US Army Corps of Engineers®
New England District

WISWALL DAM REMOVAL/FISH PASSAGE FEASIBILITY STUDY DURHAM, NEW HAMPSHIRE

HYDROLOGY AND HYDRAULICS APPENDIX

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1 PURPOSES

The primary purpose of the Feasibility portion of the Planning, Design, and Analysis (PDA) phase is to determine the feasibility and costs of various alternatives and recommend a single alternative that will enable anadromous fish passage to 45 miles of riverine habitat upstream of Wiswall Dam. At present, anadromous fish are prevented from accessing this habitat due to the blockage caused by the dam, and its lack of a fish passage structure. Each year, about 20,000-60,000 alewives, blueback herring and other fish species swim through a Denil fish ladder at Macallen Dam, the first dam on the Lamprey River, located approximately 3.5 river miles downstream of Wiswall Dam at tidewater in Newmarket, New Hampshire, but are prevented from further upstream access due to Wiswall Dam, the second dam on the river.

A secondary purpose is to obtain additional restoration measures to the river corridor while providing anadromous fish passage. These restoration measures include "de-fragmenting" the river habitat, maximizing the full range of aquatic habitat outputs, and creating or restoring habitat on a year-round basis. Additionally, the river is designated as a Wild and Scenic River and the Wiswall Dam site is a significant historical mill site, so aesthetics and cultural resource protection are also important measures.

This appendix presents hydrologic and hydraulic information for the three alternatives identified (in addition to the "without-project" alternative): the removal of Wiswall Dam; the construction of a Denil fish ladder at Wiswall Dam; and the construction of a nature-like bypass channel around Wiswall Dam.

2 AUTHORITY

This study was conducted by the Corps of Engineers under Section 206 of the Water Resources Development Act of 1996 (PL 104-303) entitled "Aquatic Ecosystem Restoration". This study was conducted at the request of the New Hampshire Fish and Game Department, and was performed by New England District.

3 DESCRIPTION OF STUDY AREA

3.1 General

The study area is located on the Lamprey River in the town of Durham, New Hampshire, at approximately latitude 43 06' N., and longitude 70 58' W. in Strafford County. 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, New Hampshire (below Macallen Dam) and emptying into the coastal estuary known as Great Bay, a National Estuarine Reserve. The drainage area of the Lamprey River at its mouth is approximately 212 square miles. Figure 1 shows the boundary of the Lamprey River watershed.

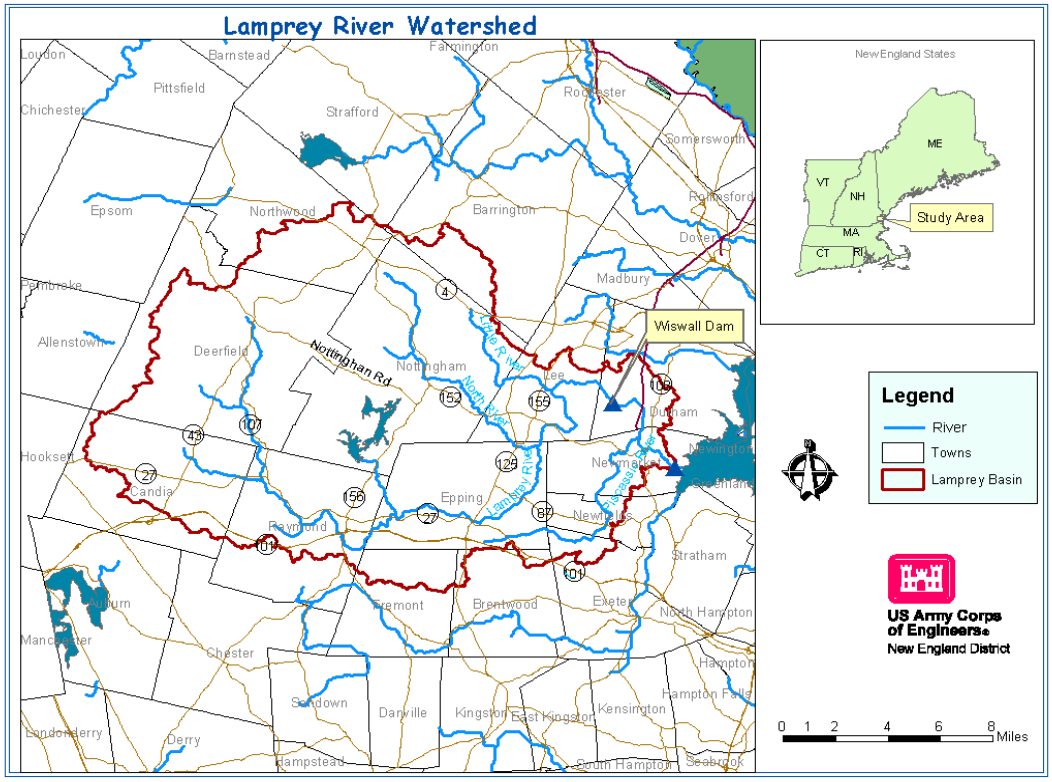

Figure 1 - Lamprey River Watershed

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 Lamprey River, from the Bunker Pond Dam in the town of Epping to the confluence with the Piscassic River in the vicinity of the Durham-Newmarket town line, has been designated into the National Park Service's Wild and Scenic Rivers System. In addition to its rich ecological resources, the river is abutted by archaeological sites of prehistoric and nineteenth century culture representative of early settlement of the seacoast region.

3.2 Wiswall Dam and Impoundment

Wiswall Dam is located in the Town of Durham, New Hampshire, approximately 0.7 mile upstream of Packers Falls, and 5 miles upstream of the mouth of the Lamprey River. Drainage area at Wiswall Dam is approximately 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 Durham, with the remaining 3000 feet located in the town of

Lee, New Hampshire. 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's spillway to safely pass major floods.

Figure 2 - Photograph of Wiswall Dam

3.3 Climatology

The area has a moderate, but variable, climate, and frequently experiences periods of heavy precipitation produced by local thunderstorms, and large weather systems of tropical and extratropical origin. The area lies in the path of the prevailing "westerlies" which generally travel across the country in an easterly or northeasterly direction, producing frequent weather changes. Mean annual temperature is 47 degrees Fahrenheit with mean monthly temperatures ranging from an average 24 degrees F in January to an average of 70 degrees F in July. The average yearly rainfall in the Durham area is about 43 inches and the average yearly snowfall is approximately 54 inches.

3.4 Streamflow

The U.S. Geological Survey (USGS) has recorded Lamprey River flows at the gage "Lamprey River near Newmarket, New Hampshire" (gage #01073500), located 200 feet upstream of Packer's Falls, 3500 feet downstream of Wiswall Dam, and 4.6 miles upstream of the mouth of the Lamprey River. Drainage area at the gage is 183.0 square miles (versus approximately 182 square miles at Wiswall Dam). The gage has a 67-year continuous record, from 1935 to the present. 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. Records of this gage were used for several purposes in this report, including the determination of flood-flow frequencies, and the range of flows that can be expected during the anadromous fish migration season.

4 DAM REMOVAL ALTERNATIVE

4.1 General

This section discusses the methods and assumptions used in the study of the removal of Wiswall Dam. Because without-dam results are usually compared to with-dam results, peak water surface elevations and velocities were determined for a range of flood events using the HEC-RAS computer model for both scenarios. Peak water surface elevations and velocities were of special concern at Wiswall Road, the only structure potentially impacted by increased water velocities associated with removal of the dam. Wiswall Road is located only two hundred feet upstream from Wiswall Dam. Riverbanks, which would be subject to higher velocities and possible erosion, would also be a concern.

In addition to the flood modeling, a more detailed HEC-RAS model, with cross-sections located every 50-feet along the river, was set up primarily to ascertain the location of the riffles and pools that would be formed during low and average flows. A bathymetric survey of Wiswall impoundment, performed by a Corps contractor in spring of 2002, provided the below-water data used in this detailed model.

4.2 Flood Discharge-Frequencies

Hydrologic analyses were performed to establish the peak flood discharge-frequency relationships using the U.S. Army Corps of Engineers Flood Frequency Analysis program (Ref. 4). Sixty-six years of peak flow records at the Lamprey River near Newmarket gage (#01073500) were analyzed. Results of the gage analysis for various recurrence intervals are presented in Table 4.2-1, as are peak flows for the same location and recurrence intervals as published in Durham's August 2001 Flood Insurance Study (FIS). There is a 12.5% difference in the 100-year discharge between that calculated for this study and that listed in the FIS. The discrepancy is primarily due to different periods of gage records having been analyzed (Note: the hydrologic analyses published in Durham's August 2001 FIS had not been updated from those published in the 1990 version of the FIS).

Table 4.2-1 Peak Flood Flows at Gage #01073500, Lamprey River near Newmarket		
Recurrence Interval	**COE, 1935-2001 (cfs)**	**Durham FIS Flows (cfs)**
10-year	4250	4120
50-year	6850	6270
100-year	8210	7300
500-year	12,100	10,000

The Corps statistical analysis was based on a longer period of record than that used in the FIS, accordingly the Corps analysis was adopted for this study. For this reason, the flows calculated by the Corps were used in subsequent HEC-RAS hydraulic modeling of the with- and without dam scenarios. Due to the very small difference between the drainage area at the gage (183.0 square miles) and at Wiswall Dam (approximately 182 square miles), flows estimated at the gage and at Wiswall Dam have been assumed to be the same. Peak flows used in HEC-RAS modeling of the with- and without dam scenarios are provided in Table 4.2-2.

Table 4.2-2 Peak Flood Flows (cfs) at Wiswall Dam			
10-year	**50-year**	**100-year**	**500-year**
4250	6850	8210	12,100

4.3 HEC-RAS Backwater Analysis.

The Corps of Engineers HEC-RAS computer model was used to conduct backwater analyses to compare the with- and without-dam scenarios. HEC-RAS employs a standard step method for calculating water surface elevations for steady gradually-varied flows, based on river geometry and structures crossing the channel. Input to the model primarily includes flows, loss coefficients, cross-section geometry, and reach lengths. Output from the model includes computed water surface elevations, channel velocities, and storage in the various reaches.

The HEC-2 input (used by USGS in the preparation of Durham's August 2001 FIS) was converted to HEC-RAS format by the Corps. The HEC-RAS model was initially run using the flows published in the FIS, and found to yield peak water surface elevation results that duplicated those published in Durham's FIS. (Note: there are no FEMA-published flood elevations for the Town of Lee to compare to the HEC-RAS model). The HEC-RAS model was then expanded to include the upstream end of the pool, in the town of Lee by adding a few cross-sections that consisted of the merging of data from two sources: 1. underwater data from the bathymetric survey (Ref. 8) of Wiswall Impoundment conducted in spring 2002, and 2. above-water data obtained from a 2-foot contour map (Ref. 7). A 3-foot adjustment (downward) was made to the overbank contours on the 2-foot contour map (no datum is stated on the map) since a three-foot adjustment appears to obtain the best vertical correlation to the cross-sections surveyed by USGS in Durham as part of their work in preparing the FIS for Durham. Cross-

section locations used in the HEC-RAS model are shown on Plate 1. Flows in the Corps HEC-RAS model were then updated with the adopted peak streamflows provided in Table 4.2-2 of this report. Starting elevations at the downstream end of the model, located 500 feet downstream from Wiswall Dam, were determined from a rating curve for that location developed using the HEC-RAS model. The HEC-RAS model was then run with the dam removed. The results of the with- and without-dam models were then compared.

4.4 HEC-RAS Flood Modeling Results

4.4.1 Water Surface Elevations

Table 4.4.1-1 presents computed peak water surface elevations at selected locations for the with- and without-Wiswall Dam scenarios for the 10-year and 100-year recurrence intervals. Plates 2 and 3 show peak water surface profiles of the 100-year and 10-year flood flows, respectively, for the with- and without-dam scenarios. Plates 4 and 5 show peak water surface profiles for various recurrence intervals for the with- and without-dam scenarios, respectively.

With Wiswall Dam in place, the 10-year and 100-year peak water surface elevations at the dam are 60.1 feet NGVD and 62.3 feet NGVD, respectively. (These values may be compared to the spillway crest elevation of 56.15 feet NGVD). The 10-year and 100-year peak water surface elevations at the upstream end of Wiswall Road are 60.2 feet NGVD and 63.0 feet NGVD, respectively. (These values may be compared to the top of road elevation of 63.8 feet NGVD). The flood profiles indicate an increase in peak water surface elevations just upstream of Wiswall Road, due to the head losses associated with the road's relatively small openings. Upstream of Wiswall Road, peak water surface elevations gradually increase continuing upstream to the tail of the impoundment.

With Wiswall Dam removed, the 10-year and 100-year peak water surface elevations at the location where the dam had stood are 49.6 feet NGVD and 55.7 feet NGVD, respectively. The 10-year and 100-year peak water surface elevations at the upstream end of Wiswall Road are 54.3 feet NGVD and 58.4 feet NGVD, respectively. The constricted openings under Wiswall Road increase peak water surface elevations quite significantly for all recurrence intervals examined.

A comparison of the with-Wiswall Dam and the without-Wiswall Dam scenarios was made. For the 100-year flood (Plate 2), it can be seen that removing Wiswall Dam reduces peak water surface elevations by approximately 7 feet at the dam and 5 feet immediately upstream from Wiswall Road. At the Durham-Lee corporate limit, located about a mile upstream of the dam, removing Wiswall Dam causes the peak 100-year water surface elevation to drop by approximately 1 foot. At the most upstream cross-section modeled, 8200 feet upstream of the dam and in the Town of Lee, the peak 100-year water surface elevation drops 0.5 feet with the dam removed.

Table 4.4.1-1
Channel Velocities and Peak Water Surface Elevations with and without Wiswall Dam

		With Dam			Without Dam			
Section Description	**Recurrence**	**Flow (cfs)**	**CWSEL* (ft, NGVD)**	**VCH** (ft/sec)**	**CWSEL* (ft, NGVD)**	**VCH** (ft/sec)**	**Change in Elev. (ft)**	**Change in Velocity (ft/sec)**
FEMA x-sec J (450 ft d/s dam)	10-year	4250	49.2	3.4	49.2	3.4	0.0	0.0
	100-year	8210	55.6	3.6	55.6	3.6	0.0	0.0
Wiswall Dam	10-year	4250	60.1	1.7	49.6	5.9	-10.5	4.2
	100-year	8210	62.3	2.9	55.7	4.8	-6.6	1.9
Wiswall Road (downstream)	10-year	4250	60.0	4.2	51.9	12.6	-8.1	8.4
	100-year	8210	62.1	6.6	54.6	15.4	-7.5	8.8
Wiswall Road (upstream)	10-year	4250	60.2	3.4	54.3	7.1	-6.0	3.7
	100-year	8210	63.0	4.6	58.4	7.9	-4.7	3.3
1100 ft u/s dam	10-year	4250	60.6	2.4	56.7	4.4	-3.9	2.1
	100-year	8210	63.6	3.3	60.6	4.6	-3.0	1.3
FEMA x-sec N (Pump House) (2750 ft u/s dam)	10-year	4250	61.4	2.4	59.6	2.8	-1.9	0.5
	100-year	8210	64.6	3.5	63.0	4.0	-1.6	0.5
Corporate Limit (5100 ft u/s/ dam)	10-year	4250	62.2	2.9	61.1	3.3	-1.2	0.5
	100-year	8210	65.6	4.0	64.5	4.4	-1.1	0.4
FEMA x-sec O (5800 ft u/s dam)	10-year	4250	62.5	3.5	61.5	4.0	-1.0	0.6
	100-year	8210	65.9	4.5	65.0	5.0	-0.9	0.5
Near End of Pool (8200 ft u/s dam)	10-year	4250	64.1	3.8	63.7	4.1	-0.4	0.3
	100-year	8210	67.6	4.7	67.1	5.0	-0.5	0.3

*Computed water surface elevation
**Channel velocity

For the 10-year flood (Plate 3), it can be seen that removing Wiswall Dam reduces peak water surface elevations approximately 10 feet at the dam and 6 feet immediately upstream from Wiswall Road. At the Durham-Lee corporate limit, removal of Wiswall Dam causes the peak 10-year water surface elevation to drop by a foot. At the most upstream cross-section modeled, 8200 feet upstream of the dam, the peak 10-year water surface elevation drops by less than 0.5 foot with the dam removed.

4.4.2 Velocities

Table 4.4.1-1 presents computed water velocities of selected cross-sections for the with-Wiswall Dam and without-Wiswall Dam scenarios. Plates 6 and 7 present channel velocities along the river reach for the 100-year and 10-year flood flows, respectively, for these scenarios. For the 100-year flood flow, the channel velocity without the dam increases by 2 feet/second compared to the with-dam scenario. For the 10-year flood flow, the channel velocity without the dam increases by about 4 feet/second compared to the with-dam scenario. Channel velocities at the location of the removed dam would be 4.8 feet/second and 5.9 feet/second, for the 100-year and 10-year floods, respectively.

Velocities in the vicinity of Wiswall Road, located approximately 200 feet upstream of Wiswall Dam, are of critical interest, as they may be increased sufficiently upon removal of the dam to require additional erosion and scour protection. Wiswall Road is the only crossing of the subject reach of the Lamprey River. All flow passes through the two openings under the bridge (except during a 500-year flood with Wiswall Dam in place, when there is a slight amount of overtopping at a low point on the eastern approach to the bridge). The HEC-RAS model was used to determine velocities at the approach, exit, and through the bridge openings with dam in place and with it removed under various flood flows. Velocities at all of these locations were found to greatly increase upon dam removal, with the greatest velocities, and increase in velocities, noted at the exit cross-section. The increases in velocities at the exit section, with Wiswall Dam removed, were determined to be 8.4 feet/second, 8.7 feet/second, 8.8 feet/second, and 2.9 feet/second for the 10-year, 50-year, 100-year, and 500-year floods, respectively. The resulting velocities at the exit section from Wiswall Road with the dam removed are 12.6 feet/second, 14.6 feet/second, 15.4 feet/second, and 10.5 feet/second for the 10-year, 50-year, 100-year, and 500-year floods, respectively. The bridge needs scour protection sufficient to withstand the shearing forces associated with a water velocity of at least 15.4 feet/second if the dam were to be removed. Rock protection sizing and bridge safety analysis was not conducted for this stage of the study.

Mean annual water velocities were also examined. The fastest water velocity in the study reach with Wiswall Dam removed would be immediately downstream of Wiswall Road. The water velocity at this location would be increased to 7.0 feet/second, versus only 0.4 feet per second with the dam in place.

4.4.3 Role of Storage in the Impoundment to Downstream Flood Levels

The HEC-RAS output was also used to determine if storage of water behind Wiswall Dam reduces flood levels in downstream reaches. The volume of water stored behind Wiswall Dam was obtained from HEC-RAS output for the various recurrence intervals of floods. In each case, storage was found to be minimal. Storage behind the dam with a 100-year flood was found to be approximately 565 acre-feet, with approximately 435 acre-feet of this volume serving as surcharge storage, i.e. the storage temporarily available during a flood. This is equivalent to a runoff from the basin of less than 0.05 inches. Compared to the several inches of runoff that can be expected during a 100-year flood, the storage behind Wiswall Dam is insignificant, therefore it is concluded that Wiswall Dam provides virtually no reduction in peak water surface elevations downstream of the dam. This finding also holds true for other flood recurrence intervals.

4.5 Ice Jam and Sediment Issues

Ice jam issues would be a possible concern should the dam be removed due to the cold climate. Contact was therefore made with the U.S. Army Cold Regions Research and Engineering Laboratory for guidance (CRREL). CRREL suggested the collection of at least one year of ice data in reaches upstream, at, and downstream of the dam in order to characterize the existing ice regime; the searching of records prior to the dam's construction for clues on the likely ice regime without a dam; and to perform hydraulic modeling if jams are known to occur near the dam. Further ice jam analysis was not conducted at this stage of the study, but would be pursued if the dam removal option became the selected alternative.

Sediment was found to be of no concern for two reasons: 1. The spring 2002 bathymetric and sediment survey conducted by the Corps found sediments only in the fringes of the impoundment, with the majority of the impoundment being well-scoured; and, 2. The fine-grained sediments that were found were determined to be relatively clean. No further investigation of sediment, or its transport, was therefore undertaken.

4.6 HEC-RAS Non-Flood Flow Backwater Analysis

HEC-RAS was also used to conduct backwater analyses to determine the locations of riffles and pools under various non-flood flow scenarios with the dam removed. A highly detailed HEC-RAS model, with cross-sections located every 50 feet along the profile of the river, was set up for these purposes, using below-water geometric data obtained during the spring 2002 bathymetric survey (Ref. 8) of Wiswall impoundment.

Five flow scenarios were evaluated: mean annual flow; mean August flow, and the Q60, Q80, and Q90 low flows. Mean annual and mean (typical) August flows were determined using the records of USGS gage 01073500, Lamprey River near Newmarket, New Hampshire. As with the flood flow frequency analysis, flows at the gage and at Wiswall Dam have been assumed to be equal. The Q60, Q80, and Q90 flows are those listed in the 401 Water Quality Certificate for Durham's pumping station, flows at which

certain restrictions would be placed on pumping from the Lamprey River. The flows for which low flow computer modeling runs were performed are listed in Table 4.6-1.

Table 4.6-1
Mean and Low Flows (cfs) At Wiswall Dam

Mean Annual	Mean August	Q60 low flow	Q80 low flow	Q90 low flow
283	71	45	21	13

Plate 8 provides the profiles for the mean annual flow, mean August flow, and the Q60 and Q90 low flows (Q80 low flow omitted for clarity). The locations of the riffles and pools (the segments with flat profiles) are readily apparent by examining the profiles shown in Plate 8. The locations of the pools appear consistent with all flow rates examined. The locations of the pools are determined by sections of the river with relatively perched channel bottoms.

The water surface profiles associated with mean annual flow with- and without Wiswall Dam are provided on Plate 9. An examination of this plate shows that removal of Wiswall Dam will cause the water surface elevation to drop by approximately 12 feet at the location of the dam, 9.5 feet immediately upstream from Wiswall Road, and 2.6 feet at the Durham-Lee corporate limit. At the most upstream cross-section modeled, 8200 feet upstream of the dam, the mean annual water surface elevation drops by 0.3 feet with the dam removed. Similar drops were found with the other flows examined.

5 DENIL FISH LADDER ALTERNATIVE

5.1 General

Denil fish ladder designs are based upon the species having the most difficulty when ascending fishways. In this instance, a four-foot-wide, 1' on 8' sloped Denil fishway is required for American shad to ascend into the headpond. Wiswall Dam has an 11-foot head differential; therefore, a total length of approximately 88 feet of closely-spaced upstream-sloping V-shaped baffles is required to dissipate energy enough to enable fish passage. In addition to the sloped baffle section, Denil fish ladders are designed with an entrance channel (at the foot of the dam) with a level floor section and walls, a level resting or turning pool for every 6 to 9 feet of vertical rise, and an exit channel, with optional provisions for a trapping facility. The primary function of the turning pool is to switch the direction of the ladder so that the entrance may be placed near the foot of the dam, where fish swimming at the base of the dam can find it. Denil fishways have been widely tested and have been found to be successful with passing some anadromous fish species. Denil fish ladders are used for upstream passage only, and are operated only during the fish migration season. Downstream fish passage is achieved simply by construction of a notch in a spillway that discharges to a plunge pool that reduces injury to the fish as they pass over the dam. Downstream passage occurs in late summer when flows are usually at their lowest.

Denil fish ladders 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 "known" commodity with passage rates of up to 90% for herring entering the ladder but much lower for shad. Denil fish ladders require frequent maintenance, and need frequent adjustment where headpond elevations vary widely (such as that of the Wiswall Dam impoundment).

5.2 Discharges

Because of U.S. Fish and Wildlife Service's (USFWS) extensive experience with the design of Denil fish ladders, USFWS flow criteria used in Denil design are cited here. Flows examined in the design of Denil fishways are the normal, minimum and maximum discharges for the April through mid-June migration period. Minimum flows are used primarily to insure that minimum depths of 2 feet are attained at both the entrance and exit channels during the migration season. Attainment of minimum depth at the entrance channel often requires excavation in the channel; attainment of a minimum depth of 2 feet at the exit channel usually requires cutting into the spillway crest. At locations where headpond elevations greatly during the migration season, frequent headpond structure adjustments are required. During excessively high flows (expected to occur a small percentage of the time), anadromous fish generally hold up in low velocity sections of the river and stop migrating until flows subside sufficiently.

Migration season flows were determined using USGS gage #01073500, Lamprey River near Newmarket, New Hampshire, considered representative of the flows at Wiswall Dam. Mean flows are 693 cfs for April, 347 cfs for May, and 190 cfs for June, for the period of record. The year 1985 had particularly low migration-period flows, with flows of 170 cfs, 105 cfs, and 40 cfs in April, May and June, respectively. USFWS has cited maximum flows to be 3 to 4 times the average annual flow. Since the average annual flow is 283 cfs, maximum flow would be 850 to 1130 cfs. Flow in a Denil fish ladder is primarily a function of the width of the ladder. It does not take much water to operate a Denil fish ladder: normal flow through a four-foot wide Denil is 10 to 11 cfs, with minimum and maximum flows in the ladder ranging from 4 to 30 cfs.

Typically, a tailwater staff gage is installed to get tailwater ratings, however, in this case, a tailwater rating curve was developed using the HEC-RAS model for a surveyed cross-section (from the USGS HEC-2 model) located at the foot of the dam. The analysis indicated that only a slight amount of channel excavation would be necessitated in order to insure a 2-foot depth of water at the entrance of the fish ladder during the minimum flows when the ladder is expected to be operational.

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 ensure that fish swimming at the base of the dam can find the ladder. A small outlet pipe is proposed at Wiswall Dam to augment the ladder's velocity vectors.

5.3 Results

Detailed consideration of the hydrologic and hydraulic aspects of Denil fish ladder construction was not pursued at the feasibility phase of this project. Further analysis would be conducted if the Denil fish ladder were selected as the preferred alternative for construction. At this time, only the limited cursory-level hydrologic (see preceding section) information that had been developed early in the study is presented. The rating curve for a 4-foot wide, 1 vertical on 8 horizontal Denil fishway has been determined through laboratory tests and is readily available, and, therefore, there is no need for its calculation.

6 NATURE-LIKE BYPASS FISHWAY ALTERNATIVE

6.1 General

The type of a nature-like bypass fishway considered for 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: this study does not discuss the various types of natural bypass methods]. 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" (Ref. 8). Major benefits of stream-like fishways are their provision of semi-natural habitat for both upstream and downstream fish passage and year-round functioning, and their aesthetically-pleasing appearance. The success rate of stream-like fishways in passing shad is believed to exceed that of Denil fishways due to the greater width and flow rate of the nature-like fishway. The chief drawback of the channels is the significant amount of land that they require. USFWS has, however, no local experience with their construction (at least in the New England area), and were unable to provide significant design guidance concerning stream-like fishways. 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 drawn upon through records research, and personal conversations and site visits with experts (including 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).

The needs of the target species drive the design of the bypass channel. Since shad prefer to swim in schools and are relatively large fish compared to herring, it is desirable to maximize the width of the channel, and provide adequate channel depth. 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 and Parasiewicz, 2002). Additionally, large pools and long reaches with minimal flow velocity should be avoided to minimize delays and keep fish migrating upstream (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 and without excessively lowered of the impoundment during late-summer months (when the water may be needed), construction of a low flow channel within the river-like fishway is to be considered. Another objective is to have a channel that requires minimal maintenance. The channel as located in the preliminary design has a channel bottom in bedrock that can be sculpted to provide high roughness and will be highly durable with little to no maintenance required. Additionally, materials will be sized to minimize bed load scour.

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).

6.2 Discharges

Flows during the April to mid-June migration period are determined as they were for the Denil fishway (refer to that section of the report). However, it is likely that anadromous fish migrate upstream during a very broad range of flows, and since a nature-like bypass channel will "look and feel" like a river, it is expected that the fish will use nature-like fishways under a larger range of flows than for Denils. At the direction of the Corps Study Manager, the quantity of flow through the bypass channel will be maximized, rather than allowed to spill over the spillway, in order to present the most attractive (or only) flow path for upstream-migrating fish. This will be achieved by maximizing the size of the channel (given financial constraints) and by constructing the bottom of the channel's upstream end lower in elevation than that of the spillway crest.

6.3 Results

Because average velocities and depths, as computed by a HEC-RAS model, will not necessarily be representative of what migrating fish encounter as they swim upstream, detailed hydraulic modeling of the fishway is most likely unwarranted. Manning's equation should suffice for determination of average flow, velocity, and depth in the channel at various headpond elevations.

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 (lots of large boulders to increase roughness, provide variety, and provide temporary "hiding/resting" spots for migrating fish), and a channel slope of 1%. A 1% slope is a good starting point according to experts in the field. Table 6.3-1 provide the results of the hydraulic calculations (using the Manning formula for channel flow and the weir

equation for spillway flow) including average flow, depth, and water velocity in the channel for various headpond elevations.

Table 6.3-1
Hydraulic Parameters of Nature-like Bypass Channel As Initially Configured

	Headpond Elevation (ft, NGVD)	Channel Depth (ft)	Channel Velocity (ft/sec)	Spillway Flow (cfs)	Flow in Channel (cfs)	Total Flow in River (cfs)	Flow in Channel (%)
Severe Drought	55.2	0.6	1.5	0	7	7	100
	55.4	0.8	1.8	0	12	12	100
	55.6	1	2.0	0	18	18	100
	55.8	1.2	2.2	0	26	26	100
	56	1.4	2.4	0	35	35	100
Spillway Crest	**56.1**	1.5	2.5	0	40	40	100
	56.2	1.6	2.6	14	45	59	76
Normal Range of Operation	56.4	1.8	2.8	72	57	129	44
	56.6	2	2.9	156	71	226	31
	56.8	2.2	3.1	258	86	343	25
	57	2.4	3.2	376	103	478	22
	57.2	2.6	3.4	508	122	629	19
	57.4	2.8	3.5	652	143	795	18
	57.6	3	3.7	808	165	974	17
	57.8	3.2	3.8	975	190	1165	16
	58	3.4	3.9	1152	217	1369	16
10-Yr Flood*	60.1	5.5	5.2	3606	644	4250	15
100-Yr Flood*	62.3	7.7	6.4	6785	1425	8210	17

*Assumes that trapezoidal channel opening is unconstrained by the opening of the access bridge crossing it near its upstream end

Results shown in the table indicate that depth and average velocity requirements for successful fish passage would be met throughout the entire operating range. Increasing the roughness coefficient would reduce velocities (and flow) in the channel; however, this appears unnecessary with a 1% slope. Increasing the slope of the nature-like channel would increase flows and velocities in the channel. (For example, at headpond elevation 57.0 and a slope of 1%, there would be 103 cfs in the channel with an average velocity of 3.2 feet/second. Increasing the slope to 2% would boost the flow in the channel to 146 cfs with an average velocity of 4.6 feet/second). Increasing roughness coefficients would lower flows and velocities in the channel. For example, at headpond

elevation 57.0 and a roughness coefficient of 0.06, there would be 103 cfs in the channel with an average velocity of 3.2 feet/second. Increasing the roughness coefficient to 0.08 would reduce the flow in the channel to 77 cfs with an average velocity of 2.4 feet/second. If, because of land or other physical constraints, it is found necessary to construct a shorter channel, steeper segments will be interspersed with milder-sloped segments to provide further variety of habitat, and to provide the fish some resting spots. Optimization of channel dimensions and elevations, including for the low flow channel, will be performed during Plans and Specifications phase. Should the low flow channel be found to excessively lower the impoundment, a simple headpond stoplog structure could be designed and constructed.

Attraction velocities may not be as important in the design of nature-like fishways as they are for Denil fish ladders. The reason for this is because a significant portion of flow will flow in the bypass channel, making it easier for fish to "find" the bypass channel. Nevertheless, 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 (Wildman, 2003). Another option to minimize turbulance at the channel entrance is to provide a stone barrier between the channel entrance and the turbulent zone at the base of the spillway (Wildman, 2003). The stone barrier would allow the water in the channel entrance to flow into the area where non-turbulent flow begins at the base of the dam. The flashboards or stone barrier would help ensure that the bypass channel has the strongest water velocity vectors, especially during "wet" migration periods when the spillway flow is more likely to be highly turbulent. The feasibility-level design incorporates the stone barrier, due to the potentially minimal operations and maintenance required for the stone barrier, and the stone barrier would be safer and fitting with the historic setting. The entrance of the bypass channel would be oriented perpendicular or turned slightly downstream in the river, using the stone barrier, so that flow vectors from the channel would point slightly downstream, away from the dam. The downstream vector would also prevent the development of an eddy in the entrance to the bypass channel (Wildman, 2003).

It is currently intended that the substrate of the channel resemble that of similarly-sloped segments of streams within the same watershed; however, it is expected that boulders will also be randomly-placed to ensure extensive variety of conditions in the channel and to slow the water down. In the Wiswall Dam area, there are numerous erratics and bedrock outcrops providing great variety of flow conditions even in short and straight run conditions. In order to withstand flood flows passing through the channel, the rock substrate will need to be large enough to withstand the size of flood flows that are allowed to pass into the fishway channel. A D30 of 0.37 feet (safety factor = 2) has been calculated to withstand the approximately 650 cfs flow in the nature-like channel during a 10-year flood. However, the D30 associated with the 100-year flood provides an excessively large stone size, approximately twice this size. It is therefore recommended that flows allowed to pass in the nature-like fishway be limited, either by the size of the opening of the access bridge crossing the fishway at its upstream end, or by a stoplog structure.

It is not believed that the nature-like fishway will fill in with sediment, since most sediment entering Wiswall Pond will settle at the upstream end of the impoundment where water velocities drop fairly suddenly. Any fine sediment that continues through the impoundment and enters the fishway should be flushed on through the fishway due to the high velocities in the fishway (as compared to in the impoundment).

The dike (outer training wall of the nature-like fishway) downstream of the dam will consist of fill placed in the 100-year floodplain. Due to the low velocities in the river at that location, the size of riprap needed to protect the dike is minimal (on the order of 0.1 feet), except at the base of the dam where turbulent flow will require much larger stone. Cursory examination of flood level impacts associated with the placement of the fill within the floodplain has been made. Placing this fill is expected to have little impact on floodwater surface levels in the area immediately downstream of the dam, and upstream of the dam, since the volume of the fill is a very small percentage of the volume of the floodplain.

7 REFERENCES

1. Federal Emergency Management Agency, Flood Insurance Study, Town of Durham, New Hampshire, revised August 23, 2001.

2. Flood Insurance Rate Maps (in the form of converted approximate maps), Town of Lee, New Hampshire, effective April 2, 1986.

3. U.S. Geological Survey (USGS), HEC-2 input file (used in determining base flood elevations published in the Town of Durham's FIS, date of computer file?

4. U.S. Army Corps of Engineers, HEC-FFA Flood Frequency Analysis, User's Manual, Davis, CA, May 1992.

5. U.S. Army Corps of Engineers, HEC-RAS User's Manual, Davis, CA, Version 3.0, January 2001.

6. U.S. Army Corps of Engineers, hydrographic survey performed spring 2002.

7. Eastern Topographics, Topographic Worksheet of Land on Lamprey River, New Hampshire, prepared for Civil Consultants, photo date May 9, 1986.

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

9. Haro, personal communication, 2002.

10. Wildman, Laura, transcribed statement, 2003

PLATES