Wiswall Dam – Hydrologic &Hydraulic Aspects of Dam Removal and Fish Passage

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Background:

Wiswall Dam, located on the Lamprey River in Durham, New Hampshire, is an 11-foot-high, 200-foot-long, run-of-river concrete gravity dam. The dam is currently owned by the Town of Durham and used for supplemental water storage and supply. Historically the 212 square-mile Lamprey River watershed supported large populations of anadromous fish including river herring, lamprey, American shad, American eel, and Atlantic salmon (McKeon and Grout, 2000). However, the construction of dams on the river for industrial and other purposes has effectively blocked their migration for numerous decades. In the early 1970's a Denil fish ladder was constructed at Macallen Dam, located approximately 3.5 miles downstream of Wiswall Dam, at tidewater in Newmarket, New Hampshire. Each year, about 20,000-60,000 alewives, blueback herring and other anadromous fish species use this ladder for passage to access portion of the Lamprey River's habitat. However, Wiswall Dam, the next dam upstream, prevents the fish from accessing an additional forty-three miles of river habitat on the river and its tributaries.

In recognition of this problem, the New Hampshire Fish and Game Department (NHF&GD), along with the United States Fish and Wildlife Service (USFWS), sought programs and funds to implement construction of a Denil fish ladder at Wiswall Dam. In a March 2000 letter to the U.S. Army Corps of Engineers (COE), NHF&GD requested that the COE investigate construction of a fish ladder at Wiswall Dam under the COE Section 206 (Water Resources Development Act of 1996, PL 104-303) Aquatic Ecosystem Restoration program. The Section 206 program pays 65% of the total cost of ecosystem restoration projects that the Federal government deems are in "the national interest" (subject to availability of resources). In July 2001, NHF&GD (now the study sponsor) requested that the study be expanded to include study of the feasibility of removal of the dam. The COE New England District prepared a Preliminary Restoration Plan in July 2001 for a study to include removal of the dam, or construction of a Denil fish ladder at an estimated total cost (including study, real estate, and construction costs) of approximately $700,000-800,000, depending which alternative is selected. After receiving funding from Headquarters, the COE began working with a local steering committee, formed specifically to provide direction concerning the proposed actions at Wiswall Dam. We are now in the feasibility study phase of this one-step Planning, Design, and Analysis (PDA) phase, with Plans and Specifications to be prepared once an alternative is selected and approved. While this paper focuses on the hydrologic and hydraulic aspects of dam removal and fish passage, the pros and cons of each of the alternatives are also discussed.

Setting:

Wiswall Dam is located on the Lamprey River in the town of Durham in Strafford County, New Hampshire. The Lamprey River begins in the Saddleback Mountains in Northwood, New Hampshire, and traverses approximately 45 miles through six towns before becoming tidal in Newmarket (below Macallen Dam) and emptying into the inland coastal estuary known as the Great Bay National Estuarine Reserve. The entire drainage area of the Lamprey River (see Figure 1, Lamprey River Drainage Basin) is approximately 212 square miles.

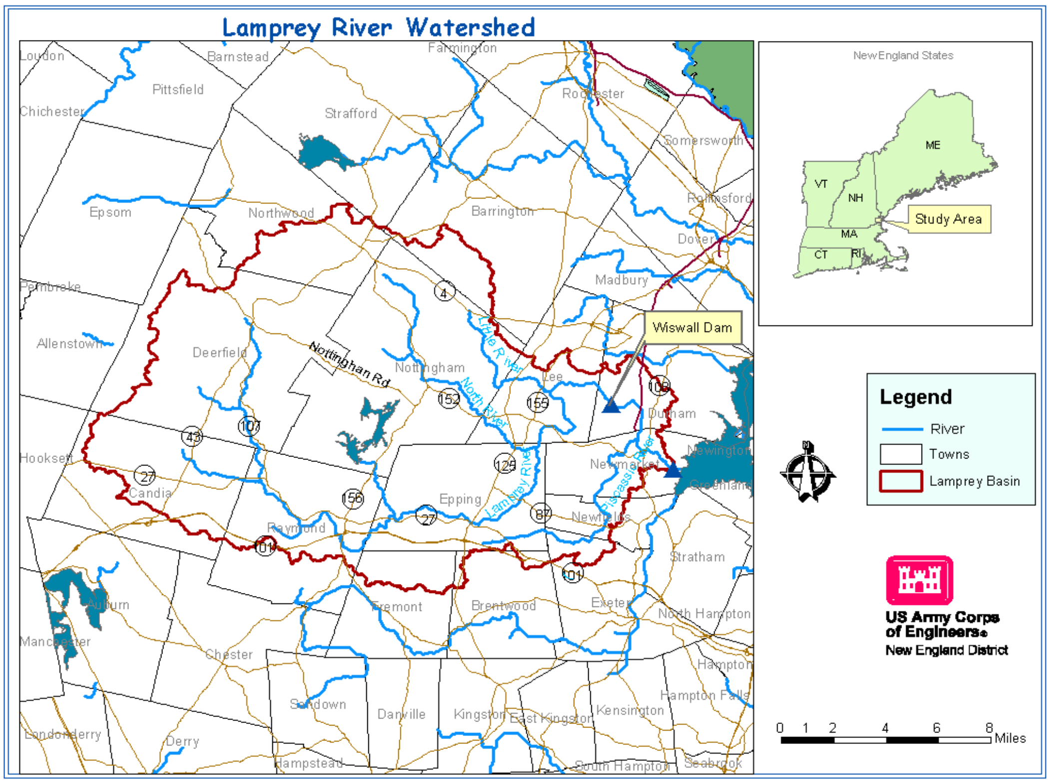

Figure 1 – Lamprey River Drainage Basin

The Lamprey River drops 600 feet in elevation as it makes its way from Northwood to Great Bay. The headwaters reach is largely undeveloped and forested as is a large percentage of the land in the river's corridor. A 23.5-mile reach of the river, including the Wiswall Dam segment, was designated as a Wild and Scenic River in November 1996 in recognition of the river's valued wildlife resources and its importance as a tributary to the Great Bay National Estuarine Reserve. In addition to its rich ecological resources, the river is abutted by archaeological sites of prehistoric and nineteenth century culture representative of early seacoast region settlement.

Wiswall Dam is located approximately 5 miles upstream of the mouth of the Lamprey River, and 3.5 miles upstream of the first dam, Macallen Dam, located at tidewater in Newmarket. Drainage area at Wiswall Dam is 182 square miles. The 200-foot long, eleven-foot high, Wiswall Dam (see Figure 2, Photograph of Wiswall Dam) has been owned by the Town of Durham since 1965. The dam, constructed in 1911, is a concrete gravity dam with a 160-foot-long spillway, low level outlet works, and a millrace. The dam was built to power manufacturing activities at the Wiswall Mills, but the impoundment is now used by the Town of Durham for supplemental water storage and supply. The dam is classified as a significant hazard dam. About 5000 feet of the impoundment is located in the town of Durham, with the remaining 3000 feet located in the town of Lee. Average annual flow at the dam is 283 cubic feet per second (cfs), with average monthly flows ranging from a low of 71 cfs in August and September to a high of 693 cfs in April. Although the entrance to the existing millrace has been filled in and is not in current use, the owner is currently considering re-opening the millrace to increase the flood-passing capacity of the dam in response to pressure from the State of New Hampshire's dam safety personnel, concerned by the inadequacy of the dam to safely pass major floods.

Figure 2 – Photograph of Wiswall Dam

Problem Statement:

Anadromous fish defines the broad class of migratory fish that hatch in fresh water, make their way to the sea to grow, then return as adults to fresh water to spawn, usually near where they hatch. The fish migrate upriver in the spring when water temperatures and flows are suitable, in the April to mid-June time period. By definition (U.S. Army Corps of Engineers, 2000), anadromous fish are a federally significant resource. Anadromous fish along the New Hampshire coastline include Atlantic salmon, American shad, river herring (a collective term that refers to alewives and blueback herring), sea lamprey, sturgeon, and striped bass. Each year, about 20,000-60,000 river herring and other fish species swim through a Denil fish ladder at Macallen Dam, the first dam on the Lamprey River. Their continued upstream migration is, however, blocked by Wiswall Dam, located 3.5 river miles upstream of Macallen Dam. Wiswall Dam prevents anadromous fish from accessing an additional 45 miles of habitat upstream of the dam.

Goals of Feasibility Study:

The primary goal of the Feasibility phase of the PDA is to determine the feasibility and costs of various solutions and recommend a single alternative that will enable anadromous fish passage by Wiswall Dam, with the target fish species being river herring and American shad. A secondary goal, added during the course of the study by the sponsor and COE, is to maximize achievement of the primary goal using "natural" means. Use of natural means may have the additional benefits of "de-fragmenting" the river habitat, maximizing the full range of aquatic habitat outputs, creating or restoring habitat on a year-round basis, and providing pleasing aesthetics.

Potential Alternatives:

Three alternatives were identified during this study. These include:

1. Removal of Wiswall Dam;
2. Construction of a Denil Fish Ladder;
3. Construction of a nature-like bypass channel.

Discussion of Alternatives at Wiswall Dam:

Removal of Dam: Benefits of removing Wiswall Dam include the allowance of the downstream and upstream passage of all fish, including resident fish and other aquatic species, and restoration of a year-round non-fragmented natural condition to this river segment. Water temperatures may be reduced slightly and water quality benefited by the lesser hydraulic residence time. Dam safety and maintenance would cease to be of concern. The chief drawback associated with the removal of the dam would be the loss of Durham's supplemental water storage. Other drawbacks would include the loss of fringing wetlands supported by the impoundment, and increased scouring protection likely needed at the abutments of Wiswall Road, located 200 feet upstream of the dam. Some changes may be viewed as either positive or negative depending upon personal viewpoints including the change in habitat type for the first 1.5 miles upstream of the dam from that of a pond to that of a river, and the associated changes to recreational opportunities (e.g. boating, swimming, skating).

Construction of a Denil Fish Ladder: Denil Fish ladders, used for upstream fish passage, consist primarily of a narrow sloped vertical-walled channel (see Figure 3, Photograph of Denil Fish Ladder) containing closely-spaced upstream-sloping V-shaped baffles designed to dissipate energy and enable fish passage at fairly high grades (U.S. Fish and Wildlife Service, 1994). The width and slope of Denil fish ladders are based upon the target species having the most difficulty ascending the fishways. Other fishway dimensions, including the width and depth of the V-shaped baffles and their spacing, are dependent upon the fishway width.

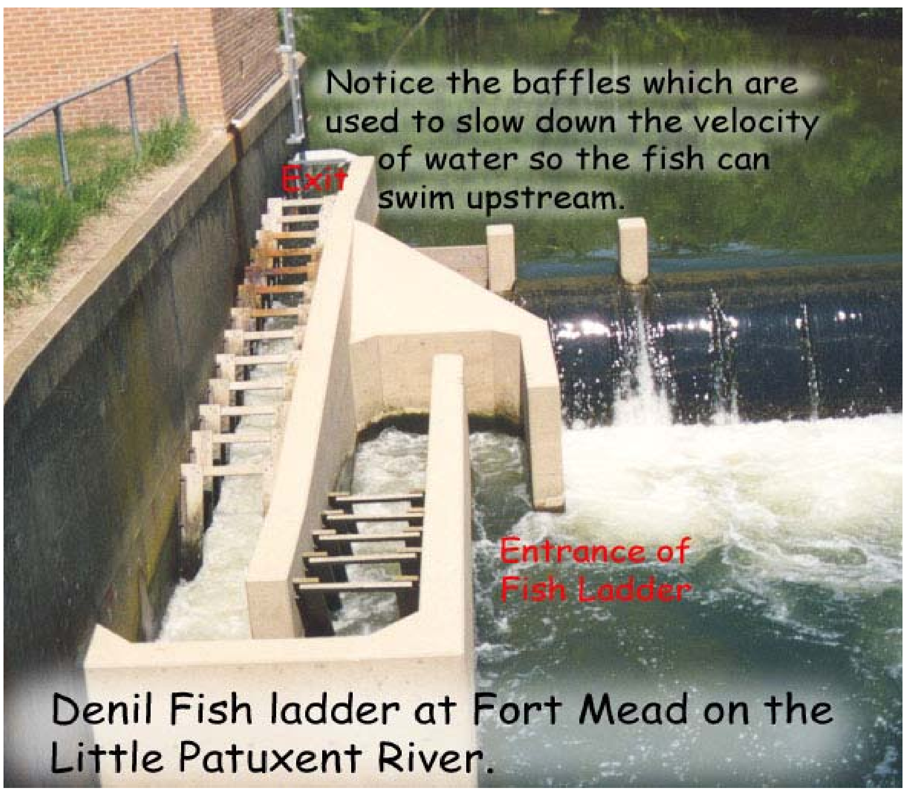

Figure 3 – Photograph of Denil Fish Ladder[1]

A level resting pool is required in the Denil fish ladder for every 6 to 9 feet of vertical rise. Turning pools are also required in order that the fishway entrance can be located near the base of the dam where fish are encountering the dam. The ladders, typically cut into the spillways of run-of-river dams, operate only during the

[1] Photo courtesy of the Maryland Department of Natural Resources. www.dnr.state.md.us

fish migration season, with stoplogs placed at the upstream end of the ladder to prevent flow at other times of the year. Denils are not designed to permit downstream fish passage, which occurs in late summer. Downstream passage is often provided by cutting a V-shaped notch into the spillway, and constructing a “plunge pool” downstream of the notch to prevent injury to the fish as they pass over the dam.

Major benefits of Denil fish ladders are that they occupy relatively small footprints and use only a small portion of the river’s total streamflow, typically only 10-11 cfs. The USFWS, long considered experts in anadromous fish passage, has a large body of experience with their construction in New England. Denils are a fairly “known” commodity with passage rates of up to 90% for herring entering the ladder. Disadvantages of Denils, however, include a low passage rate for shad, lack of habitat within the ladder, design that favors certain species, need for frequent maintenance, and need for frequent adjustment where headpond elevations vary widely.

Construction of a Nature-like Bypass Fishway: The type of a nature-like bypass fishway considered for Wiswall Dam (see Figure 4 for Preliminary Layout of River-Like Fishway at Wiswall Dam) is one with the morphology of a natural stream, and without the sharp drops found in the step-pool type of fishway. [Note: discussion of the various types of natural bypass methods is beyond the scope of this paper]. The bypass channel may take the form of a variety of natural channels ranging from those that are relatively straight and steep to those that are braided and meandering. This type of fishway may be referred to as a “stream-like fishway” (Parasiewicz, 2002).

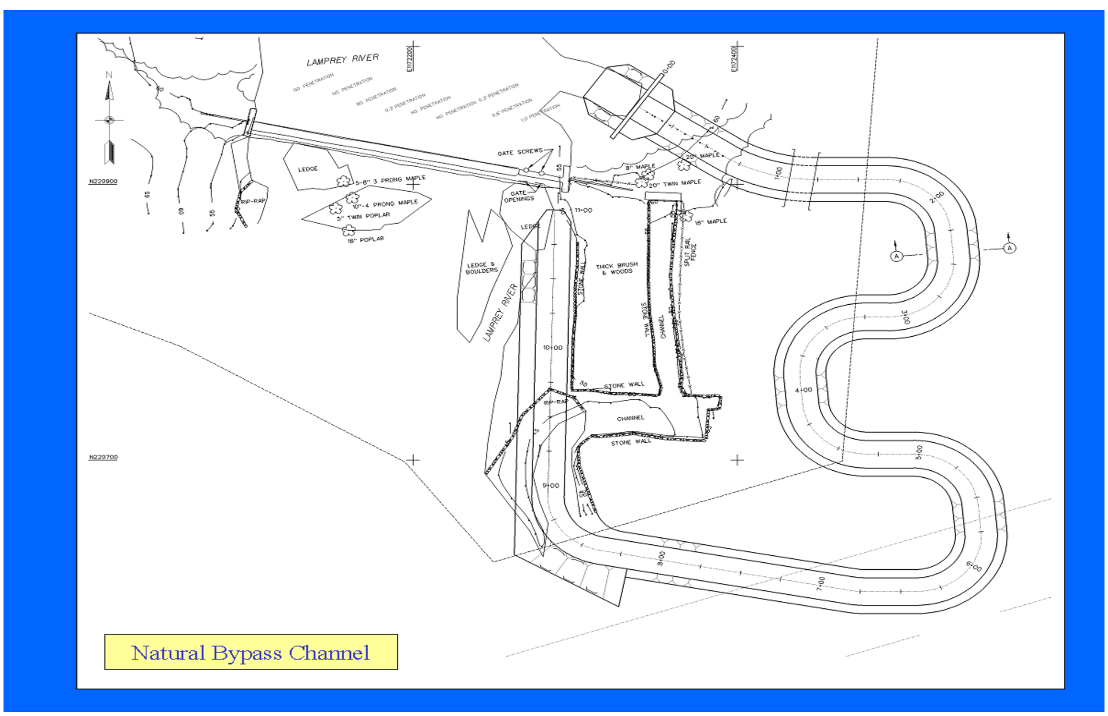

Figure 4 - Preliminary Layout of River-Like Fishway at Wiswall Dam

Major benefits of stream-like fishways are their provision of semi-natural habitat for both upstream and downstream fish passage and year-round functioning, their reported high rate of passage of fish species, and their aesthetically-pleasing appearance. The chief drawback of the channels is the significant amount of land that they require. USFWS has, however, virtually no experience with their construction (at least in the New England area), and were unable to provide significant design guidance concerning stream-like fishways. [Note: Because of the local limited experience with respect to nature-like bypass channels, the experience of national experts in nature-like fish passage design was heavily drawn upon through records research, personal conversations, and site visits. The experts included Mr. Piotr Parasiewicz of the Cornell University Department of Natural Resources' Instream Habitat Program, Mr. Alex Haro of the U.S. Geological Survey Biological Research Division's Conte Anadromous Fish Research Center, and Ms. Laura Wildman of American Rivers].

Preliminary Comparison of Alternatives:

Although removal of Wiswall Dam would likely be the most effective at achieving both goals, the water storage concerns of the owner effectively precludes its removal. Therefore, only the two types of fishways are discussed. The usual significant benefits of a Denil fish ladder in requiring little water and of occupying only a small footprint were found to have little importance to the sponsor and the owner of the dam. The town has offered no objection to the small lowering of the impoundment expected in late summer months with a properly designed nature-like fishway. (Owner support of the bypass channel may also be being driven by their presumption that it could reduce the flood discharge requirement being imposed upon them by the state for dam safety reasons). The relatively large land needs of an approximately 1100-foot long nature-like bypass channel also appear of little consequence to the Sponsor. Sponsor ownership of the land appears likely, with the sponsor to receive credit for the full market value of the land.

The success rate of stream-like fishways in passing shad is believed to exceed that for Denil fishways due to the greater width and flow rate of the nature-like fishway. Preliminary cost analyses indicate the costs of construction of a nature-like fishway and a Denil fish ladder to be comparable. At present, both the sponsor and the COE believe the benefits of stream-like fishways to outweigh the negatives.

Hydrologic and Hydraulic (H&H) Aspects Associated with Various Alternatives

Dam Removal:

H&H aspects associated with the removal of Wiswall Dam included the performance of hydrologic calculations, the establishment of with- and without-dam flood profiles and floodplain boundaries, and a determination of the role of storage in the impoundment on downstream flooding and of the increased scour protection needed at the bridge upstream of the dam. The locations of riffles and pools were identified, and sediment transport and ice jam issues were addressed.

Peak flood flows were determined by performing statistical analysis on the 67 years of peak flow records available from U.S. Geological Survey gage "Lamprey River near Newmarket, New Hampshire", located 3500 feet downstream of Wiswall Dam. Because the drainage areas at Wiswall Dam and the gage are nearly the same, results of the statistical analysis were used without adjustment.

Flood profiles with and without the dam were determined through HEC-RAS modeling. Cross-section data was obtained by combining data from three sources:

1. a bathymetric survey of the impoundment (Army Corps of Engineers, 2002);
2. a topographic survey in the vicinity of the dam; and (Army Corps of Engineers, 2001),
3. an existing two-foot contour topographic map of the entire reach (Eastern Topographics, 1986).

Data from the three sources was rectified and merged using CADD and other software, and a HEC-RAS input file was generated with minimal manual coding, mainly only at the dam and bridge. [Details of the surveys and procedures used in producing the HEC-RAS input are beyond the scope of this paper]. The HEC-RAS flood model was initially run using the flows published in Durham's FIS (Federal Emergency Management Agency, 2001) and model results were compared to the FIS flood profiles for calibration purposes. Flows in the flood model were then updated with flows from our hydrologic analysis, and the model run to establish final with- and without-dam flood profiles (see Figure 5, 100-year Flood Profile with and without Wiswall Dam). [Only 100-year flood profiles are shown for sake of clarity]. Removing Wiswall Dam would reduce the 100-year peak water surface elevation by nearly 7 feet at the dam, 5 feet immediately upstream from Wiswall Road, and lesser amounts upstream. The HEC-RAS .SDF output files for the with-dam and without-dam scenarios were then exported into software enabling the automatic delineating of floodplain boundaries that were subsequently displayed onto aerial orthophoto maps.

The role of storage provided by Wiswall impoundment on flooding downstream of the dam was assessed by comparing the volume of water stored behind Wiswall Dam (obtained from HEC-RAS output) during flood events to the several inches of runoff that can be expected during a major flood. Surcharge storage with a 100-year flood was found to be 435 acre-feet, equivalent to less than 0.05 inch of runoff from the basin. The surcharge storage is deemed insignificant.

The HEC-RAS flood model was also used in an assessment of scour protection needs at Wiswall Road, located 200 feet upstream of the dam, with the dam removed. Water velocities inside and immediately outside of the bridge's opening were found to increase greatly with the dam's removal. Without-dam channel water velocities during a 100-year flood are over 15 feet/second, representing

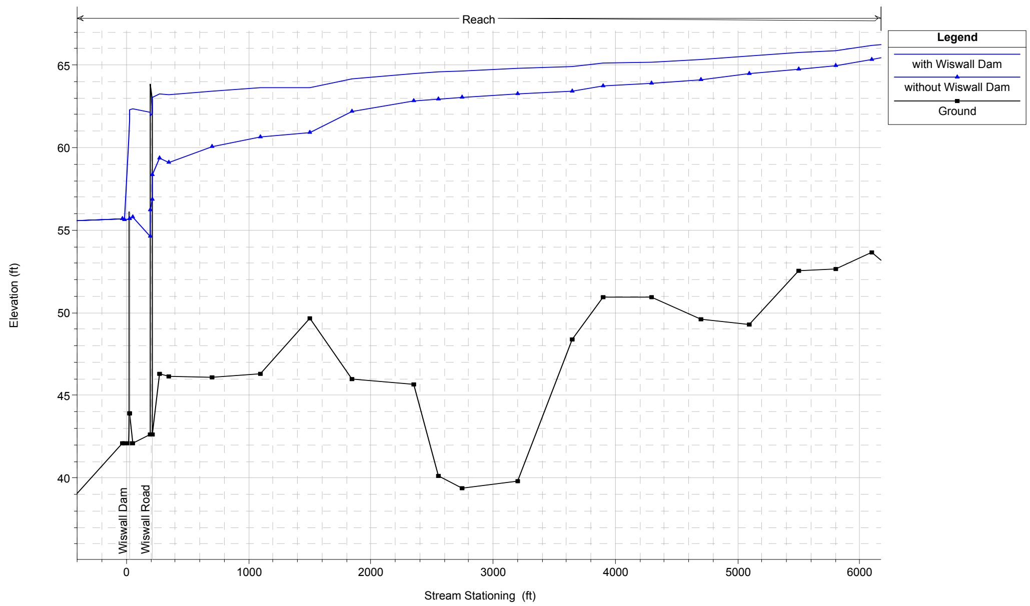

Figure 5, 100-year Flood Profile with and without Wiswall Dam

an increase of nearly 9 feet/second compared to the with-dam scenario. Addressing of scour protection is therefore of paramount concern should the dam be removed.

A low-flow HEC-RAS model was set up using the bathymetric data, with the purpose being to identify the locations of riffles (short steeper reaches) and pools (flat reaches) upstream of the (removed) dam under low flow scenarios. Cross-sections in the low-flow model were closely spaced, and Manning's roughness values increased.

The Cold Regions Research and Engineering Laboratory provided the steps to be taken concerning ice evaluations. These steps included the characterization of the existing ice regime at the dam and the downstream reach over at least one winter, the ascertainment of the ice regime prior to construction of the dam, hydraulic modeling of ice jam conditions if jams are known to occur near the dam, and the addressing of riverbed or bank erosion associated with ice-induced scour. [These tasks were not initiated due to dam-removal being ruled out as a feasible alternative early in the study]. Sediment was found to be of minor concern, with sediment depths measured during the bathymetric survey indicating a well-scoured impoundment. Sediments found only in outer fringes of the impoundment were found to contain minimal levels of contaminants.

Denil Fish Ladder:

H&H aspects of Denil fish ladders included the determination of the range of streamflows when the ladder is expected to be operational, the establishment of tailwater and headwater rating curves, and consideration of fish attraction velocities.

Flows important in the design of Denil fishways (refer to Figure 3) are the normal, minimum and maximum discharges for the April to mid-June migration period. Minimum flow at Wiswall Dam was determined to be 120 cfs (median June flow), although our analysis considered lower flows. The maximum streamflow for the operational period is assumed to be 3-4 times the average annual flow, approximately 1100 cfs. The normal streamflow with fish ladder operation is around 450 cfs, the approximate mean flow for the migration period.

Headwater and tailwater rating curves are used in the design of Denil fishways. A tailwater staff gage is typically installed and read under various flows to establish water surface elevations at the proposed location of the fishway entrance (downstream of the dam). It is crucial that the floor of the entrance channel have a minimum water depth of 2 feet during the lowest operating flows, with excavation sometimes required to meet this requirement. A tailwater staff gage was not installed at Wiswall Dam since HEC-RAS modeling at a surveyed cross-section below the dam indicated ample depths during low flows. A headwater rating curve was developed using the simple weir equation for the Wiswall Dam spillway. Depth of the exit channel upstream of the dam is also set at a minimum of 2 feet, usually necessitating a 2-foot cut into the spillway for low flow operation.

Attraction flows in the vicinity of the Denil entrance channel are of critical importance to anadromous fish seeking upstream passage, since the width of the fish ladder is very small in comparison to that of the channel at the base of the dam. The attraction flows insure that fish swimming at the base of the dam can find the ladder. A small outlet pipe was proposed to augment the ladder's velocity vectors.

Other H&H considerations include flood levels at the entrance and exit channels of the fishway (with the top of the sidewalls set accordingly), and the range of flows at the ladder's upstream end for control structure design.

<u>Nature-like bypass fishway</u>:

H&H aspects associated with nature-like fishways include the determination of the range of flows during the anadromous fish migration period, the establishment of the dimensions and bottom elevation of the bypass channel, and the consideration of flows at other times of the year (if year-round bypass is desired).

Flows during the April to mid-June migration period are determined (as they were for the Denil fishway). It is desirable to maximize the flow through the bypass channel rather than allowed over the spillway, in order to present the most attractive (or only) flow path for upstream-migrating fish. This is achieved by constructing the bottom of the channel's upstream end lower in elevation than the spillway crest.

The needs of the target species drive the design of the bypass channel. Since "finicky" shad prefer to swim in schools, it is desirable to maximize the width of the channel. Also, since shad and herring cannot jump, they cannot migrate past cascading water. Water depths and velocities are the most important considerations in nature-like fishway design. A minimum 1.5-foot channel depth should be attained during the lowest migration season flows, with water velocities less than 4.5 feet/second (Haro, 2002).

Although a trapezoidal-shaped channel may be assumed to determine average flows and velocities within the channel, it is desired that construction of the channel be made to mimic what is found in a natural stream of similar slope, i.e. with a variety of shape, slope, and roughness "blended" to appear and function as natural as possible. It is also desired that significant hydraulic roughness be provided. Since it is desired that year-round operation of the channel occur without human intervention, the river-like fishway is being designed with a low flow channel, also "blended". The small cross-sectional area of the low flow channel will ensure that the impoundment is not excessively lowered during late-summer months when the water may be needed. Use of the currently closed historic power canal for a nature-like fishway was ruled out due to its excessive slope (3%), historic vertical stone walls, and outlet that doesn't discharge near the base of the dam (to attract fish). A newly-constructed river-like channel therefore became the only option receiving close scrutiny.

As a starting point, we have assumed a 6-foot wide channel bottom set 1.5 feet below the spillway crest, 3H to 1V side slopes, a Manning's roughness coefficient of 0.06 (this may be on the high side), and a channel slope of 1%. Table1 provide the results of the hydraulic calculations (primarily the Manning formula for channel flow and the weir equation for spillway flow) including average flows, depths, and velocities in the channel for various headpond elevations.

Results shown in the table indicate that depth and average velocity requirements for successful fish passage will be met throughout the entire operating range. Optimization of channel dimensions and elevations, including for the low flow channel, will be performed prior to a final recommendation being made.

Although attraction velocities are not as important in the design of nature-like fishways as is the percentage of flow in the channel, it may be worthwhile to place flashboards on the portion of Wiswall Dam's spillway immediately upstream of the fishway entranceway in order to dampen the velocity and turbulence of water flowing over the spillway. This should insure that the bypass channel has the strongest water velocity vector in the area, especially during "wet" migration periods.

The substrate of the channel will resemble that of similarly-sloped segments of streams within the same watershed. In the Wiswall Dam area, there are numerous erratics and bedrock outcrops providing a great variability of flow conditions even in short and straight run conditions. Average velocities and depths as computed by the HEC-RAS model will not necessarily be representative of what migrating fish encounter as they swim upstream. More detailed hydraulic modeling is most likely unwarranted.

Table 1: Hydraulic Parameters of Nature-like Bypass Channel As Initially Configured

	headpond elevation	channel depth	channel velocity	spillway flow	total flow in river	% of flow in channel
Severe drought	55.2	0.6	1.5	0	7	100
	55.4	0.8	1.8	0	12	100
	55.6	1	2.0	0	18	100
	55.8	1.2	2.2	0	26	100
	56	1.4	2.4	0	35	100
spillway crest =	**56.1**	1.5	2.5	0	40	100
	56.2	1.6	2.6	14	59	76
min. operation	56.4	1.8	2.8	72	129	44
	56.6	2	2.9	156	226	31
	56.8	2.2	3.1	258	343	25
Normal operation	57	2.4	3.2	376	478	22
	57.2	2.6	3.4	508	629	19
	57.4	2.8	3.5	652	795	18
	57.6	3	3.7	808	974	17
max. operation	57.8	3.2	3.8	975	1165	16
	58	3.4	3.9	1152	1369	16
10-yr flood	60.2	5.6	5.3	3652	4324	16

REFERENCES

Eastern Topographics (1986), "Topographic Worksheet of Land on Lamprey River".

Federal Emergency Management Agency (2001), "Flood Insurance Study, Town of Durham, New Hampshire"

Haro, A. (2002), personal communication.

McKeon, J.F., and Grout, D. (2000), "Wiswall Dam Fish Ladder, Lamprey River, Durham, New Hampshire", unpublished briefing package.

Parasiewicz, P. (2002), Review of Nature-Like Bypass Channels".

U.S. Army Corps of Engineers (1992), "HEC-FFA Flood Frequency Analysis, User's Manual".

U.S. Army Corps of Engineers (2000), "Planning Guidance Notebook".

U.S. Army Corps of Engineers (2001), "HEC-RAS User's Manual", Version 3.0.

U.S. Army Corps of Engineers (2001), topographic survey of Wiswall Dam.

U.S. Army Corps of Engineers (2002), bathymetric survey of Wiswall impoundment.

U.S. Fish and Wildlife Service (1994), letter from Mr. Dick Quinn, Hydraulic Engineer, to Mr. William Mullen of COE.

Additional Information:

Wildman, L., Parasiewicz, P., Katopodis, C., and Dumont, U. (2002), "An Illustrative Handbook on Nature-Like Fishways- Summarized Version".

Haro, A. (2002), "Passage of American Shad through Natural and Experimental High Velocity Flow Environments".

Larinier, M. (2002), "Environmental Issues, Dams and Fish Migration"