target Attraction Flow (3% of River Flow)
Existing Attraction Flow
Proposed Attraction Flow
1,400 cfs River Flow
2,600 cfs River Flow

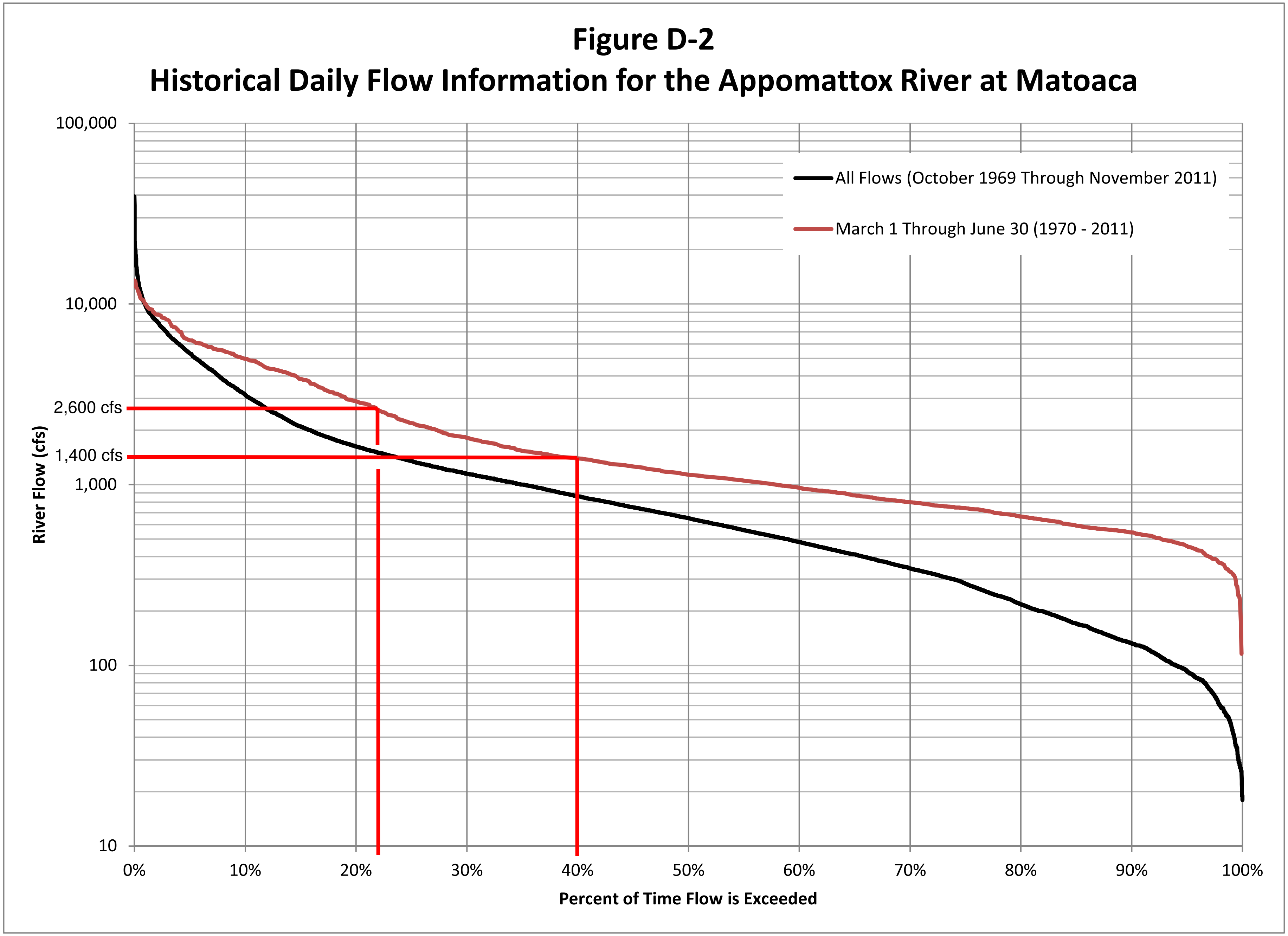


Figure D-2
Historical Daily Flow Information for the Appomattox River at Matoaca
100,000
10,000
2,600 cfs
1,400 cfs
1,000
100
10
River Flow (cfs)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Percent of Time Flow is Exceeded
All Flows (October 1969 Through November 2011)
March 1 Through June 30 (1970 - 2011)

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
HARVELL DAM FISHWAY ALTERNATIVES ASSESSMENT

APPENDIX E

ESTIMATED CONSTRUCTION COST FOR DENIL FISHWAY MODIFICATIONS

APPENDIX E

Appendix E provides a preliminary construction cost estimate for the recommended improvements to the Harvell Dam Denil fishway. Source: Gannett Fleming, Inc., Harrisburg, PA; contact: Gannett Fleming, Inc., 717-763-7212.

Harvell Dam Fishway Assessment
Modifications to Existing Denil Fishway
Conceptual Design Cost Estimate

Item No.	Work or Material	Estimated Quantity	Unit	Unit Price	Amount
1.	**Mobilization and Demobilization (~6%)**	1	LS	XXX	$17,000
2.	**Bonds and Insurances (~2%)**	1	LS	XXX	$6,000
3.	**Diversion and Care of Water**				
	a. Cofferdams (Flow Diversion at Secondary Fish Entrance)	1	LS	XXX	$20,000
	b. Temporary Site Access to Fishway	1	LS	XXX	$10,000
4.	**Erosion and Sediment Control**	1	LS	XXX	$10,000
	a. Clear Vegetation from Island as Needed to Allow Construction	0.2	AC	$2,000	$400
5.	**Boulder Weir in Siphon Tailrace**				
	a. R-7 Riprap	50	CY	$80	$4,000
6.	**Vertical Grating System to Close Opening to Lower Fish Entrance**				
	a. Grating (Assume a 6.5' Wide x 6.5' High Grate)	42	SF	$50	$2,100
	b. Anchoring System to Attach Grate to Concrete Walls	1	LS	$500	$500
7.	**Seal Down Migration Opening**				
	a. Concrete Wall	0.35	CY	$800	$280
	b. Anchoring System (i.e., Dowel Bars)	1	LS	$500	$500
8.	**Reconstruct Main Fishway Entrance With Automated Gate**				
	a. Select Demolition of Existing Concrete Walls	21	LF	$300	$6,300
	b. Rock Excavation - Mechanical	20	CY	$250	$5,000
	c. Foundation Preparation	21	SY	$20	$420
	d. Cast-In-Place Concrete (Complete with Rebar)	30	CY	$800	$24,000
	e. Close Existing Attraction Flow Opening With Steel Plate	1	EA	$500	$500
	f. Leaf Gate and Operator	1	EA	$50,000	$50,000
	g. Electrical Service and Control for Leaf Gate	1	EA	$50,000	$50,000
	h. Staff Gage	2	EA	$500	$1,000
9.	**New Concrete Wingwall at Secondary Fishway Entrance**				
	a. Foundation Preparation	15	SY	$20	$300
	b. Cast-In-Place Concrete (Complete with Rebar)	15	CY	$800	$12,000
10.	**Extend Steel Spillway Barrier**				
	a. Steel Plate Extension (Assume 10 Feet)	10	LF	$50	$500
	b. Addition of One Support Brace on Downstream Side of Dam	1	LS	$2,000	$2,000
11.	**Rock Excavation In Front of Secondary Spillway**				
	a. Rock Excavation (Assumed Area of 20' x 30' x 1.5' Deep)	30	CY	$250	$7,500
12.	**Relocation of Downstream Migration Chute**				
	a. Saw Cut & Removal of Existing Spillway	1	LS	$2,000	$2,000
	b. Stop Log Slots	1	LS	$1,000	$1,000
13.	**Additional Catwalk Area for Maintenance Access**				
	a. Catwalk Decking	350	SF	$50	$17,500
	b. Handrail	115	LF	$60	$6,900
	c. Support System	1	LS	$30,000	$30,000
14.	**Adjustments to Fishway Exit**	1	LS	$10,000	$10,000
15.	**Replace/Repair Crowder**	1	LS	$2,000	$2,000
				Subtotal:	**$299,700**
16.	**Contingency (50%)**				$149,850
				Total Estimated Construction Cost:	**$450,000**

Say $350,000 to $500,000

VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES
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APPENDIX F

ESTIMATED CONSTRUCTION COST FOR ROCK RAMP OPTION

APPENDIX F

Appendix F provides a preliminary construction cost estimate for an alternative fishway (i.e., rock ramp) at the Harvell Dam. Source: Gannett Fleming, Inc., Harrisburg, PA; contact: Gannett Fleming, Inc., 717-763-7212.

Harvell Dam Fishway Assessment
Alternate Rock Ramp Fishway Option
Conceptual Design Cost Estimate

Item No.	Work or Material	Estimated Quantity	Unit	Unit Price	Amount
1.	**Mobilization and Demobilization (~6%)**	Job	LS	XXX	$128,000
2.	**Bonds and Insurances (~2%)**	Job	LS	XXX	$43,000
3.	**Diversion and Care of Water**				
	a. Cofferdams (Flow Diversion at Dam Crest)	Job	LS	XXX	$50,000
	b. Activate Main Powerhouse for Primary Flow Diversion	Job	LS	XXX	$5,000
4.	**Erosion and Sediment Control**				
	a. Rock Construction Entrance	2	EA	$2,000.00	$4,000
	b. Compost Filter Sock (or Silt Fence)	700	LF	$10.00	$7,000
	c. Stabilized Staging Areas with Aggregate	1,700	SY	$10.00	$17,000
5.	**Site Preparation and Access**				
	a. Clearing, Tree Removal and Grubbing (Island Areas)	0.400	AC	$12,500.00	$5,000
	b. Replace (or Provide Temporary) Bridge Structures for Site Access	2	EA	$50,000.00	$100,000
6.	**Demolition Activities**				
	a. Cut Notch in Dam Crest	1	LS	$2,500.00	$2,500
7.	**Rock Ramp**				
	a. R-7 Riprap	15,000	CY	$80.00	$1,200,000
	b. R-3 Riprap Chinking Material	4,000	CY	$80.00	$320,000
	c. Weir Stones (Boulders)	800	EA	$500.00	$400,000
8.	Site Restoration	1	LS	$20,000.00	$20,000
				Subtotal:	**$2,301,500**
9.	Services of River Morphologist for Direction of Boulder Placement	Job	LS	XXX	$25,000
10.	On-Site Construction Observation/Office Support	Job	LS	XXX	$125,000
				Subtotal:	**$2,451,500**
11.	Contingency (50%)				$1,225,750
				Total Construction Cost:	**$3,680,000**
					Say $2.0 to $3.5 Million