Feasibility Study for Willowdale Dam Fish Passage Project

Prepared by:
Alden Research Laboratory, Inc.

Gregory Allen, Civil Engineer
Thomas Cook P.E., Director of Environmental Services
Nathaniel Olken, Civil Engineer

Prepared for:

Commonwealth of Massachusetts
DIVISION of MARINE FISHERIES

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INTRODUCTION

Alden Research Laboratory, Inc. (Alden) was contracted by the Massachusetts Division of Marine Fisheries (DMF) to perform a feasibility study for the Willowdale Dam fish passage project. The purpose of the project is to restore access to historic spawning and nursery habitat for alewife and blueback herring, the primary target species. Other diadromous species and freshwater fishes in the Ipswich River could also benefit from improved fish passage at Willowdale Dam. American eel, sea lamprey and American Shad have been observed in the river.

Alden has met the objectives of the study by performing field investigations and inspections, hydrology and hydraulic computations, and an assessment of fish passage options. Various fish passage alternatives were screened and four were selected for a detailed evaluation. The selected alternatives include: a Denil fishway, a bypass channel, a rock ramp, and dam removal. Considerations discussed for each fish passage alternative include:

- Fish passage effectiveness
- Construction considerations (include sediment transport potential and sediment disposal requirements)
- Sediment management
- Dam stability
- Impacts on wetlands and aquatic habitat
- Estimated construction costs

This report summarizes the efforts to complete the feasibility study and includes a description of the site, a summary of the field investigations, results of the hydrologic and hydraulic analysis, screening of fish passage alternatives, detailed evaluation of fish passage alternatives, estimated costs, and conclusions and recommendations.

SITE DESCRIPTION

Willowdale Dam is located in the town of Ipswich, Massachusetts on the Ipswich River, approximately 3.3 miles upstream from the confluence with the Miles River and 8.5 miles inland from the mouth of the Ipswich River. The dam, which is owned by the Foote Brothers and the Essex County Greenbelt Association, is located near the Foote Brothers Canoe Rental off of Topsfield Road. A vicinity map showing the dam location is provided on Figure 1.

Willowdale Dam Features

The construction date of the original dam is not precisely known. The Massachusetts Department of Environmental Management (DEM), Office of Dam Safety, Notice of Inspection indicates that the dam was built in 1850 (DEM 1993). However, the US Army Corps of Engineer's (USACE) National Inventory of Dams lists the dam as being constructed in 1900 (USACE 2006). The dam was originally designed to provide water to a mill located near Willowdale Road approximately 1,200 ft downstream of the dam. The canal leading to the old mill site is separated from the impoundment by approximately 25 ft of earthen fill embankment.

Willowdale Dam

The dam is an earthen embankment approximately 260 ft long with a 100 ft long granite block spillway (Figure 2). The spillway crest is at El. 26.8 ft National Geodetic Vertical Datum 1929 (NGVD 1929). All elevations in this report refer to NGVD 1929. Flashboards are normally installed on the spillway increasing the dam to El. 27.7 ft (10 inch board height). The spillway has a sluice that is 6 ft wide and 4 ft deep with wooden stoplogs. The dam has a structural height of 8 ft and a hydraulic height of about 2.6 ft to 3.8 ft. A summary of Willowdale Dam pertinent information is provided in

Table 1.

The drainage area above the dam is about 125 square miles. The impoundment created by the dam is about 2.5 miles long with a storage volume of about 785 acre-ft of water. The dam creates a slow moving backwater that is popular among boating and canoeing enthusiasts. The impoundment is reported as one of the most popular rivers for canoeing in New England. The Foote Brothers operate a business that rents canoes and provides access to the impoundment on the north side of the dam.

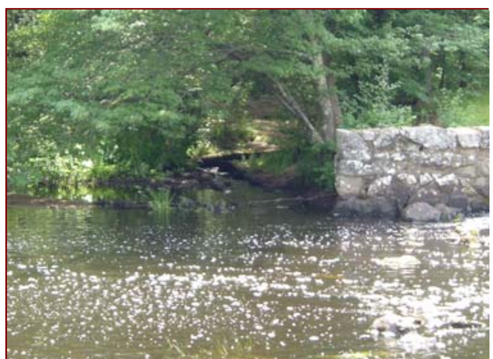
The existing impoundment bathymetry indicates very little sediment deposits in the impoundment. The existing survey of the site completed by Donohoe and Parkhurst in 2003 (Figure 2) shows a main river channel in the impoundment approximately 50 ft wide with gravel substrate extending to the dam. The bottom elevations upstream of the dam are similar to elevations downstream of the dam. Elevations upstream in the main channel are actually slightly lower averaging about El. 21.0 to 21.5 ft, while downstream elevations average between El. 21.5 and 22.5 ft. The survey shows a wedge of material extending approximately 40 ft immediately upstream of the dam from El. 21.0 ft to El. 25.0 ft. This material could be part of the original dam construction or sediment deposits.

Table 1 Willowdale Dam Pertinent Information

National ID	MA00276
State ID	5-5-144-5
Hazard Class	Low (class III)
Condition	fair to poor
Year constructed	1850
Dam type	earthen embankment granite block spillway
Abutments	granite block
Dam length	~250 ft
Spillway length	100.6 ft
Spillway crest	EL. 26.8 ft (NGVD 1929)
Flashboard	EL. 27.7 ft (NGVD 1929) (10 inch height)
Structural height	8 ft
Hydraulic height	2.6 to 3.8 ft
Storage capacity	785 acre-ft
Drainage area	125 square miles
Spillway sluice	6 ft wide 4 ft deep with wooden stoplogs

Existing Fishway

A concrete pool and notched weir style fishway is located adjacent to the south dam abutment. The fishway is about 3 ft wide and 60 ft long with a slope of about 0.09 ft/ft. There are ten, 6-ft long pools divided by a weir and vertical slot. A summary of the existing fishway's design is presented in Table 2.

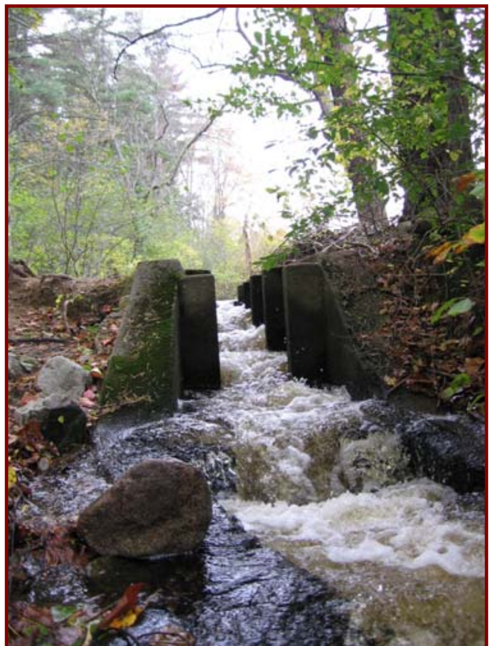


Willowdale Dam Fishway entrance and south abutment

The fishway has been reported to be ineffective at passing fish. The concrete is in poor condition, heavily weathered, spalling, and cracking. There is significant river bank and dam embankment erosion adjacent to the fishway, and the lower fishway section is filled with gravel (DEM 1993). Erosion from the south abutment area likely deposited within the fishway.

Alden's preliminary assessment has identified potential problems with the existing fishway that may contribute to low fish passage efficiencies. In particular, the hydraulics in the fishway may not meet criteria for passing the target species and hydraulic conditions at the fishway entrance may not be adequate for attracting fish. The lower portion of the fishway is submerged at all flows and is filled with gravel. The middle portion overtops under normal flow conditions.

These conditions significantly reduce the fishway entrance flow and velocity making it difficult for fish to find the entrance. The mid and lower portion of the fishway should have higher walls to prevent overtopping and convey water to the fishway entrance. In addition to these issues, rock boulders located upstream of the fishway entrance may be diverting river flow away from the entrance. The boulders may have been placed to fill scour holes undermining the spillway apron that were identified in the 1993 dam inspection report. To alleviate this condition, the boulders in the river channel could be rearranged or the spillway flashboards could be modified to provide greater attraction flow in the vicinity of the existing fishway entrance.



Willowdale Dam Pool and Weir Fishway

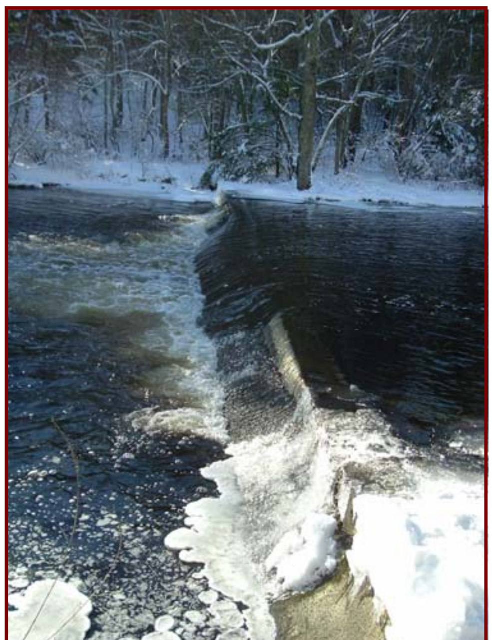
Fish passage at Willowdale may also be hindered by the United States Geological Survey (USGS) gage weir located approximately 150 ft downstream of the dam. The USGS weir may be a barrier to upstream fish movement at low or average river flows.

Table 2 Existing Fishway Design Summary

Type	pool and weir
Width	3 ft
Slope	~ 0.09
Fishway length	60 ft
Pool length	6 ft
Number of pools	10

USGS Gage 01102000

USGS Gage number 01102000 is located approximately 152 ft downstream of the Willowdale Dam. Design drawings, which were dated June 1930, were obtained by Alden from the USGS. The drawings show a 16 ft wide by 3 ft deep notch at the center of the weir. The as-built conditions of the weir as observed by Alden do not include a notch. The weir is a 110 ft long concrete weir with a sloping crest. The center crest elevation is El. 22.5 ft and the ends of the crest are at El. 24.8 ft, as shown on the survey drawings and field verified by Alden on December 14, 2005. The total height of the weir is about 2.5 ft. Historical stream flow data are summarized in the hydraulic and hydrologic section.



USGS Gage 01102000

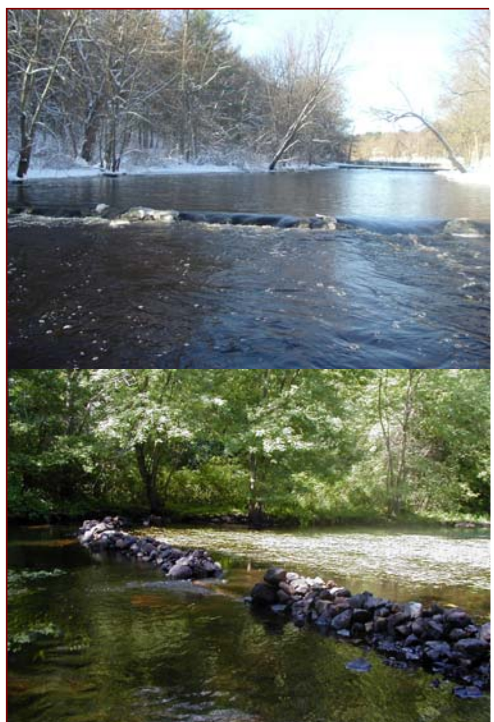
The USGS weir is in fair to poor condition. Concrete is spalling and cracked and has broken off along the crest of the weir. Scour holes were observed upstream and downstream of the weir. Water could be passing under the weir through these scour holes.

The gage is a barrier to fish passage at lower river flows. Alden briefly discussed fish passage issues with the USGS and they were receptive to notching the weir to provide fish passage at lower flows (USGS 2005). USGS indicated that a notch would also improve the accuracy of flow measurements at low river flows.

Table 3 USGS Gage 01102000 Summary

Latitude	42°39'35"
Longitude	70°53'39" NAD27
Type:	Concrete weir with sloping crest
Weir crest elevation, center	22.5 ft
Weir crest elevation, end	24.8 ft
Length:	110 ft
Height:	~2.5 ft
Drainage Area:	
Historic stream flow data:	1930 to present

Rock Weir



Rock Weir

During the December 14, 2005 site survey, Alden personnel discovered a stone wall extending across the entire river width approximately 200 ft downstream of the USGS gage. This stone wall acts like a weir and has a structural height of 1 to 2 ft and a hydraulic height of 0 to 1 ft. The purpose of the weir and the installation date is not known. There are three gaps in the stone wall, with each gap about 3 ft wide. The structure does not appear to create a barrier to fish and was completely submerged during Alden's inspection.

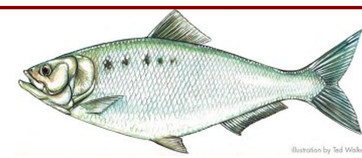
Target Species

The primary species targeted for upstream passage at the Willowdale Dam are alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). Due to their similarity in appearance, life history, and range, alewife and blueback herring often are collectively referred to as river herring. In addition to these species, American eel (*Anguilla rostrata*), sea lamprey (*Petromyzon marinus*) and American Shad (*Alosa sapidissima*) have been observed in the river and would benefit from improved fish passage. River herring, sea lamprey, and American shad are anadromous (i.e., adults spawn in freshwater habitats; juveniles migrate to marine environments where they grow to sexual maturity). American eel are catadromous (adults spawn in the marine environment; the young migrate to freshwater habitats where they grow to sexual maturity).

Alewife and blueback herring and American shad are members of the family Clupeidae (herrings and shads). In Massachusetts, adult Clupeidae migrate from the ocean to freshwater spawning areas from early spring to early summer. After hatching, young-of-the-year fish typically remain in freshwater nursery areas for several months before moving downstream to estuarine and coastal areas. After spending between three to five years in the marine environment, mature adults return to their natal streams and rivers to spawn.

Alewife
Alosa pseudoharengus

Blueback herring
Alosa aestivalis



American Shad
Alosa sapidissima

Sea Lamprey
Petromyzon marinus

American Eel
Anguilla rostrata

Source: PA Boat and Fish Commision

Similar to river herring and American shad, adult sea lamprey move upstream from the ocean to freshwater spawning habitats during the spring. After hatching, the young lamprey (referred to as ammocoetes) spend several years burrowed in stream substrates before they undergo metamorphosis to a parasitic stage and move downstream to the ocean. Sea lampreys reach sexual maturity and return to freshwater habitats to spawn after spending about two to three years in the ocean environment.

American eel are a member of the family Anguilladae, which includes catadromous eel species that occur throughout the world. American eel spawn in the marine environment (the Sargasso Sea), with the young returning to freshwater habitats to grow and mature. Adult American eels begin downstream spawning migrations in the fall (September through November) after spending anywhere from 5 to 25 years in freshwater systems. Outmigrants are typically referred to as silver eels due to their coloration. After reaching the ocean, silver eels travel to the Sargasso sea, where spawning occurs for both American and European eels. After hatching, leptocephalus eel larvae migrate to estuaries along the east coast over a 9 to 12 month period. The leptocephalii transform to the glass eel phase during their ocean migration and become elvers (i.e., pigmented) after reaching estuary environments. Elvers migrate upstream during the fall into freshwater habitats, where they enter the yellow eel phase. Yellow eels remain in freshwater habitats until they are ready to return to the Sargasso Sea to spawn as silver phase adults.

Aquatic Habitat

The Ipswich River is an important economic and ecological asset to northeastern Massachusetts. According to the Ipswich River Management Plan prepared by Horsley and Witten, Inc. (HWI), this small coastal plain river, which flows about 45 miles from headwaters to sea, provides drinking water to over 330,000 residents and thousands of businesses in fifteen northeastern Massachusetts communities (HWI 2003). The Ipswich River watershed has experienced less development and industrialization than nearby watersheds to the north and south, and thus was spared some of the pollution problems which afflicted rivers such as the Merrimack, Nashua, and Charles Rivers. Since the Ipswich River was less polluted than others in the area, it became an important source of drinking water, not only for communities within the watershed, but even more so for neighboring communities along the southern boundary and outside of the watershed. Today, much of the river's water is pumped for municipal water supplies and is being consumed at a rate which has left the river significantly impaired from an ecological standpoint due to the extremely low flows. Approximately 80% of the flow is exported from the watershed, resulting in a significant net loss of water to the river system (HWI 2003).

The Ipswich River appears to have a considerable amount of potential spawning habitat for river herring and American shad. Although there are no sizeable impoundments or ponds, there are many miles of stream habitat upstream of Willowdale Dam that could be utilized by anadromous clupeids for spawning. However, as mentioned previously, a significant amount of flow is withdrawn from the river for municipal water supplies (HWI 2003). These large withdrawals may adversely affect restoration efforts for herring and shad by significantly reducing or impairing available spawning and nursery habitats above the dam.

Willowdale Dam during low flow, photo courtesy of Mass DMF

Key findings from available studies (Ipswich River Watershed Association 2002; HWI 2003; Milone and MacBroom 2004) addressing environmental issues include the following:

- Base flow, the river's flow between precipitation events which is provided by groundwater inflow to the river, is significantly diminished by municipal water withdrawals and the effects of watershed imperviousness.

- Groundwater withdrawals by municipal wells are a major factor in reducing flow volume by more than an order of magnitude in the upper watershed, and by significant amounts basin-wide, during the critical summer/early fall periods.

- A reduction in groundwater storage in the upper watershed occurs due to the presence of impervious surfaces, such as paved areas and buildings, which prevent the replenishment of groundwater aquifers.

- The Ipswich River's species composition has been seriously damaged by the chronic and extreme nature of low-flow/no-flow events, resulting in the loss of flow-dependent fish species.

- Water quality issues and depleted dissolved oxygen have been responsible for several fish kills during low-flow/no-flow periods.

- Critical habitats, including riffles and streambank areas, are the first areas of the river lost when flows diminish; when riffles dry up, the river becomes segmented into a series of isolated pools instead of flowing water.

- A flow regime that approximates the natural hydrograph seasonal variation, with minimum flows in the range of 0.42-0.49 cfs per square mile, would result in sufficient flows to prevent loss of riffles and streambank habitats, and would provide adequate habitat for the protection of fish populations (HWI 2003). However, MMI 2004 indicates that these minimal flow recommendations exceed the current developed watershed stream flow rates and would severely limit the current water supply withdrawals and interbasin transfers.

There are a number of management alternatives that were identified in the available studies to improve flows, including:

- Improve water conservation, achieving reductions in water withdrawals from 20-50%.
- Stop the use of wells in Reading and Wilmington on a seasonal basis (May-October) or when flows fall below 0.50 cfs per square mile. The Towns of Reading and Wilmington just agreed to a water supply from the Massachusetts Water Resources Authority (MWRA).
- Reduce the amount of water transferred out-of-basin via sewers
- A combination of options, such as seasonal reductions in the use of streamside wells and reduction in wastewater exports, which would result in flows at or exceeding simulated "natural" baseline flows.
- The "firm yield" of the reservoir systems supplied by surface water diversions from the Ipswich River would be substantially lower than the amounts currently withdrawn if thresholds for protecting fish populations are used to govern withdrawals.
- Supplement water supplies from out of basin sources.

The studies examining flow and fish issues in the Ipswich River watershed have outlined the need for a basin wide management plan that would address the water supply source, usage and conservation measures to provide the necessary base flows for recreation use, and aquatic habitat and fish passage needs.

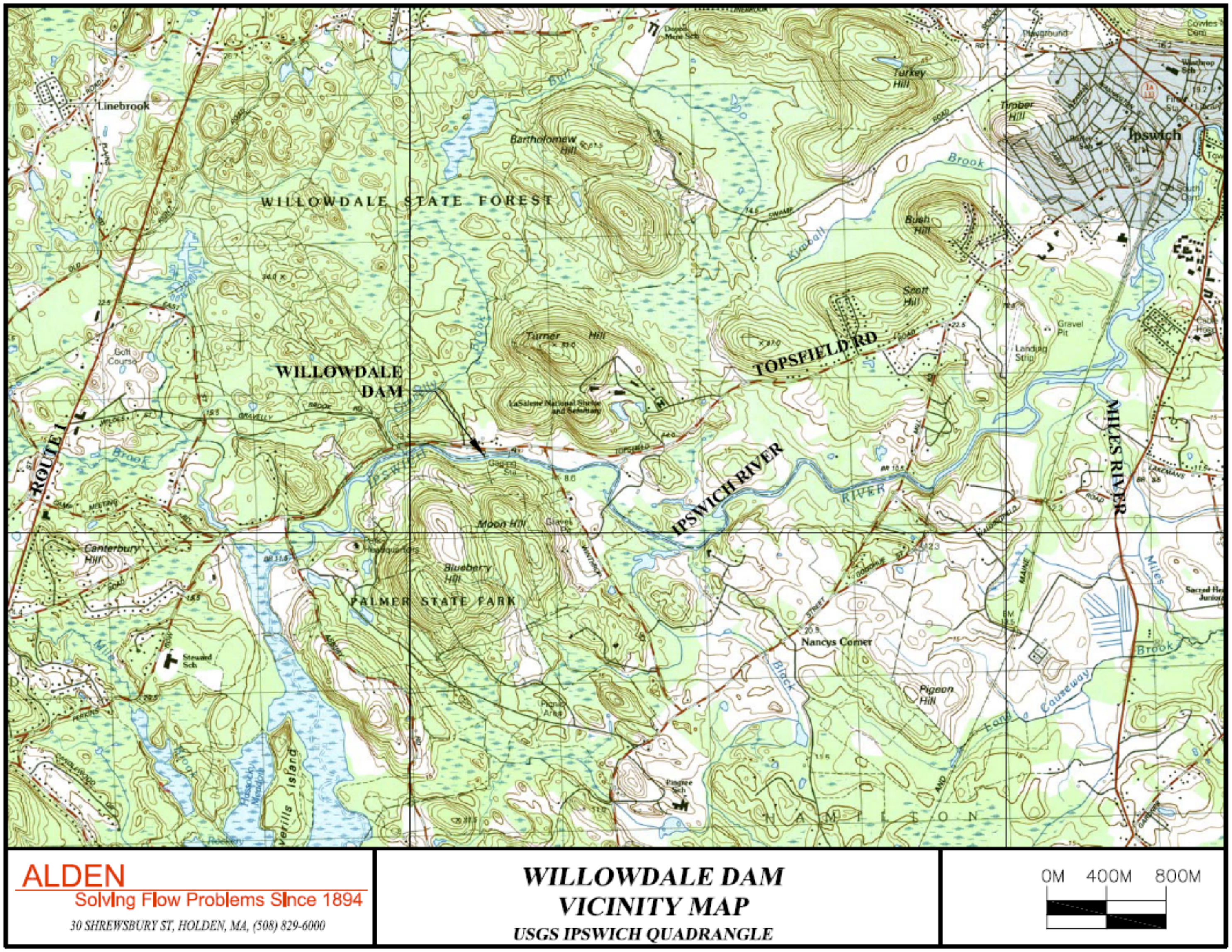


Figure 1 Willowdale Dam Vicinity

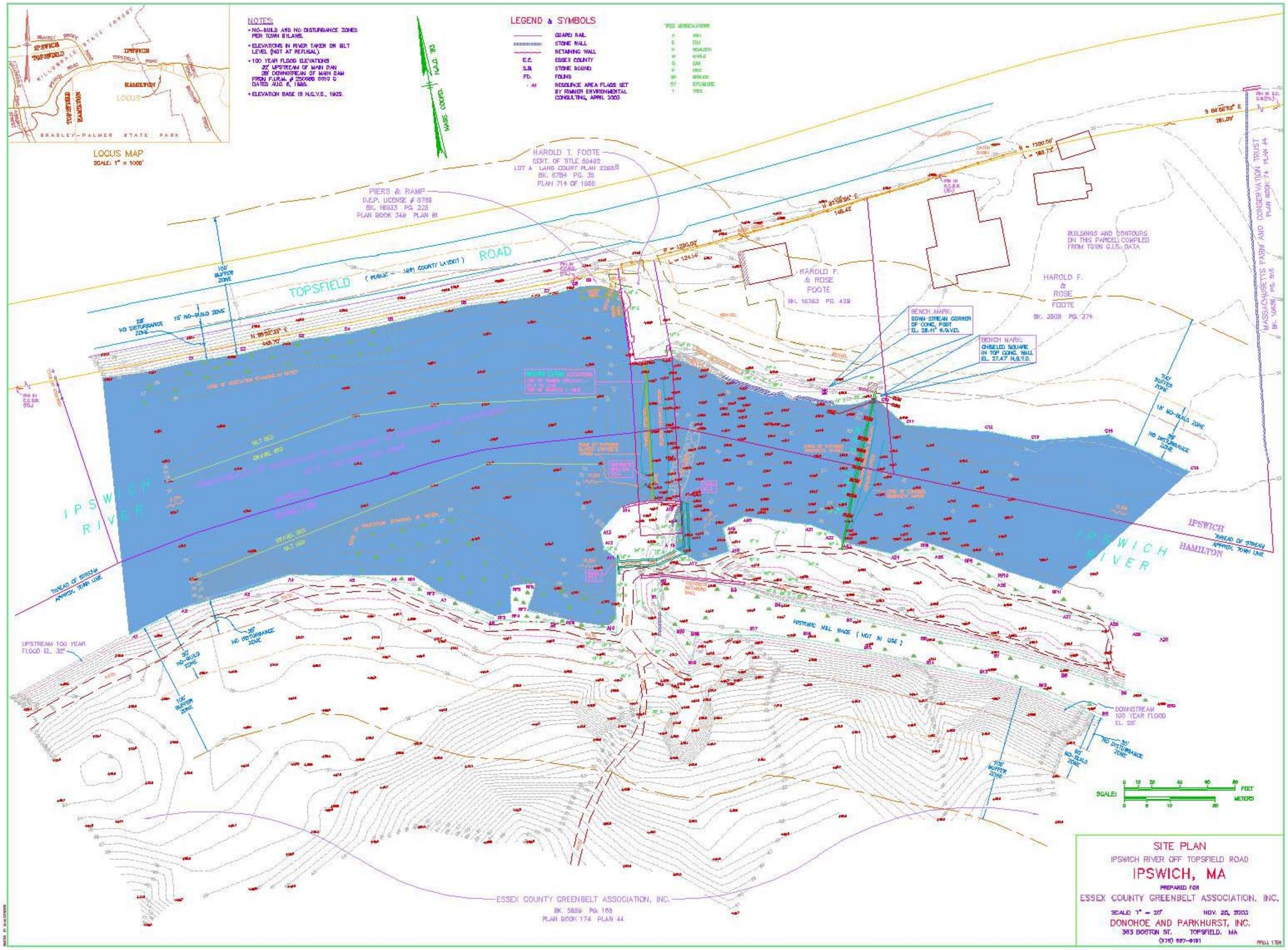


Figure 2 Existing Conditions Survey (Donohoe and Parkhurst 2003)

Dam Safety Inspection

Dam inspections were conducted by the Office of Dam Safety in 2002 (DEM 2002) and July 30, 1993 (DEM 1993). The dam is currently in fair to poor condition (DEM 2002). There is evidence of erosion and overtopping on the south dam embankment and around the existing fishway. There is large tree growth and vegetation on the south dam embankment and spillway abutment area. There is also evidence of leakage through the construction joints in the spillway (DEM 1993). The inspection reports indicate that the spillway abutments overtop during a 25 year discharge and the spillway provides inadequate discharge capacity to pass the 50 year discharge.

Recommendations from the 2002 inspection report include the following:

1. Monitor upstream slope for abnormal scarp or slough developments along right embankment.

2. Monitor crest for surface sinkholes and downstream slope settling or slough.

3. Monitor downstream for excess seepage or piping around spillway abutments, fish ladder, diversion canal, and areas of deep rooted tree growth.

4. Remove unwanted vegetative growth on the structure and toe area

5. Consider right embankment rehabilitation project to minimize adverse overtopping effects.

According to the Office of Dam Safety, the dam should have a Phase I inspection every 10 years and the last Phase I inspection at Willowdale dam was conducted in 1993. Therefore, Willowdale dam is due for a Phase I inspection. The dam owners will be responsible for conducting the inspection and submitting the report to the Office of Dam Safety. The Office of Dam Safety would then review the findings to determine maintenance and repairs that need to be conducted.

SCREENING OF FISH PASSAGE ALTERNATIVES

The first step in the evaluation of fish passage alternatives was to identify options with the greatest potential for effective application at the site. Preliminary fish passage alternatives were discussed with the project partners on January 23, 2006. Following input and comments from the project partners and stakeholders, Alden narrowed the list of alternatives to those with the greatest potential to be biologically effective and practicable to install and operate at Willowdale. The alternatives that were identified as potentially effective and practicable were then subjected to a more detailed conceptual level evaluation in which design, operational, and cost information were developed. Detailed evaluations of the selected alternatives are presented in the next section of this report.

Based on the initial review of alternatives, the following fish passage designs were investigated for fish passage at the Willowdale Dam:

1. Denil fish ladder
2. Bypass channel
3. Rock ramp; and
4. Dam Removal

Several different options or configurations for each of these alternatives were evaluated and the advantages and disadvantages of each are discussed below and summarized in Table 4.

Denil Fish Ladder Options

Alden evaluated three Denil fish ladder options, two located on the southern abutment and one on the northern abutment. One of the ladder options for the south abutment has two entrances, one at the dam and the other extending to the USGS gage (Figure 3). This option results in flow bypassing the USGS gage. The second alternative for a ladder on the south abutment would have a single entrance located upstream of the USGS gage (Figure 4). Both alternatives for the south abutment would be located on and accessed via Essex County Greenbelt Association, Inc. (ECGA) property. The ladder option for the northern abutment would be located on Foote Brothers Inc. property (Figure 5). All three Denil ladder options would require a notch in the USGS gage to allow fish to reach the fishway entrances during low water.

The primary advantages of the Denil fishway options are that they provide passage at the dam and the USGS weir, there would be minimal impact to recreational boating, and head pond water levels are not affected by their operation. Locating a fish ladder on the north abutment may be preferable because there is more flow in this area for attraction of fish to a fishway entrance (i.e., adequate attraction flows for a ladder located on the south abutment may be difficult to achieve). All three ladder options would provide more limited passage for resident fish because Denil ladders were specifically designed for faster swimming fish similar to the target species. Also, downstream canoe passage would not be provided with any of the three options. All the fish ladder designs would require the dam to be notched or a pipe to be added to allow downstream passage of fish under low flow conditions.

Bypass Channel

Two bypass channel options were evaluated for fish passage at the Willowdale Dam. Both alternatives would be located on the south abutment with access through ECGA property. One option would have an entrance located at the base of dam with the exit located at the existing fishway exit (Figure 6). This bypass channel alternative would require notching the USGS gage and would not provide downstream canoe passage at the dam. An alternative would be to remove the gage and relocate river discharge measurements to a new location. The second bypass channel option would have an entrance located at the USGS gage and could include a downstream canoe chute in the center of the ramp (Figure 7). Flow through this option would bypass the USGS Gage.

Both bypass channel options may provide passage to resident fish, would be more aesthetically pleasing than a typical fishway, and would have minimal head pond water level impacts. However, because the bypass channel alternatives would have to be located next to the south abutment, there may be insufficient flow to attract fish to the channel entrances (i.e., most flow at the dam appears to be on the north side). Also, bypass channel design criteria are still being developed for most for fish species being targeted for upstream passage in the Northeast and there is only limited published information regarding effectiveness for upstream passage. Options for providing downstream fish passage for both bypass channel designs during low flow conditions, include notching the dam, installing a bypass pipe, or constructing a low flow impervious thalwag in the center of the bypass channels.

Rock Ramp

Two rock ramp options were considered for application at Willowdale Dam. One option would include a small notch at the center of the existing dam with a ramp extending about 175 ft (30H:1V) or greater downstream (Figure 8). The USGS gage would be removed or covered by the rock ramp and a new gage would be incorporated into the existing dam. The second rock ramp option would involve reducing the spillway height by one foot, which would lower the head pond level at low flows. The ramp would also extend about 150 ft downstream and would require the USGS to use the Willowdale dam for flow measurements (Figure 9).

Both rock ramp options should provide effective upstream passage for most resident fish species and downstream passage for anadromous and catadromous outmigrants. The rock ramps also can be made to look semi-natural and would allow access from both river banks for inspection and maintenance. Disadvantages associated with the use of rock ramps at Willowdale include: (1) a lack of established design criteria for target species and limited published information on passage effectiveness; (2) relocation of the USGS gage; (3) higher costs relative to other options; and (4) modifications to docks owned by Foote Brothers, Inc may be required to reach the pond water edge. Also, to allow downstream passage during low flow periods, the dam will need to be notched or modified to increase flows at the center of a rock ramp.

Dam Removal

Two dam removal options were considered for Willowdale, one with a notch placed in the USGS weir (Figure 10) and the other with the complete removal of the USGS weir. Dam removal would likely have the greatest biological benefit because it would reconnect the upper and lower portions of the Ipswich River allowing unrestricted movement of all aquatic species that may migrate upstream and/or downstream within the watershed, not just the targeted species. Benefits of dam removal include the following:

- Unrestricted fish passage (upstream and downstream) to all riverine species.
- Elimination of operation and maintenance on the existing dam
- Elimination of dam improvements needed to increase spillway capacity and address stability concerns
- Elimination of safety liability to dam owners
- Elimination of the navigation hazard to boating enthusiasts
- Restoration of pre-dam wetland habitat currently inundated by the dam impoundment
- Boater access to river reaches downstream of the dam
- Reduction of flooding potential to Foote Brothers property

Under the current flow regime, the Ipswich River has extremely low flows during the late summer. There is potential for the river to become a segmented series of pools with the removal of the impoundment. This segmentation would adversely affect boating opportunities during the late summer months. However, the towns of Wilmington and Reading are pursuing alternative water supplies, which would increase the Ipswich River low base flow conditions. Under an improved flow regime, impacts to boating would be reduced with removal of the dam because of access to the downstream reaches of the river.

Preliminary Alternatives Selected for Detailed Evaluation

Based on the review of available fish passage options presented above, Alden has determined that the following alternatives have the greatest potential for effective application at Willowdale Dam:

- A 2.5 ft wide Denil fishway with a single entrance on the south abutment (Figure 4).
- A bypass channel on the south abutment with a single entrance at the base of the dam (Figure 6).
- Modified spillway and a rock ramp that extends past the USGS weir (Figure 9).
- Dam removal (Figure 10).

Alden also evaluated a “No Action” alternative describing fish passage conditions if a fishway is not installed or the dam is not removed. The engineering, construction, operational considerations, and costs for each of the selected alternatives and the “No Action” alternative are discussed in the following sections.

Table 4 Fish Passage Options at Willowdale Dam

Fish Passage Alternative	Description	Advantages	Disadvantages	Chosen for detailed evaluation at Willowdale Dam?
Denil fishway on south abutment, with 2 entrances	A 2.5 ft wide Denil ladder on south abutment with two entrances, one at the dam and the other extending to the USGS gage. Includes notching USGS gage. Figure 3	➢ Provides passage at the dam and the USGS weir ➢ Minimal impact to existing recreational boating ➢ Does not affect head pond water levels ➢ Located on and access over Essex County Greenbelt Association, Inc. property	➢ Attraction flow on south bank limited. Majority of river flow appears to be on north bank ➢ Provides limited passage of resident fisheries ➢ Fish ladder flow bypasses USGS gage ➢ Does not provide downstream canoe passage	NO
Denil fishway on the south abutment in general location of existing fish ladder.	A 2.5 ft wide Denil ladder on south abutment with one entrance, near the existing fishway entrance. Includes notching USGS gage. Figure 4	➢ Low costs relative to other options ➢ Does not impact head pond water levels ➢ Flow does not bypass USGS gage ➢ Small footprint compared to other options ➢ Located on and access over Essex County Greenbelt Association, Inc. property	➢ Poor attraction flow on south bank. Majority of flow appears to be on north bank. ➢ Provides limited passage of resident fish ➢ Does not provide downstream canoe passage	**YES**
Denil fishway on the north abutment on Foote Brothers Inc. property.	A 2.5 ft wide Denil ladder on north abutment with one entrance. Includes notching USGS gage. Figure 5	➢ Favorable attraction flow on north bank ➢ Low costs relative to other options ➢ Flow does not bypass USGS gage ➢ Does not affect head pond water levels ➢ Small footprint compared to other options ➢ Location on and access over Foote Brothers Inc. property	➢ Provides limited passage of resident fisheries ➢ Located on Foote Brothers Inc. property ➢ Does not provide downstream canoe passage	Not chosen for this evaluation but has several advantages and could be pursued as an alternative to the south Denil option.

Fish Passage Alternative	**Description**	**Advantages**	**Disadvantages**	**Chosen for detailed evaluation at Willowdale Dam?**
Bypass channel located on south abutment. with an entrance located at base of dam	Rock weir type fishway on the south abutment constructed to look "natural". Would require a flow control weir at the exit Figure 6	➢ May provide passage to resident fish ➢ Aesthetically pleasing, channel made to look semi-natural ➢ Minimal head pond water level impacts. ➢ Located on and access over Essex County Greenbelt Association, Inc. property	➢ Poor attraction flow on south bank. Majority of flow appears to be on north bank. ➢ Does not provide downstream canoe passage ➢ Bypass channel design criteria are still in the developmental stages. Limited published information regarding effectiveness.	**YES**
Bypass channel located on south abutment. with an entrance located at the USGS gage	Rock weir type fishway on the south abutment constructed to look "natural". Would require a flow control weir at the exit. A downstream canoe chute could be included in the center of the ramp Figure 7	➢ May provide passage to resident fish ➢ Aesthetically pleasing, channel made to look semi-natural ➢ Minimal head pond water level impacts ➢ Provides downstream canoe passage ➢ Located on and access over Essex County Greenbelt Association, Inc. property	➢ Bypass channel design criteria are still in the developmental stages. Limited published information regarding effectiveness. ➢ Bypass channel flow bypasses USGS gage ➢ Potential for fish to become trapped upstream of gage	NO
Rock ramp at the existing dam height	Rock ramp extending full width of river extending past theUSGS gage, which, would be removed or covered by ramp. New gage would use the existing dam for flow measurements. Center of ramp could include a downstream canoe chute. Figure 8	➢ May provide passage to resident fish ➢ Aesthetically pleasing, made to look semi-natural ➢ Provides downstream canoe passage ➢ Minimal impacts to head pond water levels ➢ Access from both river banks	➢ May require modifications to Foote Brothers Inc. docks to reach pond water edge ➢ Rock ramp design criteria are still in the developmental stages. Limited published information regarding effectiveness. ➢ Relocation of USGS gage ➢ High costs relative to other options ➢ Reduces discharge capacity and increases flood water levels	NO

Fish Passage Alternative	**Description**	**Advantages**	**Disadvantages**	**Chosen for detailed evaluation at Willowdale Dam?**
Reduce the spillway height and construct a rock ramp	Dam would be reduced by 0.5 to 1.5 ft with ramp extending 175 ft downstream. New gage would use dam for flow measurements. Center of ramp could include a downstream canoe chute and low flow channel. Figure 9	➢ May provide passage to resident fish ➢ Aesthetically pleasing, channel made to look semi-natural ➢ Provides downstream canoe passage ➢ Access from both river banks ➢ Does not decrease discharge capacity ➢ Does not increase flood water levels	➢ Impoundment water level is lowered by 1.5 ft at extreme low flows ➢ May require modifications to Foote Brothers Inc. docks to reach pond water edge ➢ Rock ramp design criteria are still in the developmental stages. Limited published information regarding effectiveness. ➢ Relocation of USGS gage ➢ High costs relative to other options	**YES**
Dam breach	Remove entire dam from south abutment to the north abutment and removal of the USGS weir. Site would be graded to original pre-dam conditions. Figure 10	➢ Reconnects upper and lower portions of the Ipswich River to all aquatic species, not just the targeted fish. ➢ Eliminates operation and maintenance for dam ➢ Eliminates dam improvements needed to address stability and spillway capacity ➢ Eliminates safety liability to dam owners ➢ Eliminates navigation hazard to boaters ➢ Restores pre-dam wetland habitat ➢ Provides boaters access to downstream river reaches ➢ Reduces flooding potential to Foote Brothers property	➢ Loss of impoundment, impacting recreational boating activities ➢ New river channel has potential to become segmented series of pools during extreme low water. (this risk is expected to diminish with recent agreements for new water supply for the towns of Reading and Wilmington) ➢ May directly impact Foote Brothers Inc. business	**YES**

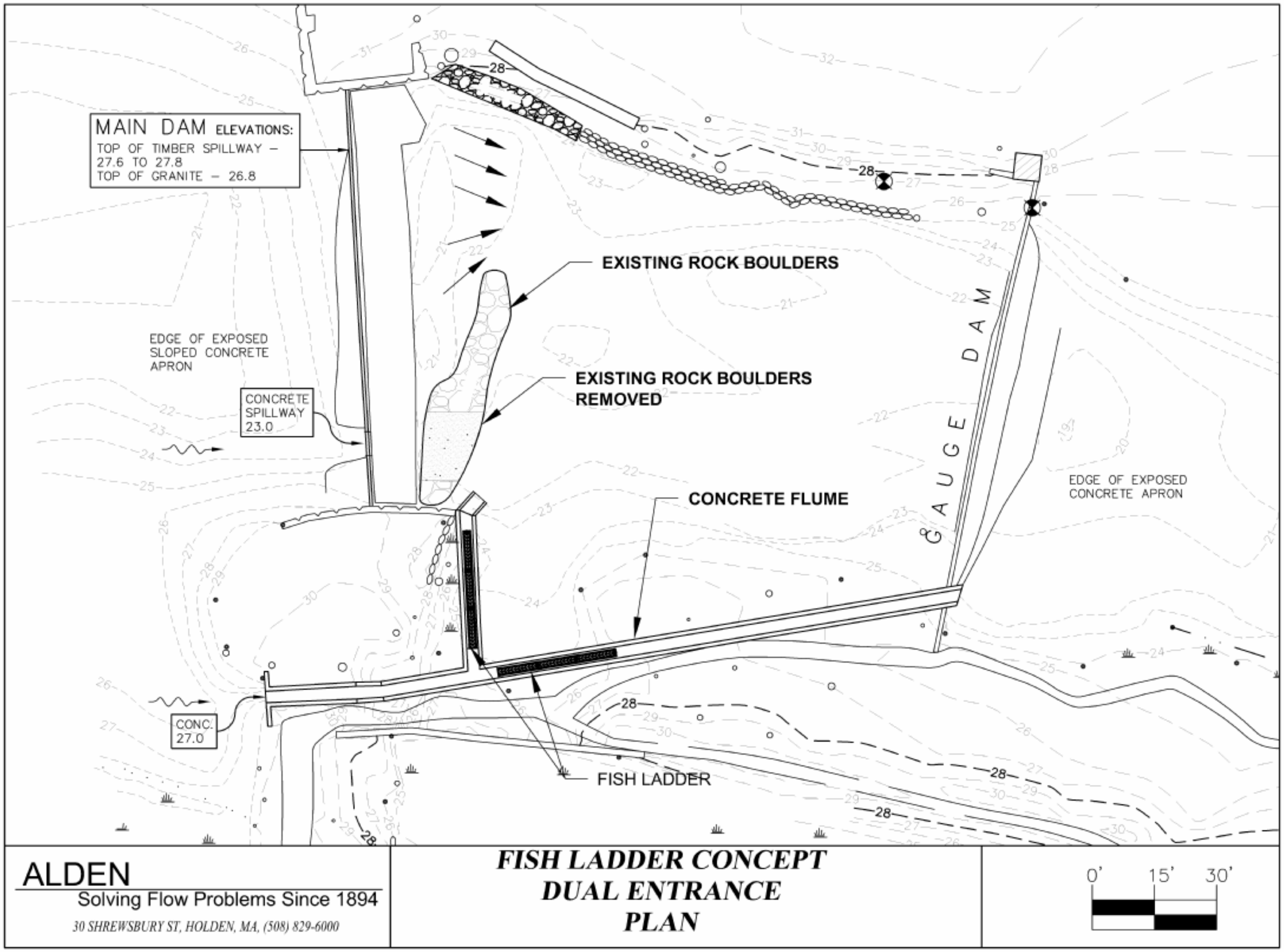


Figure 3 Fish Ladder Concept, Dual Entrance

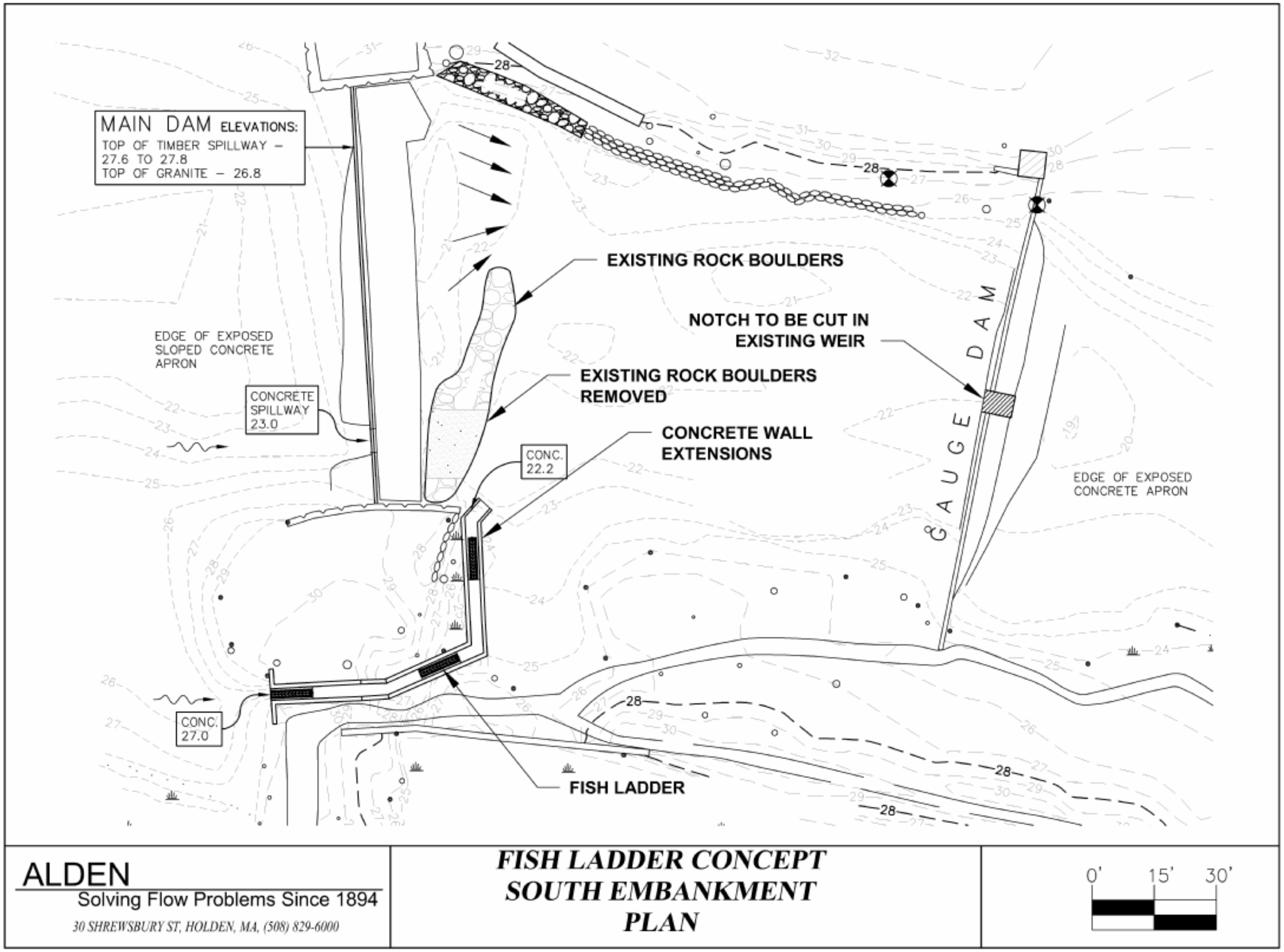


Figure 4 Fish Ladder Concept, South Embankment

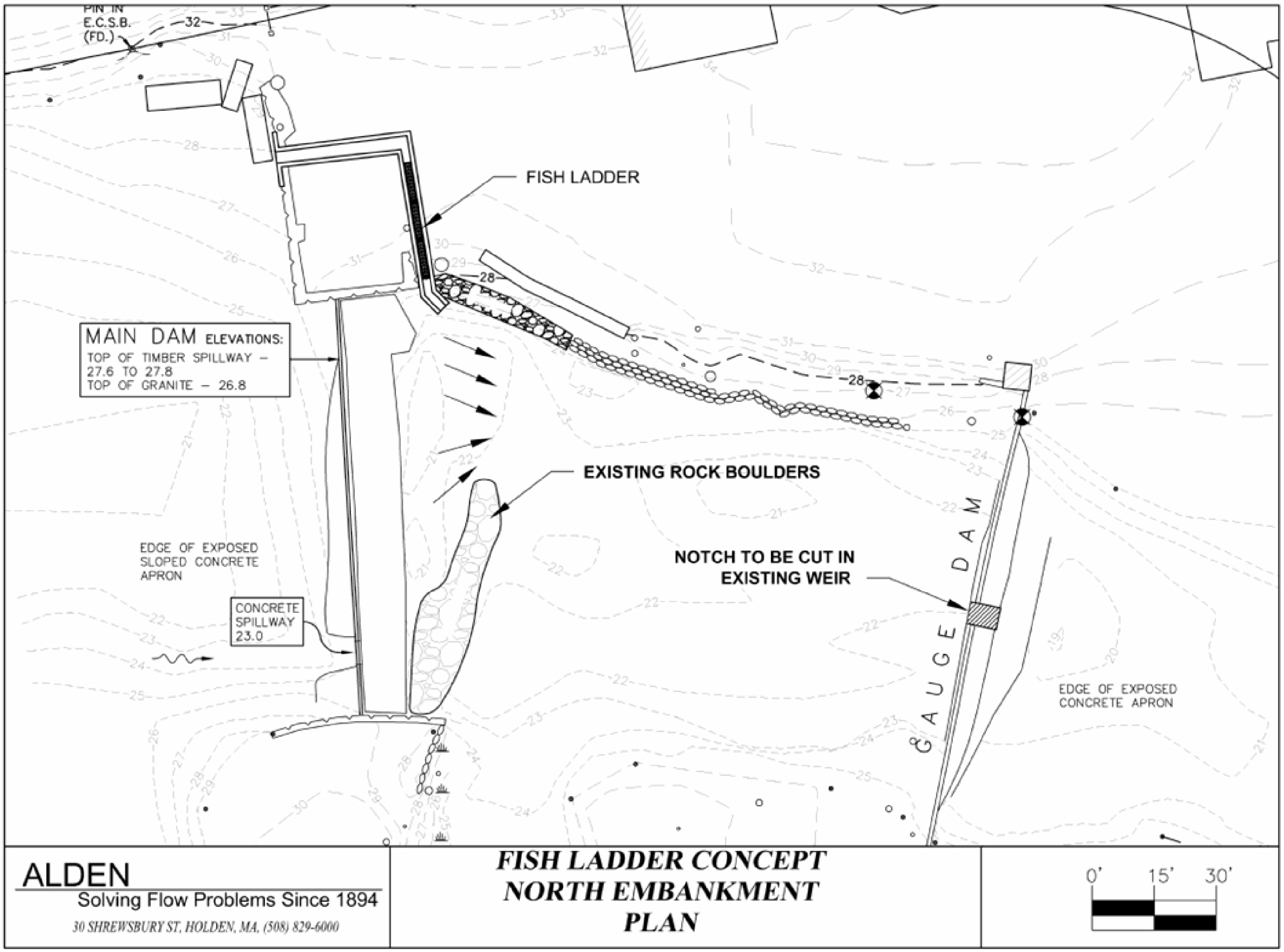


Figure 5 Fish Ladder Concept North Embankment

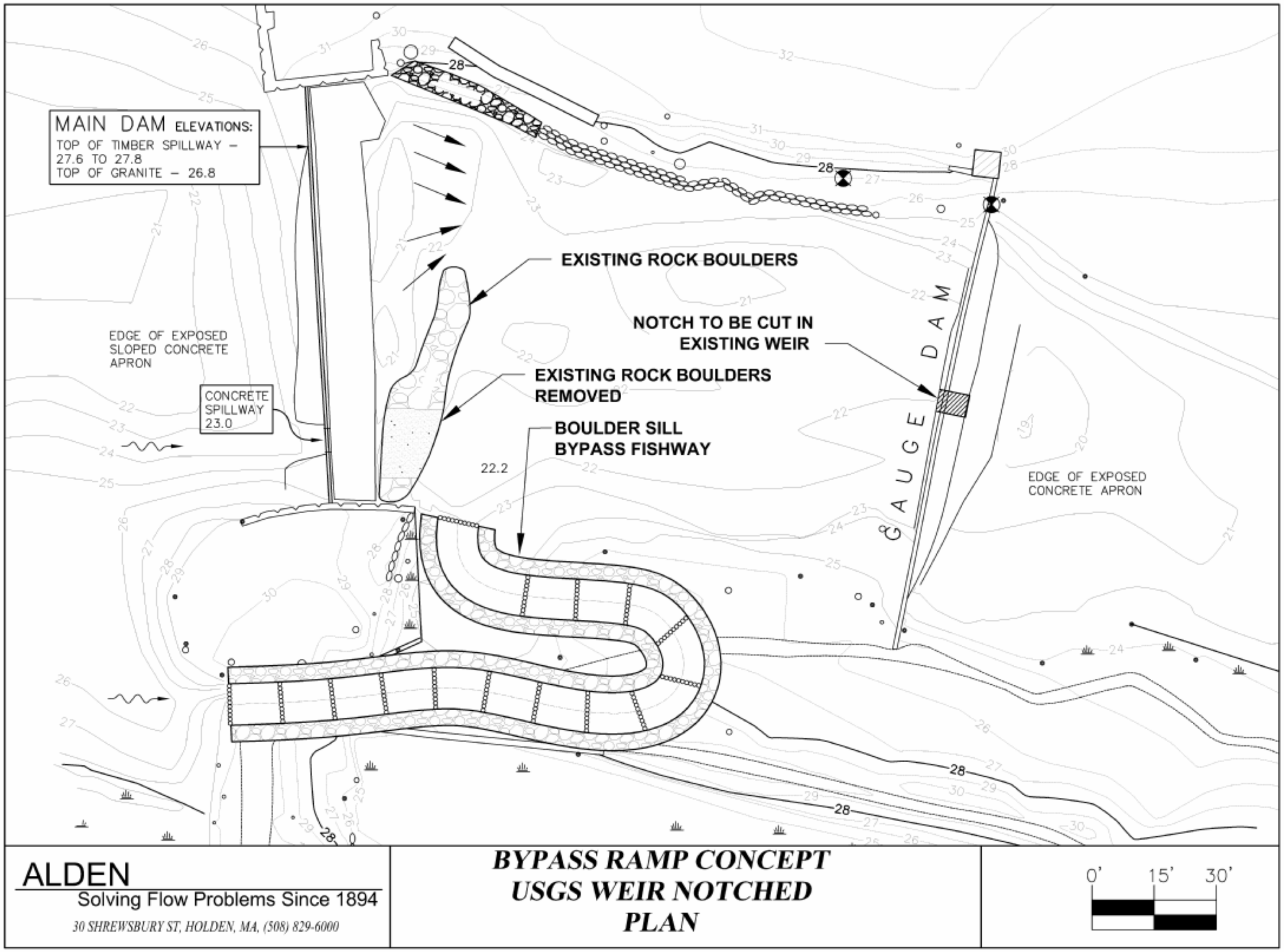


Figure 6 Bypass Ramp Concept

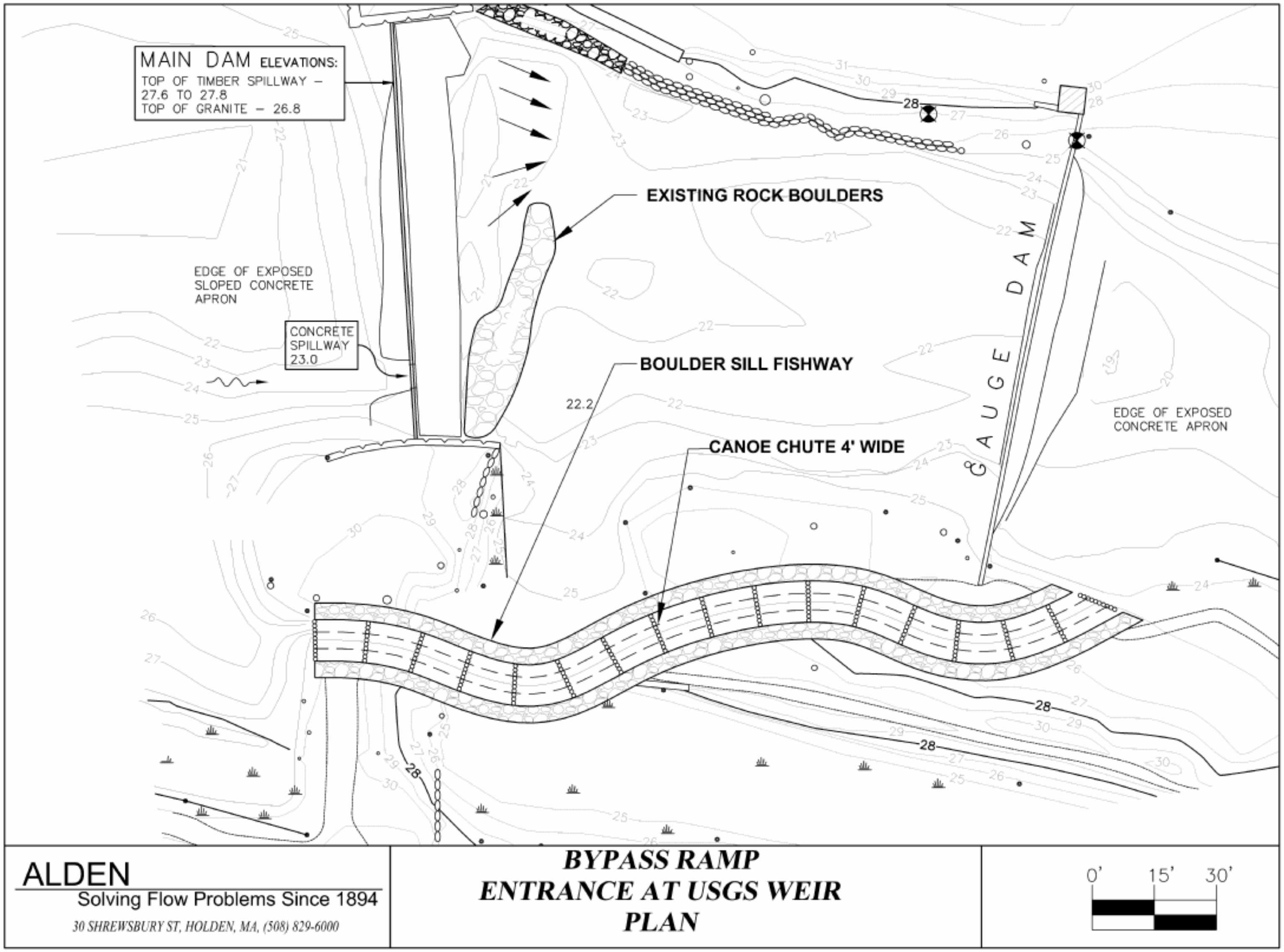


Figure 7 Bypass Ramp Concept, Entrance at USGS Weir

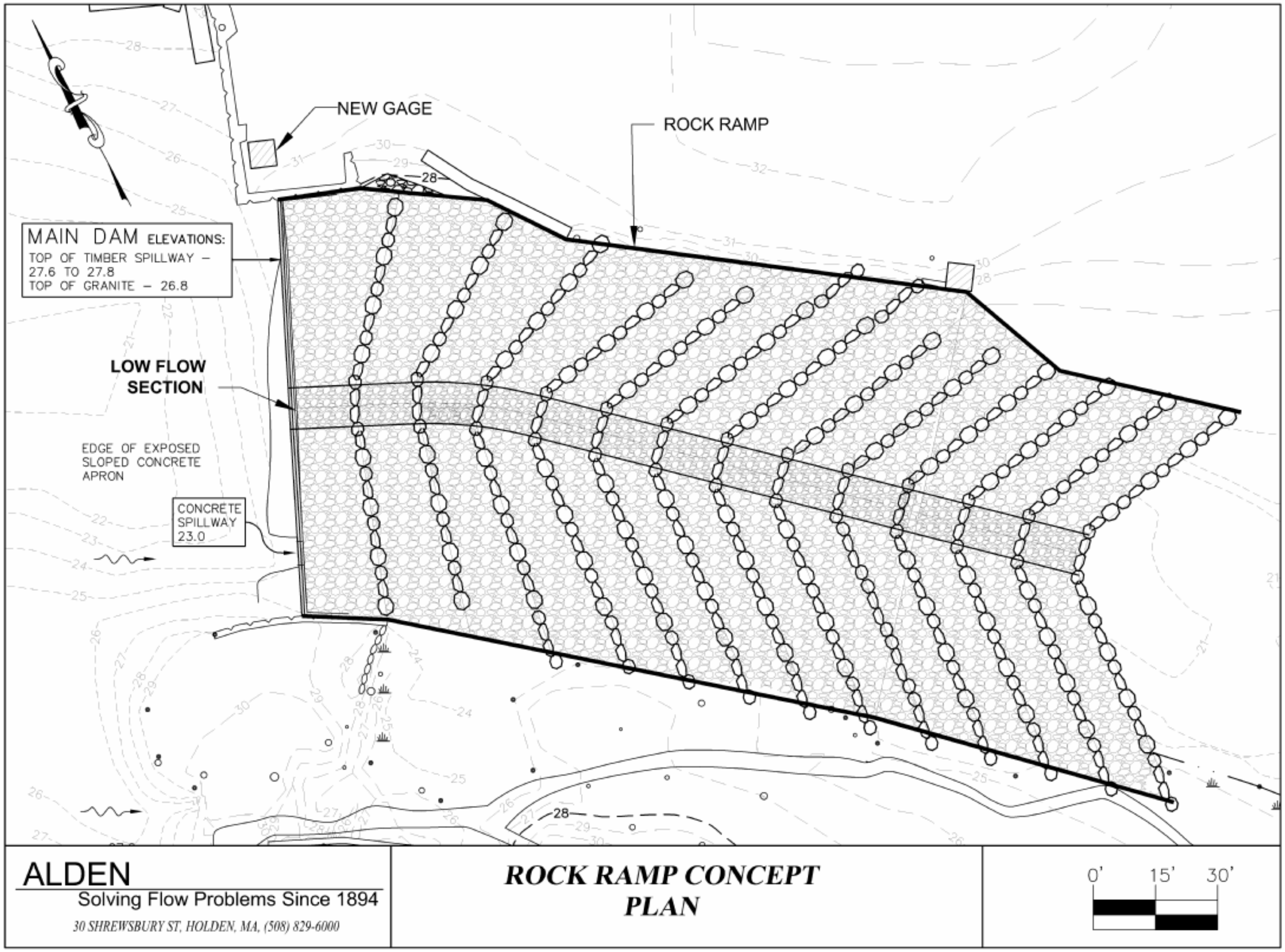


Figure 8 Rock Ramp Concept

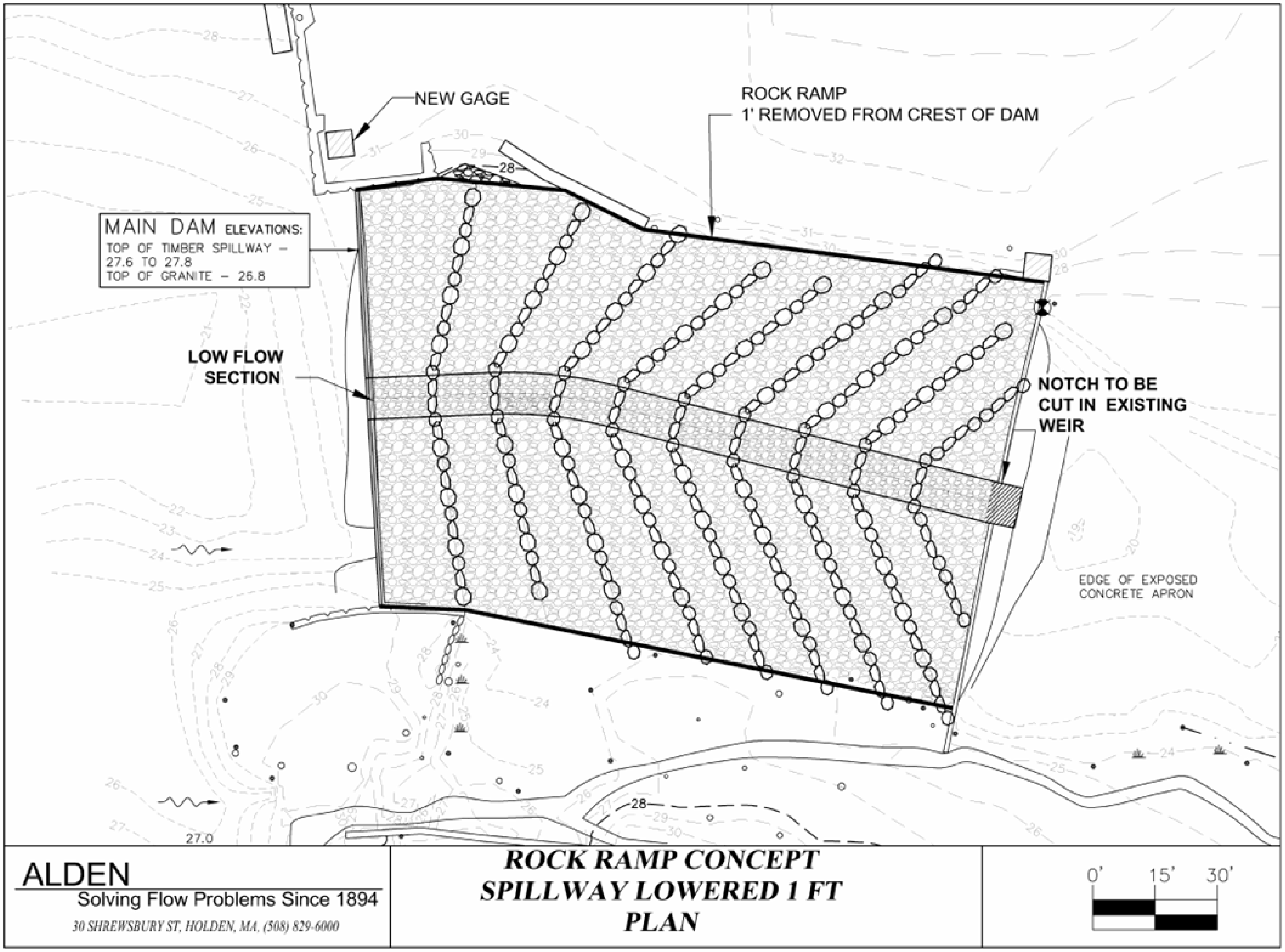


Figure 9 Rock Ramp Concept, Lowered Spillway by 1 ft

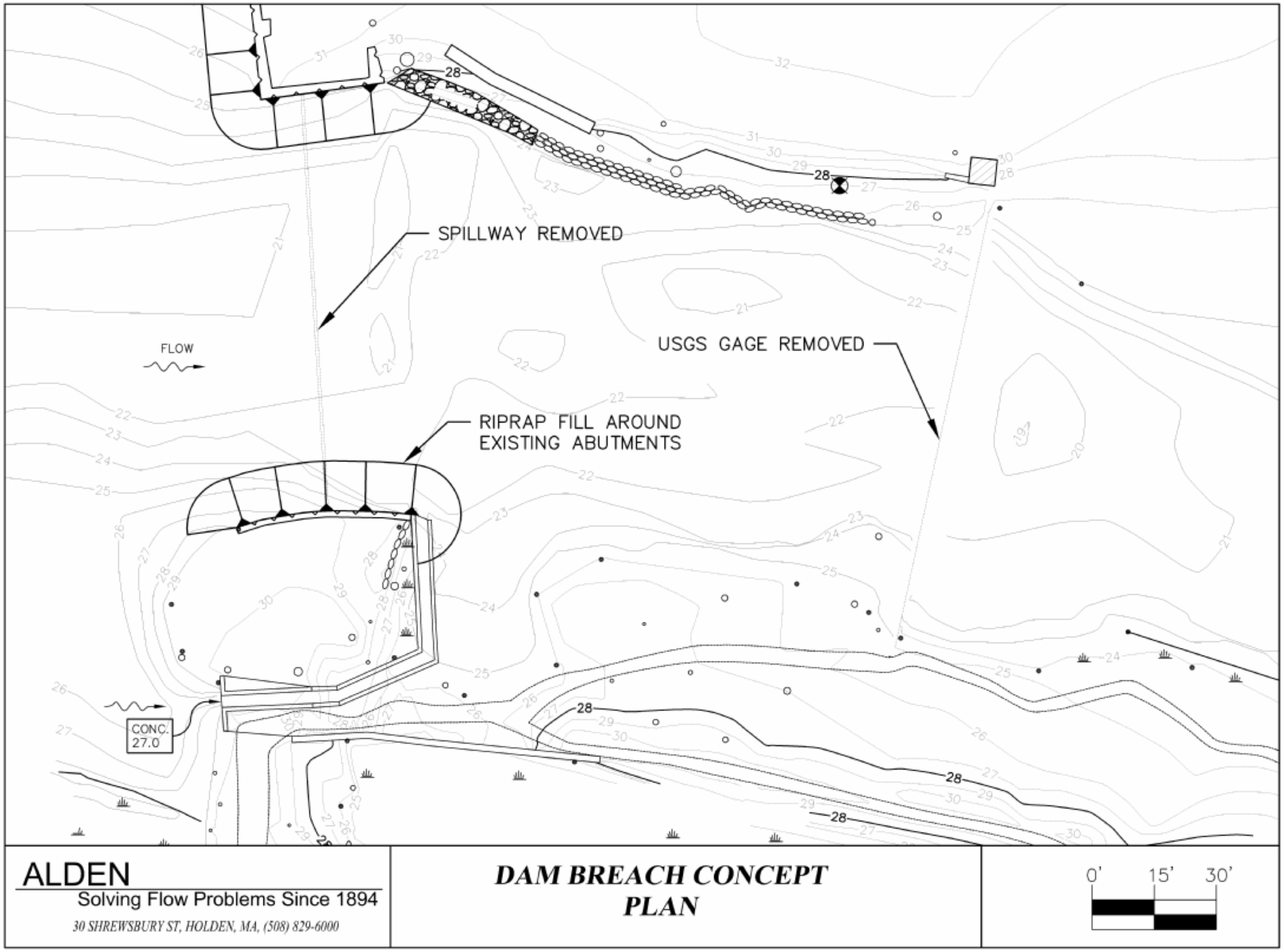


Figure 10 Dam Breach Concept

HYDROLOGY AND HYDRAULIC ANALYSIS

Hydrology

The historic daily stream flow data for USGS Gage Number 01102000 were reviewed and analyzed to determine design river flow rates and water levels during the fish migration periods. The USGS gage is located approximately 150 ft downstream of Willowdale Dam. The spring migration period (March through June) flow rates are used to define upstream fish passage design flow rates. The out-migration period (August through November) flow rates dictate downstream fish passage design flow rates. Peak river flow rates are used to compare hydraulic analysis results to existing flood water level data and determine maximum velocities and water levels for design of structures to withstand flood flows. A summary of Ipswich River flow rates are presented in Table 5.

USGS Gage 01102000 has a watershed area of 125 square miles and 73 years of historic daily stream flow data (June 17, 1931 to September 30, 2004). The average daily stream flow rate for this period is 188 cfs. The minimum flow rate of 0.6 cfs occurred on September 21st through 22nd 1978. The maximum daily flow recorded of 3,520 cfs occurred on April 8th 1987. However, recent real time flow of 4,520 cfs was recorded on May 17, 2006. An annual flow duration curve for the Ipswich River at Willowdale Dam is shown on Figure 11. Future low flows for the Ipswich River are expected to increase due to the expected new source of water supply for the Towns of Reading and Wilmington.

Fish Passage Design Flows

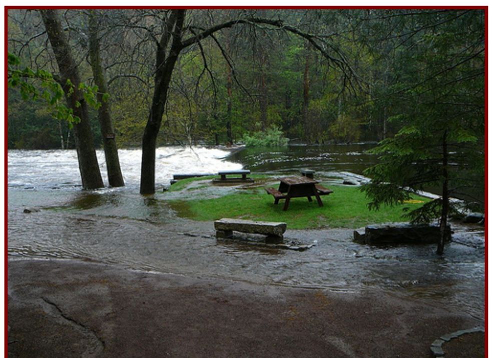
The U. S. Fish & Wildlife Service (USFWS) recommends a design high flow of 4 to 5 times the average flow during the spring (March-June) migration period for upstream passage. The average flow rate during the spring migration period is 319 cfs, therefore the design high flow rate was chosen as 1,597 cfs (5 times the average). The spring migration flow rates range from a minimum of 5.8 cfs (June 30, 1999) to 3,520 cfs (April 8, 1987). Due to the frequency of extreme low flows in the Ipswich River, the design low flow rate for upstream passage was chosen as the lowest flow practical for effective operation of the fish passage alternative. Therefore, Alden chose a flow rate of 10 cfs (99.8% exceedance) for the design low flow for upstream passage. This flow (10 cfs) is the minimum needed for effective operation of a fish bypass channel, rock ramp and Denil fish ladder. A flow duration curve for the Ipswich River at Willowdale dam for the spring migration period is shown on Figure 12.

Ipswich River discharges are much lower during the fall out-migration period between August and November and have diminished to a near zero flow during recent years. During periods of virtually no flow, the river dries up and becomes segmented consisting of isolated pools between riffles. The downstream fish passage options must be designed to provide downstream fish movement during extreme low flow events. The average Ipswich River flow rate during the out-migration period is 73 cfs, the minimum is 0.6 cfs, and the maximum is 3,070 cfs. A flow rate of 3 cfs (a 95% exceedance value) was selected by Alden as the design low flow rate for downstream passage to maintain a minimum water depth in a downstream fish passage system. A flow duration curve for the Ipswich River during the out-migration period is shown on Figure 13.

Peak Flows

The Federal Emergency Management Agency (FEMA) performed a hydrologic analysis of the Ipswich River for the Towns of Topsfield and Ipswich. These studies were summarized in Flood Insurance Studies (FIS) dated February 5, 1985 for Ipswich (FEMA 1985) and June 2, 1994 for Topsfield (FEMA 1992). The peak discharges used for the hydrologic analysis for the Ipswich FIS study are 1,756, 2,490, 2,822 and 3,644 cfs for the 10, 50, 100 and 500 year discharges, respectively. However, the FIS conducted for Topsfield, which was revised in 1994, lists peak discharges as 1,880, 2,700, 3,070 and 3,980 cfs for the 10, 50, 100 and 500 year discharges respectively. The FIS conducted for Topsfield is more recent (1994) and may reflect urbanization and changes in stream diversion flow from Howlett Brook to Mile Brook.

Near Willowdale Bridge May 2006 Flood



Willowdale Dam May 15, 2006 Flood

In May, 2006 the Ipswich River experienced heavy flooding from extensive precipitation for several days. Northeastern Massachusetts rainfall totals from May 12 to May 16 totaled 10 to 15 inches and the Ipswich River reached record flood stage levels (USGS 2006). The Town of Ipswich was partially flooded with many roads and bridges impassable. Four bridges were closed for repairs including the historic Choate Bridge. The pictures below show the conditions at the dam and at Willowdale Bridge on May 15, 2006. The real time flow rate from USGS gage 01102000 at the time of the picture was approximately 3,740 cfs and peaked at approximately 4,520 cfs at 7:00 pm on May 16, 2006. The peak flow of 4,520 cfs was the highest ever recorded by USGS since 1930 and represent a 150 year flood reoccurrence (USGS 2006). Real time flow data downloaded from the USGS website for the May 2006 flood is presented on Figure 14.

Alden performed a flood frequency analysis of peak discharges in the Ipswich River for water years 1930 to 2006 to reflect the period of record to date. The analysis included the recent May 2006 peak discharge of 4,520 cfs. Alden calculated peak discharges of 2,309 cfs, 3,696 cfs, 4,381 cfs, and 6,219 cfs for the 10, 50, 100 and 500 year flood frequency discharges, respectively. The new 100 year reoccurrence discharge has increased by approximately 56% from the 1994 FEMA values. The increase can be attributed to the floods that have occurred since 1994, including the May 2006 flood.

Table 5 Ipswich River Hydrology Summary at Willowdale Dam

Annual Daily Discharge Statistics

Average	188 cfs
Minimum	0.6 cfs (September 21-23, 1978)
Maximum	3,520 cfs (April 8, 1987)

(peak realtime maximum: 4,520 cfs, May 16, 2006)

Ipswich River Peak Discharges	FEMA 1985	FEMA 1994	Alden 2006
10 year	1,756 cfs	1,880 cfs	2,309 cfs
50 year	2,490 cfs	2,700 cfs	3,696 cfs
100 year	2,822 cfs	3,070 cfs	4,381 cfs
500 year	3,643 cfs	3,980 cfs	6,219 cfs

Spring Migration Period Discharges (March through June)

Minimum	5.8 cfs (June 30, 1999)
Design low	10 cfs (99.8% exceedance)
Average	319 cfs
Design high	1,595 cfs (5 times the average)
Maximum	3,520 cfs (April 8, 1987)

Fall Migration Period Discharges (August through November)

Minimum	0.6 cfs (September 21-23, 1978)
Design Low	3 cfs (95% exceedance)
Average	73 cfs
Maximum	3,070 cfs (October 23, 1996)

Head Pond Water Levels without flashboards

Low water level	El. 26.9 ft NGVD 29 (10 cfs)
Normal water level	El. 27.5 ft NGVD 29 (188 cfs)
Design high level	El. 29.7 ft NGVD 29 (1,597 cfs)

Tailwater Levels

Low water level	El. 23.2 ft NGVD 29 (10 cfs)
Normal water level	El. 25.0 ft NGVD 29 (188 cfs)
Design high level	El. 27.2 ft NGVD 29 (1,597 cfs)

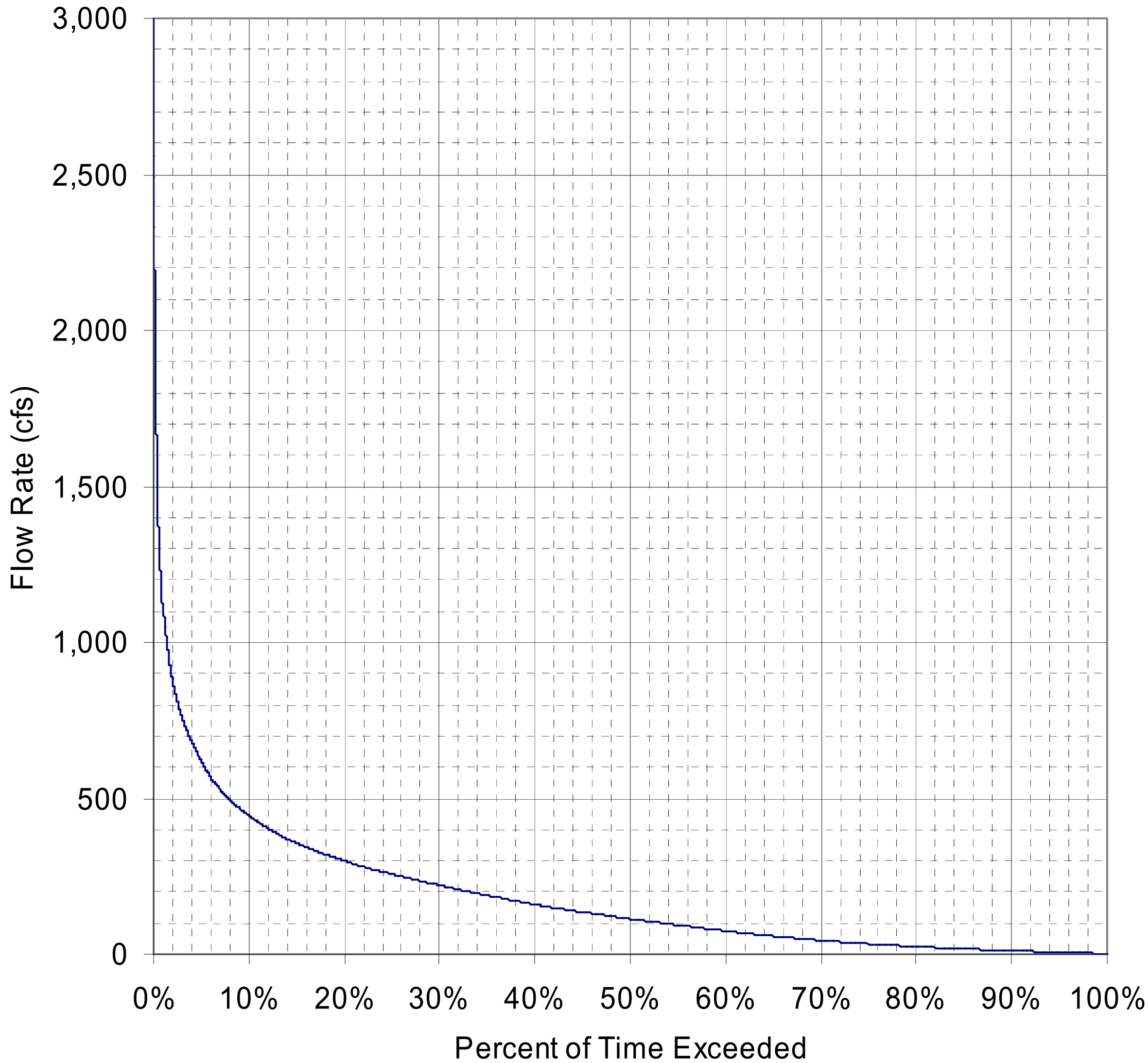


Figure 11 Ipswich River Annual Flow Duration Curve (USGS Gage #01102000 1930-2004)

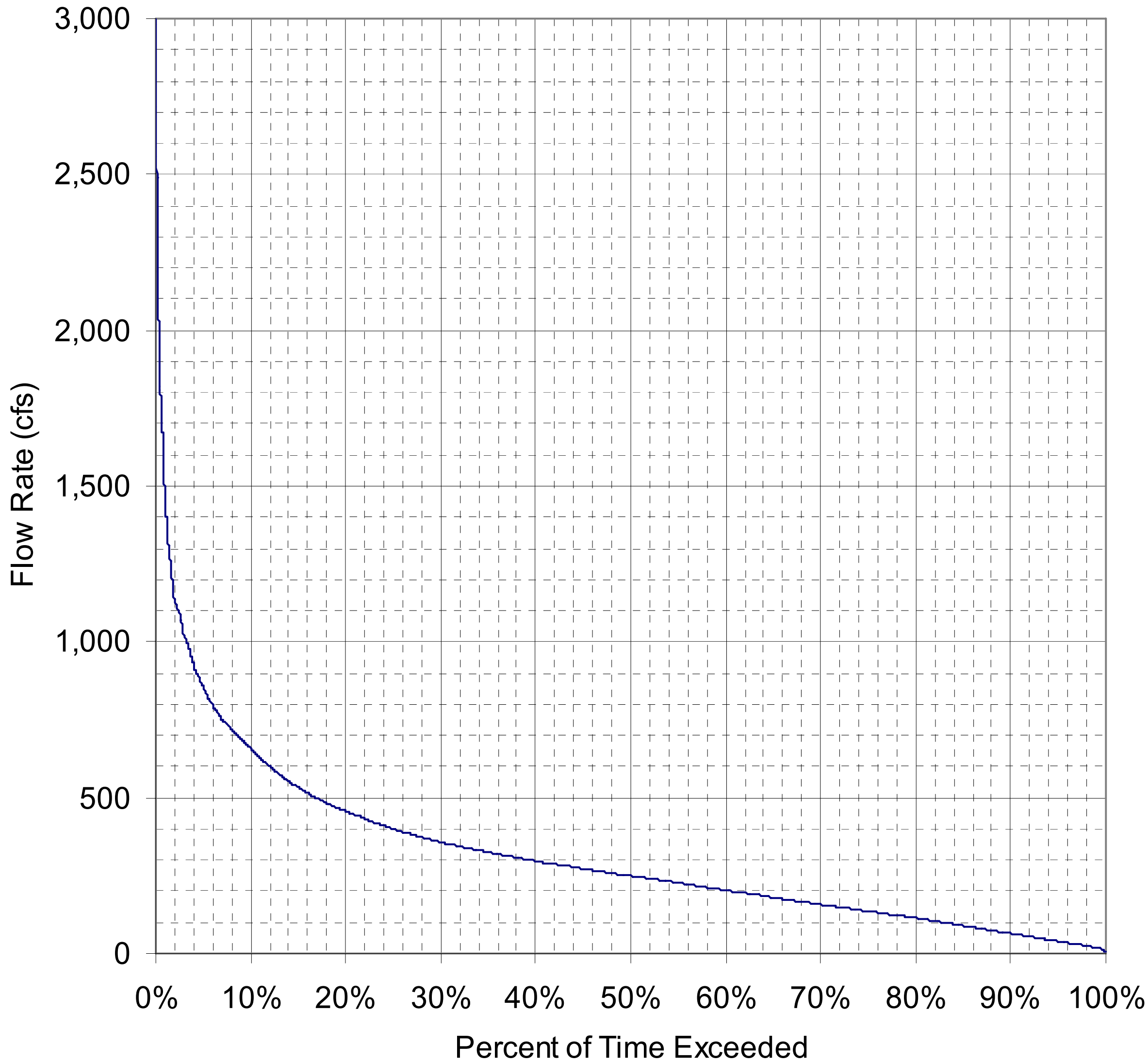


Figure 12 Ipswich River Flow Duration Curve March through June (USGS Gage #01102000 1930-2004)

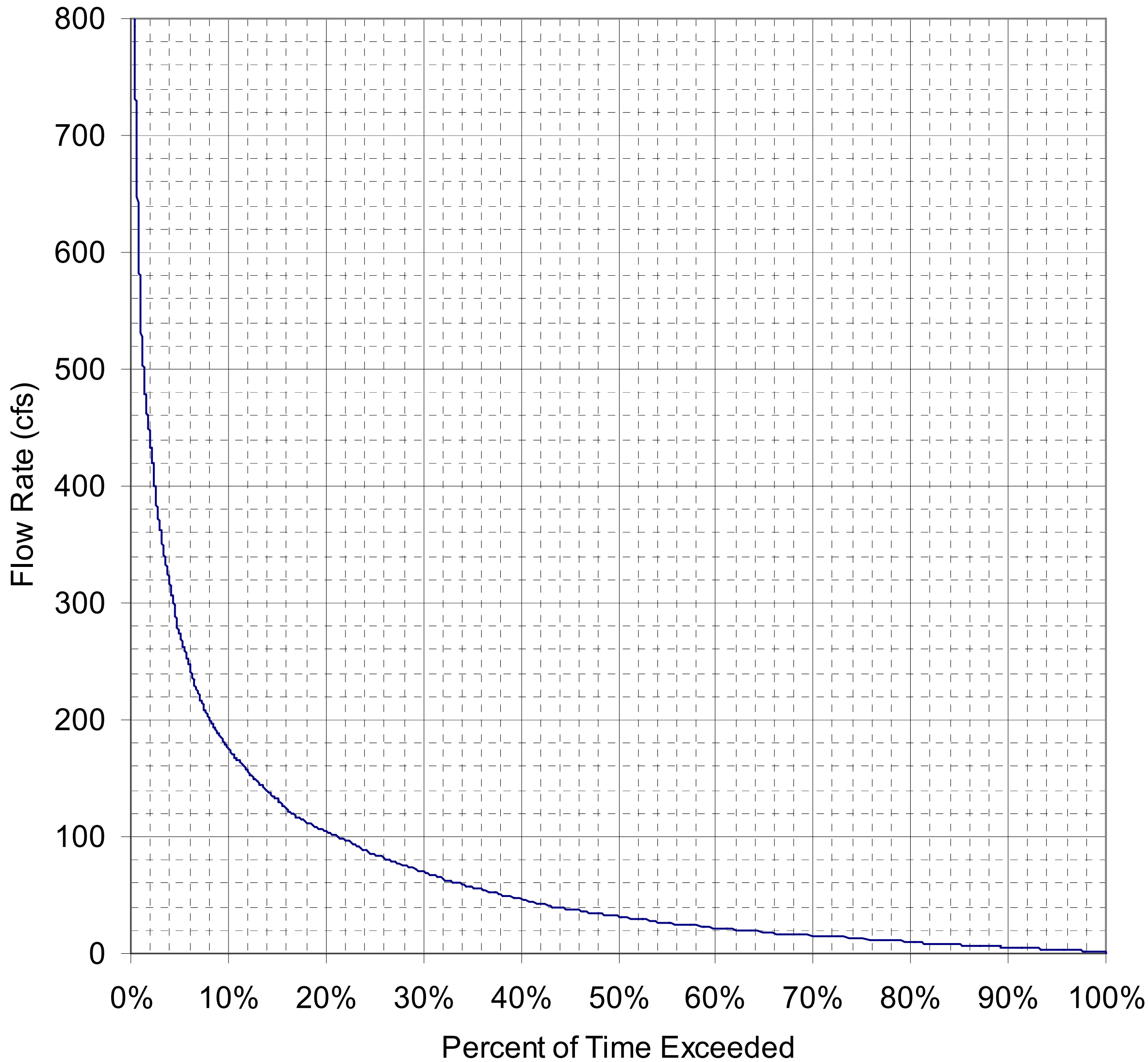


Figure 13 Ipswich River Flow Duration Curve, August through November (USGS Gage #01102000 1930-2004)

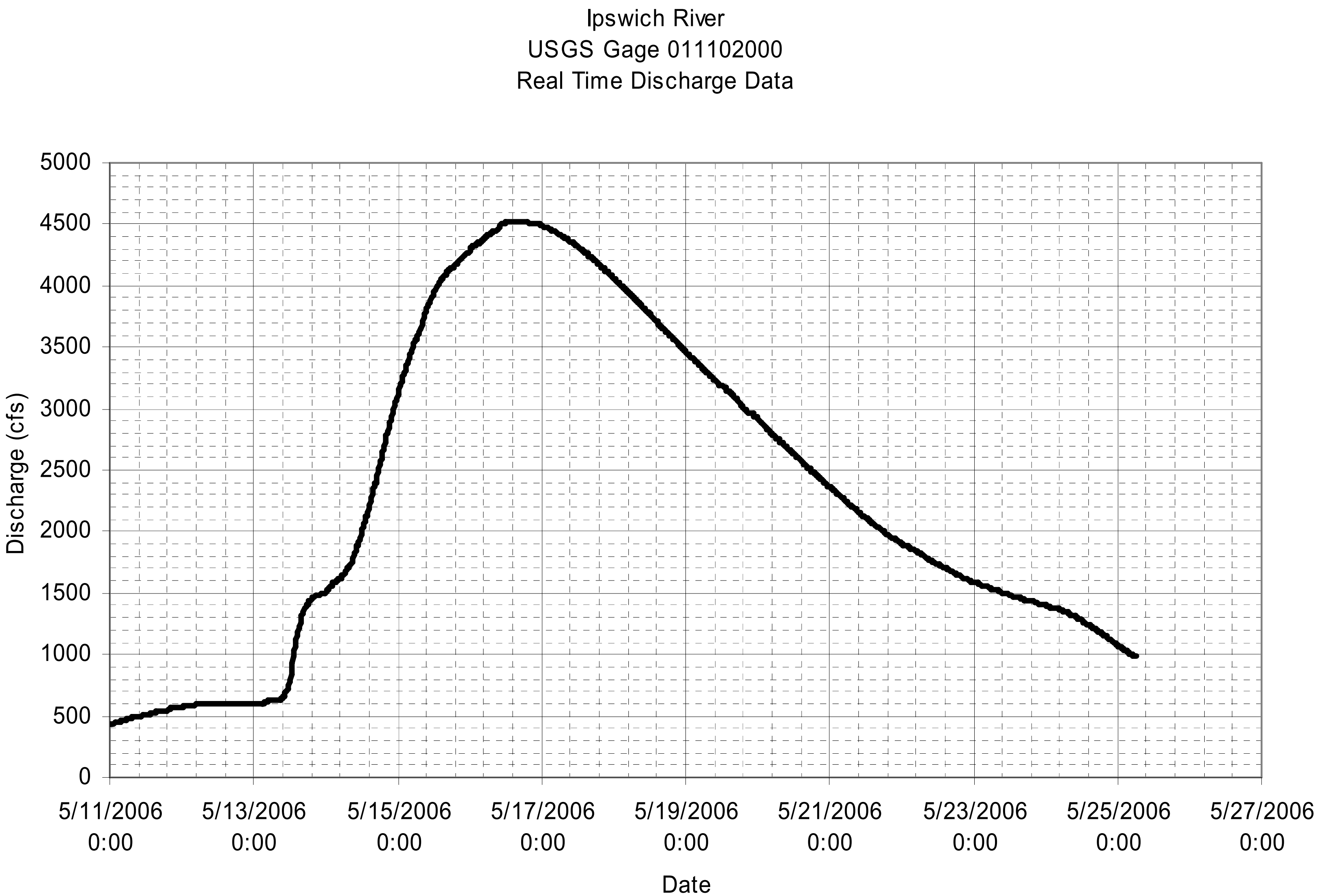


Figure 14 Ipswich River Discharge May 2006 Flood
(USGS Gage #01102000 Real time data)

Hydraulic Analysis

In order to identify changes to the impoundment and tailrace resulting from the dam removal options, Alden conducted a hydraulic analysis of the existing dam for the existing conditions, dam removal, and the fish passage alternatives. The analysis predicts water surface and average velocity magnitudes through the spillways, outlets, and breached section of the dam. The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) was used as the primary model for the analyses. The model of the Ipswich River totaled 3,400 ft in length and extended from approximately 1,110 ft downstream of the dam to approximately 2,290 ft upstream of the dam.

Existing Conditions

The geometry of the Ipswich River for the HEC-RAS model was developed using a combination of Alden's field survey, the existing bathymetry survey data, and FEMA's original hydraulic analysis data used for the Town of Ipswich FIS and are listed below:

- The FEMA 1985 Flood Insurance Study for Ipswich
- Donahoe and Parkhurst, Inc. survey dated November 25, 2003
- Alden site inspection and level survey conducted on December 14, 2005

The hydraulic analysis conducted by FEMA was crude, consisting of geometry defined by cross sections spaced roughly every 1,000 ft. Alden used the FEMA geometry data to define the upstream and downstream boundary conditions and the Willowdale Bridge cross section where detailed bathymetry data was not available for the computer model. The upstream boundary location was chosen as the farthest upstream cross section available from the Town of Ipswich FIS hydraulic model data. The Donahoe and Parkhurst bathymetric survey was used to define the conditions immediately upstream and downstream of the dam. A centerline bottom profile of the Ipswich River reach developed for the HEC-RAS analysis is shown on Figure 15 and an isometric view is shown on Figure 16.

Once the model geometry was developed, the initial HEC-RAS analysis was conducted to calibrate the model by comparing model results to observed measured water levels. Water levels were recorded and measured during Alden's site inspection on December 14, 2005. The corresponding Ipswich River flow rate on December 14, 2005 was 134 cfs. The initial calibration results for a river discharge of 134 cfs are presented on Table 6. The model roughness coefficients were adjusted and additional cross sections were added to more closely match the measured data. This model calibration resulted in an average difference in water surface elevations between the HEC-RAS model and observed data of 0.4 ft over the entire reach of the river that was modeled.

Once the model was calibrated, additional analyses were conducted to determine water levels and velocities for the fish passage design flow rates. The results of these analyses are presented in Table 7 and on Figure 17. The existing conditions analyses results indicate that maximum velocities in the river are generally less than 2 ft/sec and less than 0.4 ft/sec in the impoundment for the average river discharge.

The HEC-RAS analysis also indicates that the south dam embankment would be overtopped for the 10-year, 50-year and 100-year discharges. These results confirm the dam safety inspection report (DEM 2002) that states the abutments would be overtopped for a 25 year discharge. Table 8 summarizes the HEC-RAS simulations for the 10-, 50-, and 100-year flood events and Figure 18 presents the water surface profile. The head pond water level for the 10 year discharge of 1,756 cfs is at El. 30.9 ft (NGVD 29), which is about 12 inches above the south dam embankment near the abutment. The south dam embankment would be completely overtopped for the 50 and 100 year flood events. The north dam embankment existing grade ranges between El. 31.0 ft and El. 32.0 ft (NGVD 29) and would be partially overtopped for the 100-year flood events. These results assume that the dam flashboards would not be installed and the dam crest is at El. 26.8 ft (NGVD 29).

A discharge rating curve for the existing spillway was developed based on the results of the HEC-RAS model and is presented on Figure 19. This rating curve has been used to prepare the conceptual design of the fishway alternatives for installation at the dam. The model was also used to predict velocities, water depths, and water surface profiles for the dam removal and fishway alternatives.

Table 6 Hydraulic Analysis HEC-RAS Calibration Results[1], (134 cfs river discharge)

Cross Section ID	River Station	Description	HEC-RAS Water Surface Elevation (ft)	Observed Water Surface Elevation (ft)	Accuracy of HEC-RAS model (ft)
200180.0	3401	Upstream model boundary	28.35	n/a	n/a
200143.0	1378	impoundment	28.34	28.3	-0.04
200142.0	1295	impoundment	28.34	28.3	-0.04
200141.0	1160	upstream of dam	28.34	28.3	-0.04
200140.0	1110	**Willowdale dam**			
200139.0	1090	downstream of dam	24.28	24.3	0.02
200138.0	1040		24.27	24.3	0.03
200137.0	975	upstream of USGS gage	24.26	24.2	-0.06
200136.0	955	**USGS gage**			
200135.0	935	downstream of USGS gage	23.06	22.7	-0.36
200134.0	855		23.03	22.7	-0.33
200133.0	677	upstream of stone wall weir	23.01	22.7	-0.31
200132.0	672	**stonewall weir**			
200131.0	652	downstream of stonewall weir	21.58	21.83	0.25
200130.5	552	riffles downstream of stonewall weir	21.26	n/a	n/a
200130.0	130	upstream of bridge	20.26	n/a	n/a
200122.0	80	upstream bridge boundary	20.24	n/a	n/a
200121.5	65	**bridge**			
200121.0	50	downstream bridge boundary	20.21	n/a	n/a
200120.0	0	downstream model boundary	20.15	n/a	n/a

1) All elevations refer to NGVD 1929.

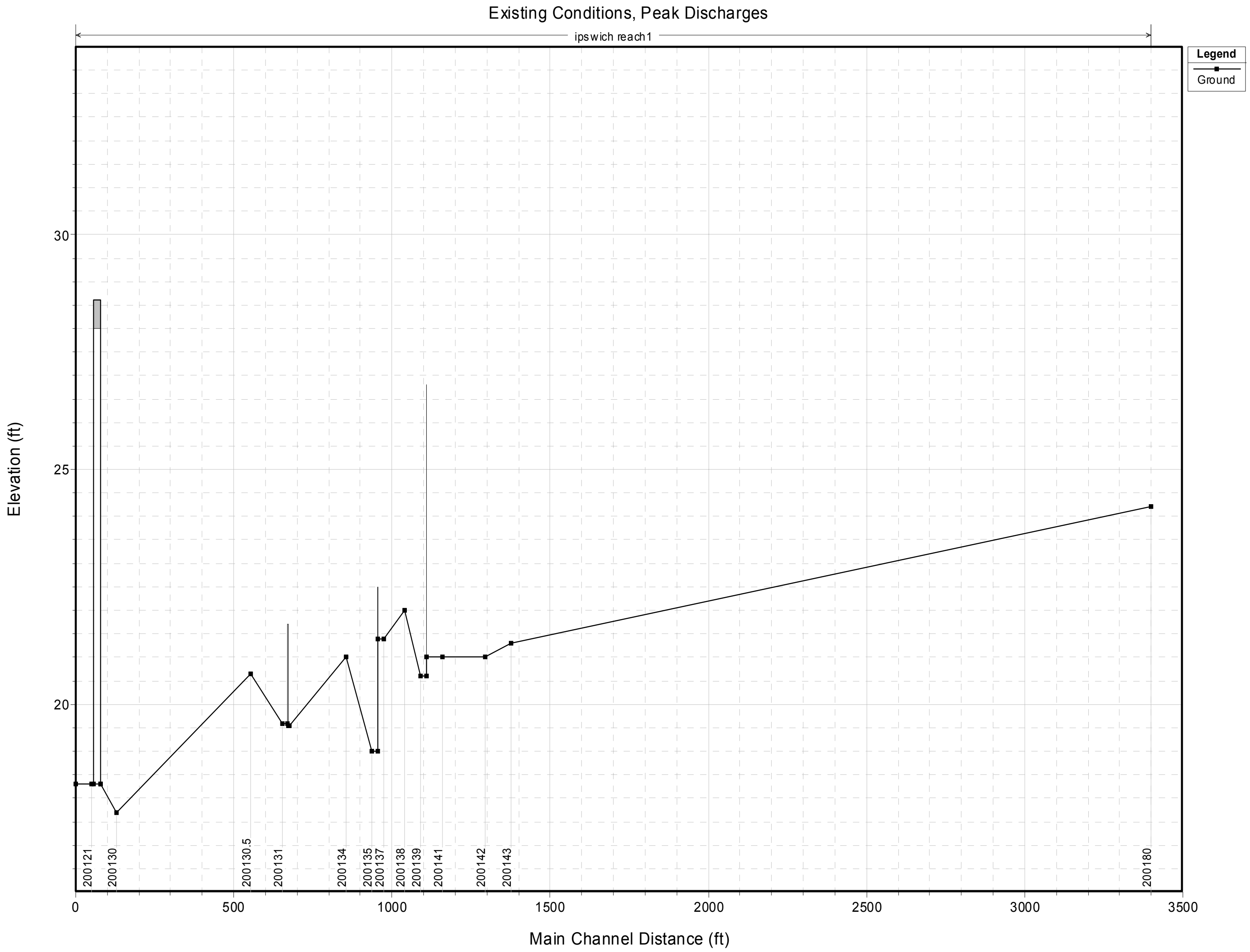


Figure 15 Existing Conditions Centerline Bottom Profile of Ipswich River (see Table 5 for cross section descriptions)

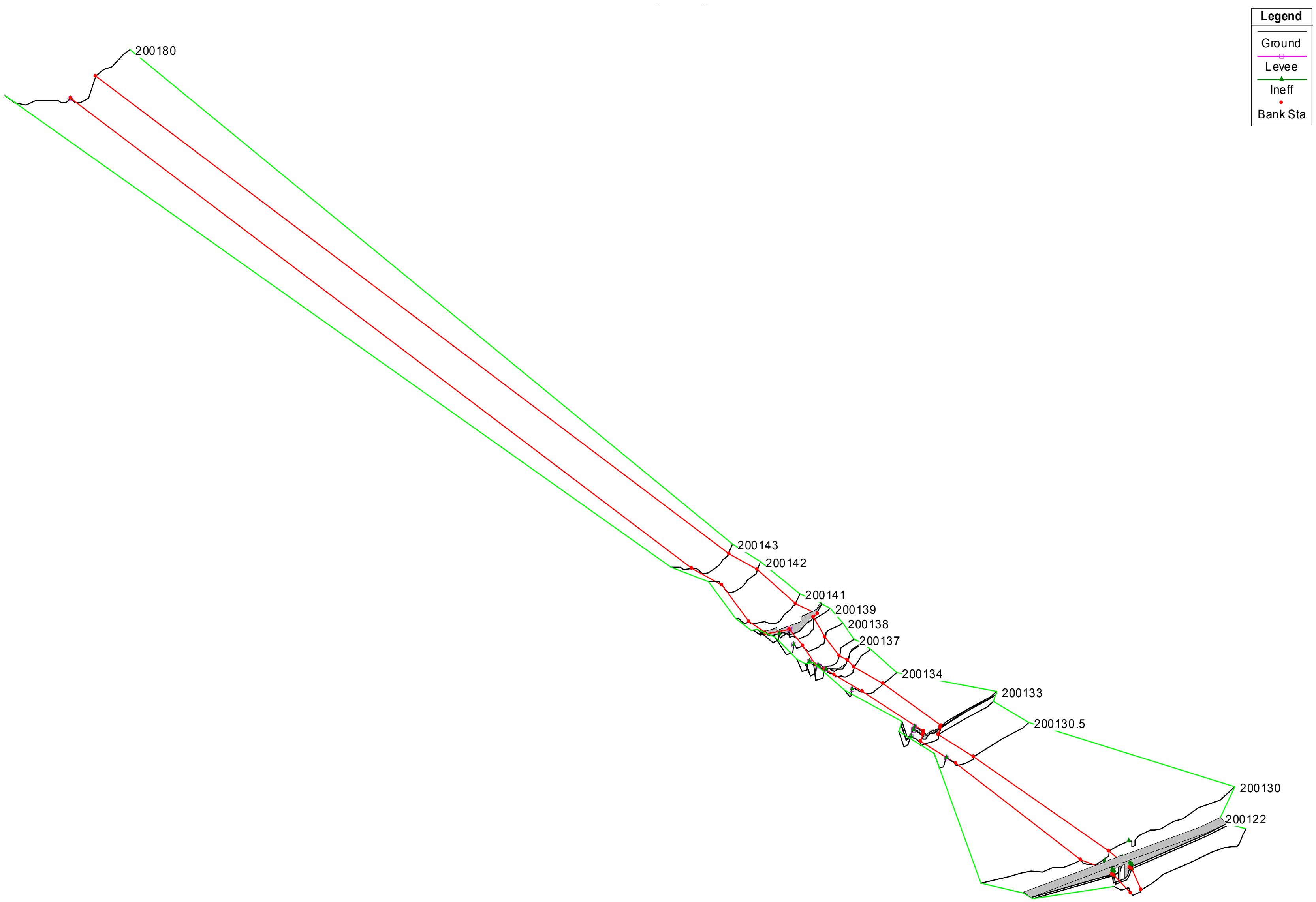


Figure 16 Existing Conditions Isometric View of Ipswich River Computer Model (see Table 5 for cross section descriptions)

Table 7 Existing Conditions Fish Passage Design Flows, Hydraulic Analysis HEC-RAS Results (no flashboards)[1)]

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)
200180	3401	Upstream model boundary	3	0.0	26.9
			10	0.1	26.9
			73	0.4	27.2
			319	1.4	28.0
			1597	3.5	30.4
200143	1378	impoundment	3	0.0	26.9
			10	0.0	26.9
			73	0.1	27.2
			319	0.5	28.0
			1597	1.6	30.1
200142	1295	impoundment	3	0.0	26.9
			10	0.0	26.9
			73	0.1	27.2
			319	0.5	27.9
			1597	1.6	30.1
200141	1160	upstream of dam	3	0.0	26.9
			10	0.0	26.9
			73	0.1	27.2
			319	0.4	27.9
			1597	1.3	30.1
200140	1110	**Willowdale dam**			
200139	1090	downstream of dam	3	0.0	22.9
			10	0.1	23.2
			73	0.4	23.9
			319	1.0	25.0
			1597	2.9	27.2
200138	1040		3	0.1	22.9
			10	0.1	23.2
			73	0.6	23.9
			319	1.5	24.9
			1597	3.7	27.1
200137	975	upstream of USGS gage	3	0.1	22.9
			10	0.1	23.2
			73	0.6	23.9
			319	1.6	24.9
			1597	3.8	27.0
200136	955	**USGS gage**			
200135	935	downstream of USGS gage	3	0.0	21.9
			10	0.1	22.0
			73	0.4	22.8
			319	1.2	23.7
			1597	3.5	25.8
200134	855		3	0.1	21.9
			10	0.3	22.0
			73	0.9	22.8

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)
			319	2.2	23.6
			1597	4.8	25.5
200133	677	upstream of stone wall weir	3	0.0	21.9
			10	0.1	22.0
			73	0.5	22.8
			319	1.5	23.6
			1597	4.3	25.4
200132	672	**stonewall weir**	Inl Struct		
200131	652	downstream of stonewall weir	3	0.1	20.8
			10	0.2	20.9
			73	0.8	21.3
			319	2.1	22.1
			1597	3.8	25.3
200130.5	552	riffles downstream of stonewall weir	3	1.5	20.8
			10	1.9	20.9
			73	3.1	21.1
			319	5.1	21.6
			1597	4.5	25.1
200130	130	upstream of bridge	3	0.2	18.5
			10	0.4	18.8
			73	0.8	19.7
			319	1.3	21.2
			1597	2.2	25.1
200122	80	upstream bridge boundary	3	0.2	18.5
			10	0.4	18.8
			73	0.9	19.6
			319	1.7	21.2
			1597	3.4	25.0
200122	50	**bridge**	Bridge		
200121	50	downstream bridge boundary	3	0.3	18.5
			10	0.4	18.7
			73	1.0	19.6
			319	1.8	21.1
			1597	3.7	24.6
200120	0	downstream model boundary	3	0.4	18.5
			10	0.7	18.7
			73	1.4	19.6
			319	2.5	21.0
			1597	4.4	24.5

1) All elevations refer to NGVD 1929

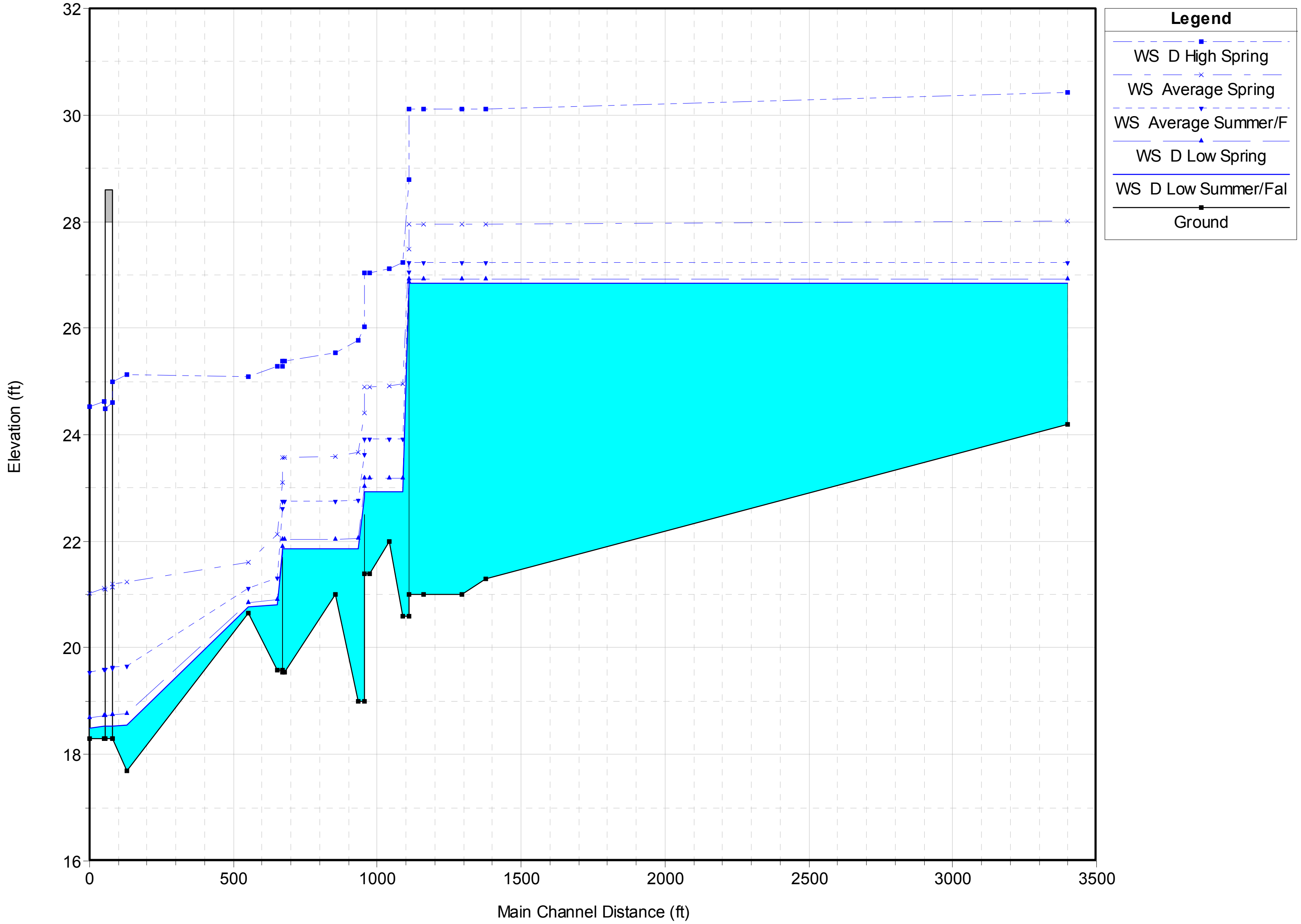


Figure 17 Existing Conditions Water Surface Profile, Fish Passage Design Flow Rates (no flashboards)

Table 8 Existing Conditions Peak Flood Discharges, HEC-RAS Results (no flashboards)

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)
200180	3401	Upstream model boundary	2309 3696 4381 6219	4.3 5.4 6.0 7.0	31.3 32.5 33.0 34.2
200143	1378	impoundment	2309 3696 4381 6219	2.0 2.8 3.1 3.9	30.9 31.9 32.3 33.4
200142	1295	impoundment	2309 3696 4381 6219	2.1 2.9 3.2 4.0	30.8 31.9 32.3 33.4
200141	1160	upstream of dam	2309 3696 4381 6219	1.7 2.3 2.6 3.2	30.9 31.9 32.3 33.4
200140	1110	Willowdale dam			
200139	1090	downstream of dam	2309 3696 4381 6219	3.6 4.7 4.5 4.6	28.0 29.4 30.3 32.9
200138	1040		2309 3696 4381 6219	4.5 5.6 5.4 5.2	27.9 29.3 30.1 32.8
200137	975	upstream of USGS gage	2309 3696 4381 6219	4.6 5.7 5.9 5.4	27.8 29.2 29.9 32.8
200136	955	USGS gage			
200135	935	downstream of USGS gage	2309 3696 4381 6219	3.9 4.6 4.8 4.7	27.1 29.0 29.9 32.7
200134	855		2309 3696 4381 6219	4.7 4.7 4.7 4.5	26.9 29.0 29.9 32.8
200133	677	upstream of stone wall weir	2309 3696	4.5 5.0	26.8 28.8

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)
			4381	4.8	29.8
			6219	4.5	32.7
200132	672	stonewall weir	Inl Struct		
200131	652	downstream of stonewall weir	2309	4.1	26.8
			3696	4.7	28.8
			4381	4.6	29.8
			6219	4.4	32.7
200131	552	riffles downstream of stonewall weir	2309	4.6	26.7
			3696	5.1	28.7
			4381	4.9	29.7
			6219	4.6	32.6
200130	130	upstream of bridge	2309	2.2	26.7
			3696	2.4	28.9
			4381	2.4	29.9
			6219	2.3	32.8
200122	80	upstream bridge boundary	2309	3.8	26.5
			3696	3.0	28.8
			4381	2.8	29.8
			6219	1.5	32.8
200122	50	bridge	Bridge		
200121	50	downstream bridge boundary	2309	4.2	26.0
			3696	5.5	27.5
			4381	3.9	28.4
			6219	3.7	29.7
200120	0	downstream model boundary	2309	5.1	25.9
			3696	5.8	27.5
			4381	6.0	28.1
			6219	6.6	29.3

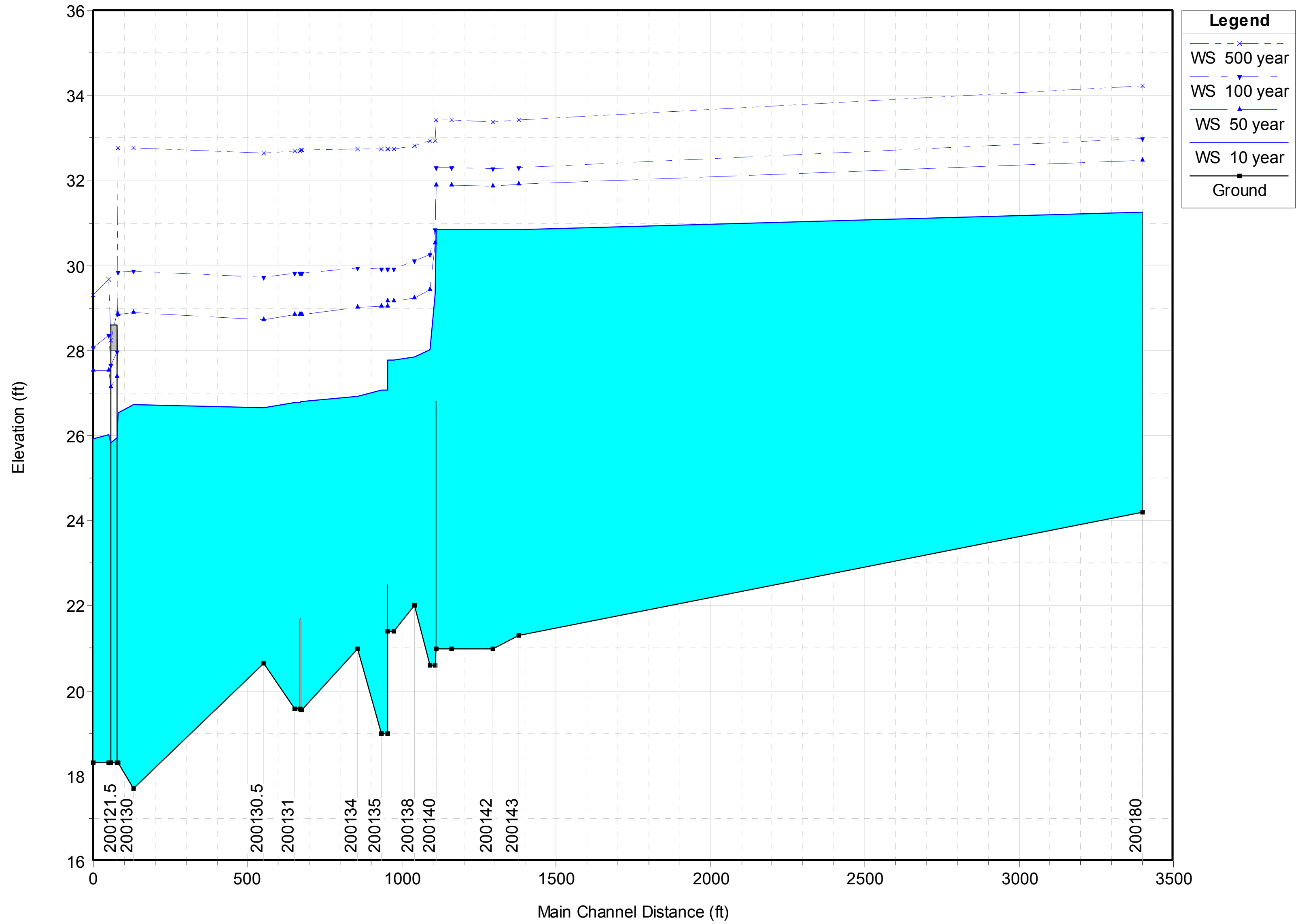


Figure 18 Existing Conditions Water Surface Profile, Peak Discharges (no flashboards)

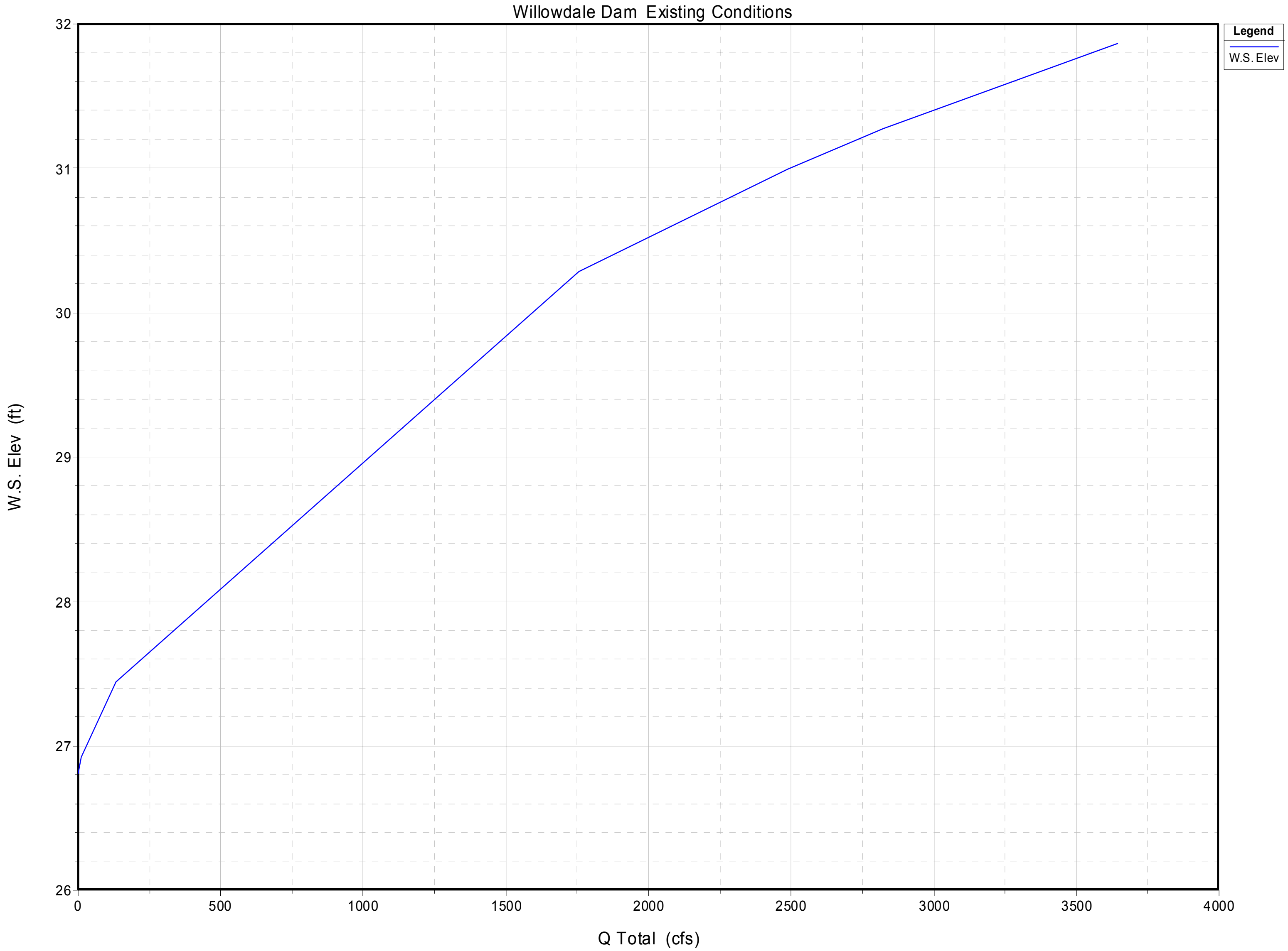


Figure 19 Willowdale Dam Discharge Rating Curve, (no flashboards)

Dam Breach

A HEC-RAS model study with the dam and USGS gage removed was conducted to determine water levels and velocities in the river channel over the range of flows. For the computer simulations, the dam removal option was assumed to be a 100 ft width breach at the spillway. Hydraulic analysis results are presented in Table 9 and water surface profiles are presented on Figure 20. An isometric view of the dam breach is shown on Figure 21. Bottom substrate material near the dam was regraded and/or removed/filled as necessary to provide the design river channel contours. The new river centerline profile through the dam breach and impoundment would be almost flat (approximately 0% slope).

The results of the hydraulic model with the dam removed were reviewed to determine the existence of any physical obstructions, velocity barriers or natural falls that may affect fish passage for the design fish passage flow rates. The criteria selected for determining velocity barriers are:

1) Maximum velocity of 7 ft/sec which is the approximate burst speed of adult herring 6 to 11 inches in length (USACE 1991).

2) Vertical drops of no greater than 0.5 ft.

3) Minimum water depths of 6 inches.

The original analyses of the dam breach indicated shallow water depths through the dam and USGS weir breach for the design low flow conditions. Therefore, a low flow channel was added to increase water depths and improve passage conditions at low flow conditions.

The analyses of the dam breach with design fish passage flow rates indicate no velocity barriers in the river reach modeled. The majority of the velocities were below 4 ft/sec for the river reach modeled. River station 975 ft, just upstream of the USGS gage had the highest velocities at 5.5 ft/sec for 319 cfs and 6.8 ft/sec for 1,597 cfs. Velocities in the river channel through the Willowdale dam breach section and impoundment were less than 4.0 ft/sec for fish passage design flows, well below the 7 ft/sec fish swimming speed criterion.

Water levels in the impoundment were reduced by 4 ft from El. 27.9 ft at the dam to El. 23.7 ft (NGVD 29) for 319 cfs (spring average flow rate) and by 5 ft for the low flow of 3 cfs. Water levels at the upstream boundary of the hydraulic model were only reduced by 1.6 ft from El. 28.0 ft to El. 26.4 ft (NGVD 29) at 319 cfs. During the late summer and fall (August through November) the average river discharge is 73 cfs and the water level is expected to change by 4.4 ft in the impoundment from El. 27.2 ft to El. 22.8 ft (NGVD 29). Water level at the upstream boundary of the model (station 3401 ft) is expected to drop by 2.2 ft from El. 27.2 ft to El. 25.1 ft (NGVD 29) for a river discharge of 73 cfs.

Table 9 Dam Breach HEC-RAS Results[1)], Fish Passage Design Flow Rates

Cross Section ID	River Station	Description	River flow rate (cfs)	Dam Breach River Channel Velocity (ft/sec)	Dam Breach Water Surface Elevation (ft)	Existing Conditions Water Surface Elevation (ft)	Change in Water Surface (ft)	Channel Depth (ft)
200180	3401	Upstream model boundary	3	0.5	24.7	26.9	2.2	0.5
			10	0.7	25.0	26.9	2.0	0.8
			73	2.0	25.4	27.2	1.8	1.2
			319	2.9	26.5	28.0	1.5	2.3
			1597	4.7	29.4	30.4	1.1	5.2
200143	1378	impoundment	3	0.9	21.4	26.9	5.4	0.4
			10	1.3	21.6	26.9	5.3	0.6
			73	1.2	22.6	27.2	4.7	1.6
			319	2.2	23.7	28.0	4.2	2.7
			1597	3.9	26.3	30.1	3.8	5.3
200142	1295	impoundment	3	2.4	20.9	26.9	6.0	0.4
			10	1.5	21.3	26.9	5.7	0.8
			73	1.1	22.5	27.2	4.7	2.0
			319	2.0	23.7	27.9	4.3	3.2
			1597	3.8	26.2	30.1	3.9	5.7
200141	1160	upstream of dam	3	0.2	20.9	26.9	6.0	1.4
			10	0.5	21.2	26.9	5.7	1.7
			73	0.9	22.5	27.2	4.8	3.0
			319	2.1	23.6	27.9	4.4	4.1
			1597	3.8	26.0	30.1	4.1	6.5
200140	1110	**Willowdale dam**	**Removed**					
200139	1090	downstream of dam	3	0.2	20.9	22.9	2.1	1.4
			10	0.4	21.2	23.2	2.0	1.7
			73	0.7	22.5	23.9	1.5	3.0
			319	1.8	23.5	25.0	1.4	4.0
			1597	3.7	26.0	27.2	1.3	6.5
200138	1040		3	1.5	20.8	22.9	2.1	0.3
			10	2.3	21.1	23.2	2.1	0.6
			73	2.1	22.4	23.9	1.6	1.9
			319	3.2	23.4	24.9	1.6	2.9
			1597	5.3	25.7	27.1	1.5	5.2
200137	975	upstream of USGS gage	3	2.6	20.1	22.9	2.8	0.2
			10	3.7	20.4	23.2	2.8	0.5
			73	5.6	21.6	23.9	2.3	1.7
			319	5.6	22.7	24.9	2.2	2.8
			1597	6.8	25.2	27.0	1.9	5.3
200136	955	**USGS gage**	**Removed**					
200135	935	downstream of USGS gage	3	0.2	20.2	21.9	1.7	1.7
			10	0.3	20.6	22.0	1.5	2.1
			73	0.7	21.7	22.8	1.0	3.2
			319	1.6	22.9	23.7	0.8	4.4
			1597	3.6	25.6	25.8	0.1	7.1
200134	855		3	0.6	20.2	21.9	1.7	0.7
			10	1.2	20.5	22.0	1.5	1.0
			73	2.4	21.6	22.8	1.1	2.1

Cross Section ID	River Station	Description	River flow rate (cfs)	Dam Breach River Channel Velocity (ft/sec)	Dam Breach Water Surface Elevation (ft)	Existing Conditions Water Surface Elevation (ft)	Change in Water Surface (ft)	Channel Depth (ft)
			319	3.6	22.7	23.6	0.9	3.2
			1597	4.8	25.4	25.5	0.1	5.9
200133	677	upstream of stone wall weir	3	0.8	20.1	21.9	1.8	0.5
			10	1.2	20.3	22.0	1.7	0.8
			73	2.1	21.2	22.8	1.6	1.6
			319	3.9	21.9	23.6	1.7	2.4
			1597	4.5	25.2	25.4	0.2	5.7
200132	672	**stonewall weir**	**Removed**					
200131	652	downstream of stonewall weir	3	0.7	20.0	20.8	0.8	0.4
			10	0.9	20.3	20.9	0.6	0.7
			73	0.9	21.2	21.3	0.1	1.6
			319	2.2	22.0	22.1	0.1	2.4
			1597	3.8	25.3	25.3	0.0	5.7
200131	552	riffles downstream of stonewall weir	3	2.5	19.5	20.8	1.3	0.2
			10	3.4	19.8	20.9	1.1	0.4
			73	3.3	20.9	21.1	0.2	1.6
			319	5.0	21.5	21.6	0.1	2.2
			1597	4.4	25.1	25.1	0.0	5.8
200130	130	upstream of bridge	3	0.2	18.5	18.5	0.0	0.8
			10	0.4	18.8	18.8	0.0	1.1
			73	0.8	19.7	19.7	0.0	2.0
			319	1.3	21.2	21.2	0.0	3.5
			1597	2.1	25.1	25.1	0.0	7.4
200122	80	upstream bridge boundary	3	0.2	18.5	18.5	0.0	0.2
			10	0.4	18.8	18.8	0.0	0.4
			73	0.9	19.6	19.6	0.0	1.3
			319	1.7	21.2	21.2	0.0	2.9
			1597	3.4	25.0	25.0	0.0	6.7
200122	50	**bridge**						
200121	50	downstream bridge boundary	3	0.3	18.5	18.5	0.0	0.2
			10	0.4	18.7	18.7	0.0	0.4
			73	1.0	19.6	19.6	0.0	1.3
			319	1.8	21.1	21.1	0.0	2.8
			1597	3.7	24.6	24.6	0.0	6.3
200120	0	downstream model boundary	3	0.4	18.5	18.5	0.0	0.2
			10	0.7	18.7	18.7	0.0	0.4
			73	1.4	19.6	19.6	0.0	1.3
			319	2.5	21.0	21.0	0.0	2.7
			1597	4.4	24.5	24.5	0.0	6.2

1) All elevations refer to NGVD 1929

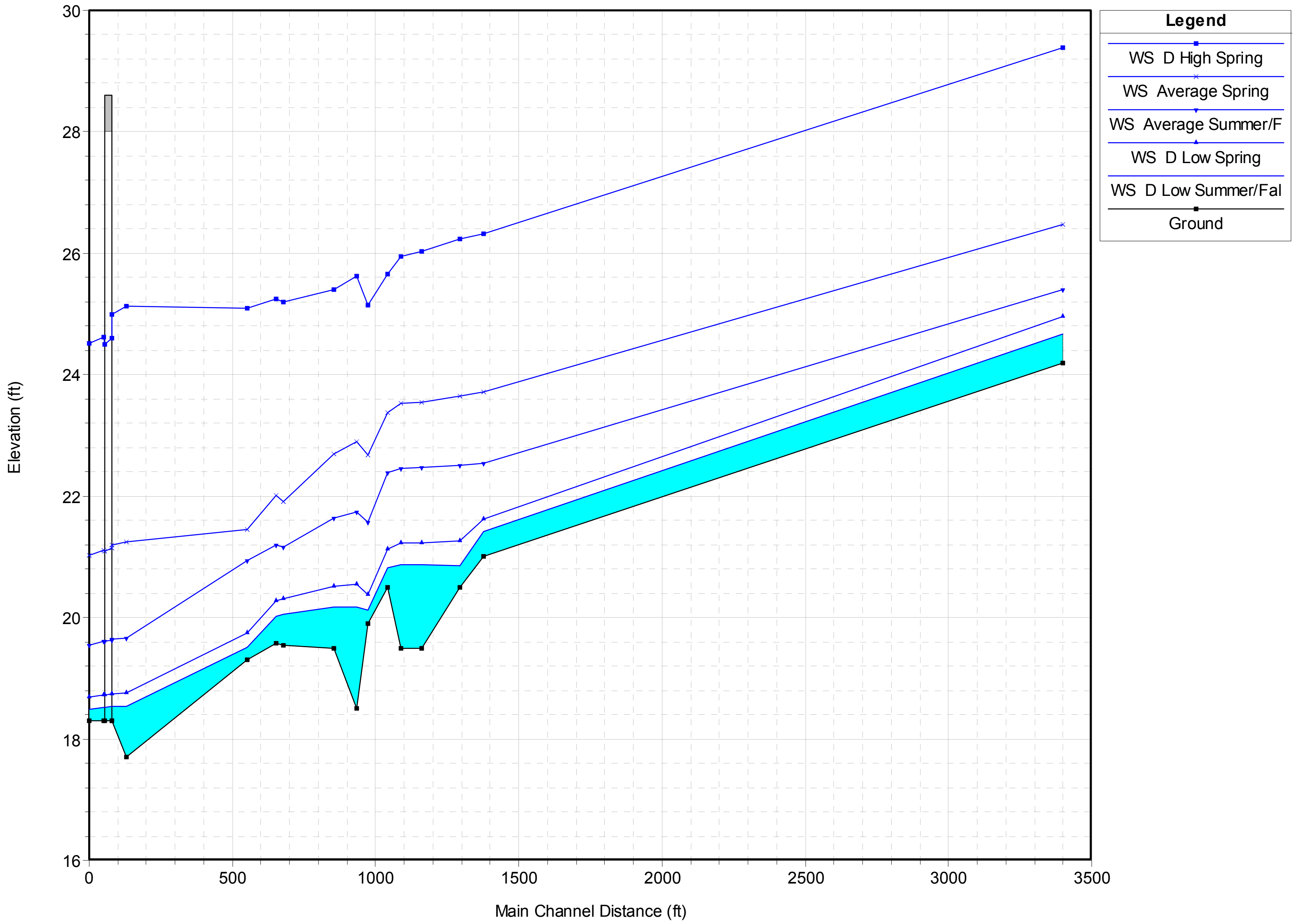


Figure 20 Dam Breach Water Surface Profile, Fish Passage Design Flow Rates

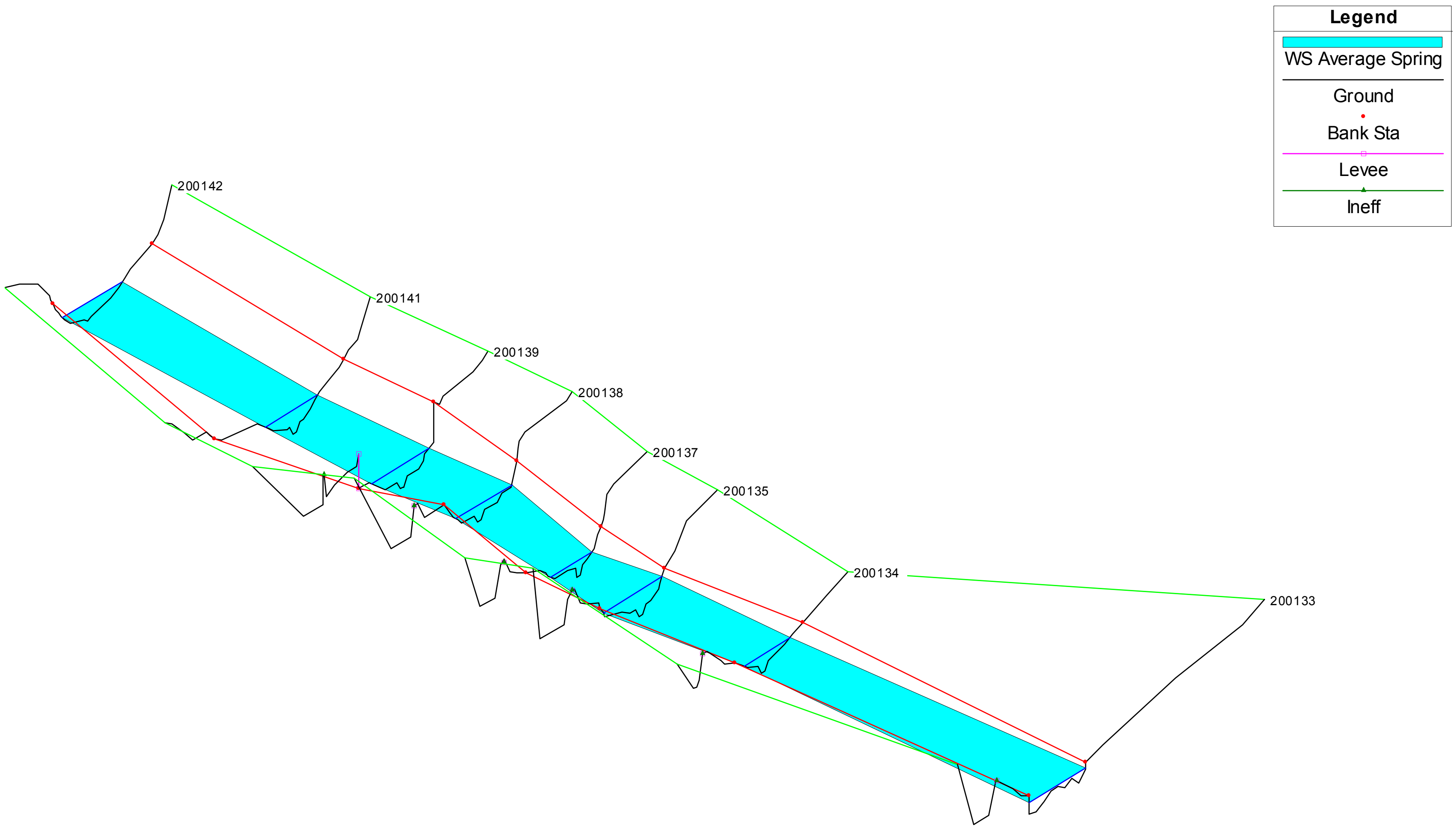


Figure 21 Dam Breach Isometric View

Rock Ramp

A HEC-RAS hydraulic model was also developed to determine approximate water levels and velocities for a rock ramp extending from the dam face to approximately 165 ft downstream of the dam. The ramp would span the width of the river with a slope 30H:1V (3.3%) slope. Two hydraulic models were developed. The first model assumed the flashboards would be removed and an 8 inch deep by 5 ft wide notch in the spillway would concentrate low flows to the center of the ramp. The results of this hydraulic model for peak flow conditions indicated that the ramp significantly reduced the discharge capacity of the spillway and increased upstream flood levels by 1.0 to 1.5 ft for the 10, 50 and 100 year floods. Increasing the flood levels was deemed unacceptable and, therefore, a second fishway ramp option was developed to limit flood water levels to the current conditions.

The spillway would have to be modified to limit flood levels by lowering the crest and increasing the discharge capacity. A 5 ft portion centered at the middle of the spillway would be lowered by 1.8 ft to El. 25.0 ft. The spillway would then slope up in both directions to El. 26.3 ft at the dam abutments (6 inches below existing spillway crest). The new spillway geometry forms a shallow "V" and concentrates flow to the center of the ramp. The ramp would extend downstream of the modified spillway at a 30H:1V slope. A further discussion and a plan and section of the rock ramp alternative are provided in the Detailed Evaluation Section of this report.

A low flow channel would be located in the center of the ramp with a 20 inch depth, 5 ft bottom width, and a 15 ft top width. The ramp would slope 10H:1V from the low flow channel to the river banks. Rock weirs would extend the width of the ramp to provide a total of 12 stepped pools about 15 ft long each with a 6 inch hydraulic drop. Alternatively, the rock ramp could be roughened with a matrix of large rocks to dissipate the flow energy and slow the channel velocities for fish passage, but the USFWS prefers weirs to control water depths and create resting pools. For this study, the hydraulic analysis approximated the rock weirs with a roughened ramp slope (with a Manning's n roughness coefficient of 0.06) to simplify model geometry. However, a more detailed hydraulic analysis should be conducted during a preliminary design phase to refine the rock ramp geometry if selected for the site.

The results of the hydraulic model were reviewed to determine the existence of velocity barriers, or shallow depths that may affect fish passage for the design fish passage flow rates. The criteria used to determine velocity barriers and shallow water depths are the same as presented previously for the dam breach alternative.

Hydraulic analysis results are presented in Table 10. Water surface profiles are presented on Figure 22 and an isometric view presented on Figure 23. The analyses of the rock ramp indicate no velocity barriers for river flows less than 319 cfs (average spring flow). At the design high fish passage flow rate of 1,597 cfs, velocities ranged from 6.7 ft/sec to 7.8 ft/sec. These velocities are near the 7 ft/sec threshold and may be a potential barrier to fish passage. However the HEC-RAS computer model calculates the average velocity over the entire river cross section and Alden believes that shallow areas in the ramp channel, particularly near the river banks outside the main channel, would have conditions acceptable for fish passage. If selected as the preferred fish passage option at Willowdale, a more detailed analysis of the rock ramp should be completed using a three-dimensional computer model or a physical model to refine the design and verify that the expected flow conditions meet the criteria for effective fish passage.

The rock ramp includes a center thalwag or low flow channel to increase fish passage efficiencies at low river flows. The modified spillway, which would be in the form of a “V”, would concentrate low flows to the rock ramp low flow channel. Water velocities for low flow conditions (3 to 10 cfs) would range from 0.1 to 3.5 ft/sec. Water depth in the channel would range from 2 to 12 inches for the low flow conditions (3 and 10 cfs). These conditions should provide acceptable fish passage at low river flow rates.

Water levels in the impoundment would be reduced by 1.6 ft at the extreme low flow of 3 cfs with the modified spillway. During the 100 year flood event, water levels would be slightly increased by 0.1 ft in the impoundment. The results of the hydraulic analysis for peak flow conditions are summarized in Table 11 and a water surface profile is presented on Figure 24.

Table 10 Rock Ramp HEC-RAS Results, Fish Passage Design Flow Rates

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)	Existing Conditions Water Surface Elevation (ft)	Change in Water Surface (ft)	Rock Ramp Channel Depth (ft)
200180	3401	Upstream model boundary	3	0.1	25.2	26.9	-1.6	1.0
			10	0.3	25.4	26.9	-1.6	1.2
			73	0.7	26.3	27.2	-0.9	2.1
			319	1.6	27.7	28.0	-0.3	3.5
			1597	3.9	30.1	30.4	-0.3	5.9
200143	1378	impoundment	3	0.0	25.2	26.9	-1.6	3.9
			10	0.0	25.4	26.9	-1.6	4.1
			73	0.2	26.3	27.2	-0.9	5.0
			319	0.5	27.6	28.0	-0.3	6.3
			1597	1.7	29.8	30.1	-0.4	8.5
200142	1295	impoundment	3	0.0	25.2	26.9	-1.6	4.2
			10	0.0	25.4	26.9	-1.6	4.4
			73	0.2	26.3	27.2	-0.9	5.3
			319	0.5	27.6	27.9	-0.3	6.6
			1597	1.7	29.8	30.1	-0.4	8.8
200141	1160	upstream of dam	3	0.0	25.2	26.9	-1.6	4.2
			10	0.0	25.4	26.9	-1.6	4.4
			73	0.2	26.3	27.2	-0.9	5.3
			319	0.5	27.6	27.9	-0.3	6.6
			1597	1.4	29.8	30.1	-0.4	8.8
200140	1110	**Willowdale dam, (start of ramp)**	3	1.9	25.2			0.2
			10	2.0	25.3			0.3
			73	1.1	26.3			1.3
			319	1.6	27.6			2.6
			1597	4.1	29.5			4.5
200139	1090	Rock ramp	3	1.5	24.6	22.9	1.7	0.3
			10	2.2	25.0	23.2	1.8	0.7
			73	4.3	26.0	23.9	2.1	1.7
			319	4.4	27.3	25.0	2.3	3.0
			1597	6.9	29.0	27.2	1.7	4.7
200138	1040	Rock ramp	3	2.4	22.9	22.9	-0.1	0.2
			10	3.5	23.1	23.2	-0.1	0.4
			73	4.9	24.2	23.9	0.3	1.5
			319	4.8	25.6	24.9	0.6	2.9
			1597	7.8	27.1	27.1	0.0	4.4
200137	975	Rock ramp	3	0.6	21.2	22.9	-1.8	0.7
			10	1.5	21.4	23.2	-1.8	0.9
			73	3.6	22.4	23.9	-1.6	1.9
			319	4.4	23.5	24.9	-1.4	3.0
			1597	5.3	25.8	27.0	-1.2	5.3
200136	955	**USGS gage removed and replaced with ramp**		0.3	21.2			1.3
				0.7	21.4			1.5
				2.2	22.2			2.3
				3.2	23.3			3.4
				4.3	25.8			5.9
200135	935	Rock ramp (end of ramp)	3	0.1	21.2	21.9	-0.7	2.0
			10	0.3	21.4	22.0	-0.7	2.2
			73	1.0	22.2	22.8	-0.6	3.0
			319	1.9	23.3	23.7	-0.4	4.1
			1597	3.5	25.8	25.8	0.0	6.6

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)	Existing Conditions Water Surface Elevation (ft)	Change in Water Surface (ft)	Rock Ramp Channel Depth (ft)
200134	855		3	1.7	21.1	21.9	-0.7	0.1
			10	2.4	21.2	22.0	-0.8	0.2
			73	3.1	21.8	22.8	-1.0	0.8
			319	4.1	22.7	23.6	-0.9	1.7
			1597	5.0	25.4	25.5	-0.1	4.4
200133	677	upstream of stone wall weir	3	0.1	20.8	21.9	-1.0	1.3
			10	0.4	20.9	22.0	-1.1	1.4
			73	1.8	21.3	22.8	-1.5	1.8
			319	3.4	22.1	23.6	-1.5	2.5
			1597	4.4	25.2	25.4	-0.2	5.7
200132	672	**stonewall weir**	removed					
200131	652	downstream of stonewall weir	3	0.1	20.8	20.8	0.0	1.2
			10	0.2	20.9	20.9	0.0	1.3
			73	0.8	21.3	21.3	0.0	1.7
			319	2.1	22.1	22.1	0.0	2.6
			1597	3.8	25.3	25.3	0.0	5.7
200131	552	riffles downstream of stonewall weir	3	1.5	20.8	20.8	0.0	0.1
			10	1.9	20.9	20.9	0.0	0.2
			73	3.1	21.1	21.1	0.0	0.5
			319	5.1	21.6	21.6	0.0	1.0
			1597	4.5	25.1	25.1	0.0	4.4
200130	130	upstream of bridge	3	0.2	18.5	18.5	0.0	0.8
			10	0.4	18.8	18.8	0.0	1.1
			73	0.8	19.7	19.7	0.0	2.0
			319	1.3	21.2	21.2	0.0	3.5
			1597	2.2	25.1	25.1	0.0	7.4
200122	80	upstream bridge boundary	3	0.2	18.5	18.5	0.0	0.2
			10	0.4	18.8	18.8	0.0	0.4
			73	0.9	19.6	19.6	0.0	1.3
			319	1.7	21.2	21.2	0.0	2.9
			1597	3.4	25.0	25.0	0.0	6.7
200122	50	**bridge**						
200121	50	downstream bridge boundary	3	0.3	18.5	18.5	0.0	0.2
			10	0.4	18.7	18.7	0.0	0.4
			73	1.0	19.6	19.6	0.0	1.3
			319	1.8	21.1	21.1	0.0	2.8
			1597	3.7	24.6	24.6	0.0	6.3
200120	0	downstream model boundary	3	0.4	18.5	18.5	0.0	0.2
			10	0.7	18.7	18.7	0.0	0.4
			73	1.4	19.6	19.6	0.0	1.3
			319	2.5	21.0	21.0	0.0	2.7
			1597	4.4	24.5	24.5	0.0	6.2

Table 11 Rock Ramp HEC-RAS Results, Peak Flow Rates

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)	Existing Conditions Water Surface Elevation (ft)	Change in Water Surface (ft)
200180	3401	Upstream model boundary	2309	4.5	31.0	31.3	-0.2
			3696	5.5	32.5	32.5	0.0
			4381	5.9	33.0	33.0	0.1
			6219	6.8	34.5	34.2	0.2
200143	1378	impoundment	2309	2.1	30.5	30.9	-0.3
			3696	2.8	31.9	31.9	0.0
			4381	3.1	32.4	32.3	0.1
			6219	3.7	33.8	33.4	0.3
200142	1295	impoundment	2309	2.2	30.5	30.8	-0.3
			3696	2.9	31.8	31.9	-0.1
			4381	3.2	32.4	32.3	0.1
			6219	3.9	33.7	33.4	0.3
200141	1160	upstream of dam	2309	1.8	30.5	30.9	-0.3
			3696	2.3	31.9	31.9	0.0
			4381	2.5	32.4	32.3	0.1
			6219	3.1	33.8	33.4	0.3
200140	1110	Willowdale dam, (start of ramp)	2309	5.0	30.2		
			3696	6.4	31.3		
			4381	7.1	31.7		
			6219	8.6	32.7		
200139	1090	rock ramp	2309	8.3	29.4	28.0	1.4
			3696	10.2	30.2	29.4	0.8
			4381	10.7	30.6	30.3	0.3
			6219	12.0	31.6	32.9	-1.4
200138	1040	rock ramp	2309	8.7	27.6	27.9	-0.2
			3696	9.2	28.8	29.3	-0.4
			4381	6.3	30.1	30.1	0.0
			6219	5.2	32.9	32.8	0.0
200137	975	rock ramp	2309	5.1	27.1	27.8	-0.7
			3696	5.3	29.1	29.2	-0.1
			4381	4.8	30.0	29.9	0.1
			6219	4.6	32.8	32.8	0.0
200136	955	USGS gage removed, replaced with rock ramp	2309	4.3	27.1		
			3696	4.6	29.1		
			4381	4.2	30.1		
			6219	4.0	32.8		
200135	935	rock ramp (end)	2309	3.8	27.1	27.1	0.0
			3696	4.2	29.1	29.0	0.1
			4381	4.4	30.0	29.9	0.1
			6219	3.8	32.8	32.7	0.1
200134	855		2309	4.7	26.9	26.9	-0.1
			3696	4.9	29.0	29.0	-0.1
			4381	4.7	29.9	29.9	0.0
			6219	4.5	32.7	32.8	0.0
200133	677	upstream of stone wall weir	2309	4.5	26.7	26.8	-0.1
			3696	5.1	28.8	28.8	0.0
			4381	4.9	29.8	29.8	0.0
			6219	4.5	32.7	32.7	0.0
200132	672	**stonewall weir**					
200131	652	downstream of stonewall weir	2309	4.1	26.8	26.8	0.0
			3696	4.7	28.8	28.8	0.0

Cross Section ID	River Station	Description	River flow rate (cfs)	River Channel Velocity (ft/sec)	Water Surface Elevation (ft)	Existing Conditions Water Surface Elevation (ft)	Change in Water Surface (ft)
			4381	4.6	29.8	29.8	0.0
			6219	4.4	32.7	32.7	0.0
200131	552	riffles downstream of stonewall weir	2309	4.6	26.7	26.7	0.0
			3696	5.1	28.7	28.7	0.0
			4381	4.9	29.7	29.7	0.0
			6219	4.6	32.6	32.6	0.0
200130	130	upstream of bridge	2309	2.2	26.7	26.7	0.0
			3696	2.4	28.9	28.9	0.0
			4381	2.4	29.9	29.9	0.0
			6219	2.3	32.8	32.8	0.0
200122	80	upstream bridge boundary	2309	3.8	26.5	26.5	0.0
			3696	3.0	28.8	28.8	0.0
			4381	2.8	29.8	29.8	0.0
			6219	1.5	32.8	32.8	0.0
200122	50	**bridge**					
200121	50	downstream bridge boundary	2309	4.2	26.0	26.0	0.0
			3696	5.5	27.5	27.5	0.0
			4381	3.9	28.4	28.4	0.0
			6219	3.7	29.7	29.7	0.0
200120	0	downstream model boundary	2309	5.1	25.9	25.9	0.0
			3696	5.8	27.5	27.5	0.0
			4381	6.0	28.1	28.1	0.0
			6219	6.6	29.3	29.3	0.0

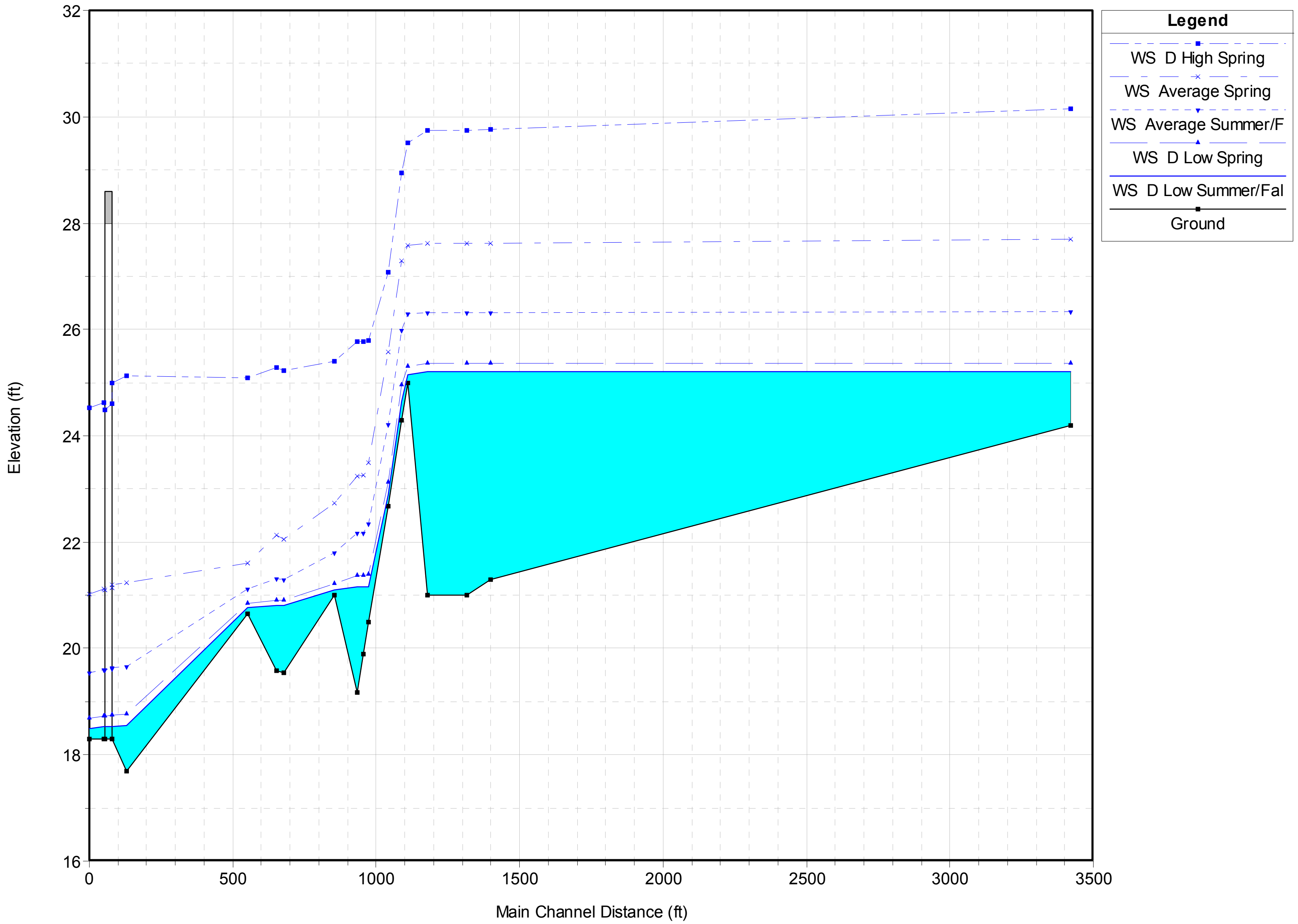


Figure 22 Rock Ramp Water Surface Profile, Fish Passage Design Flow Rates

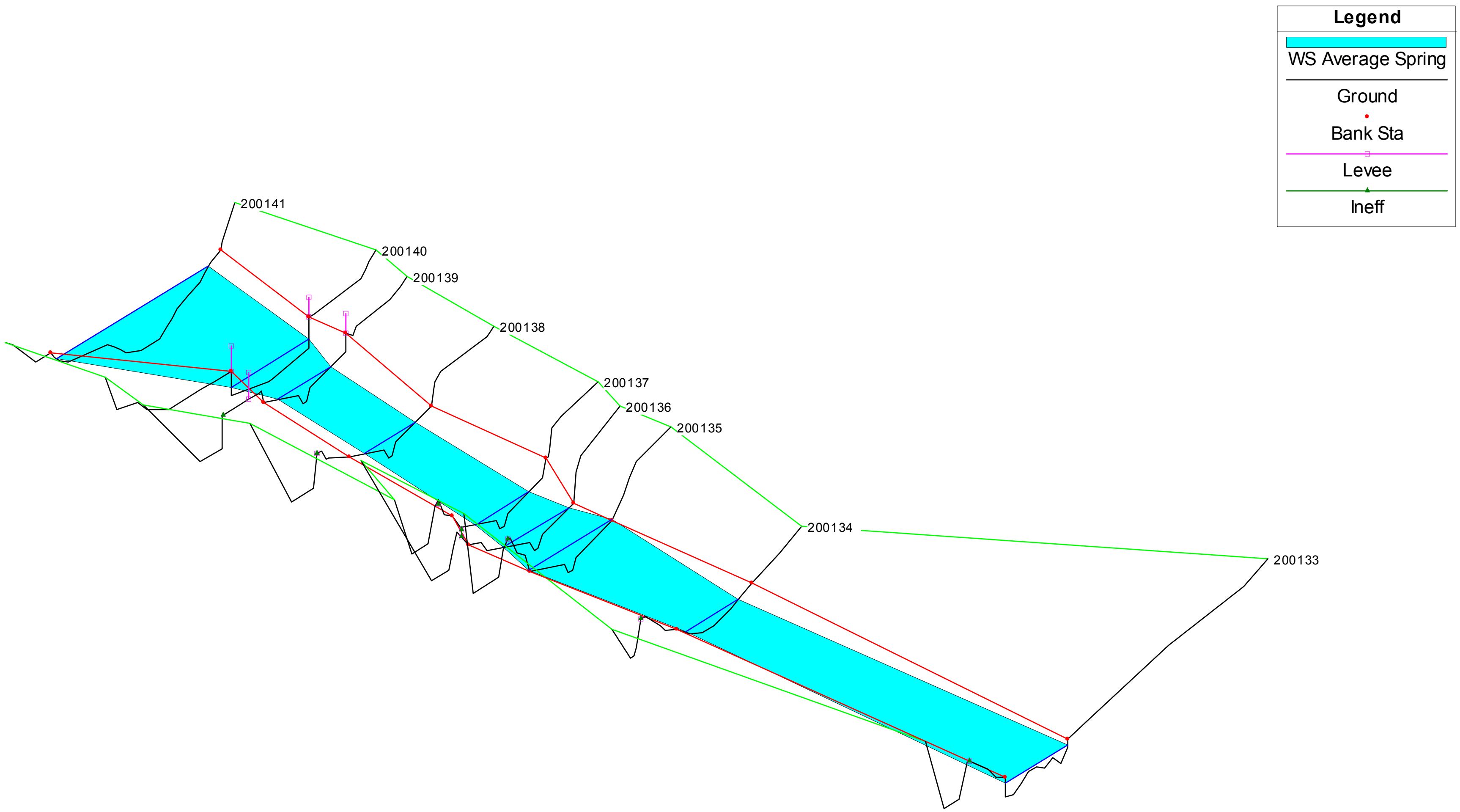


Figure 23 Rock Ramp Isometric View (water surface at 319 cfs)

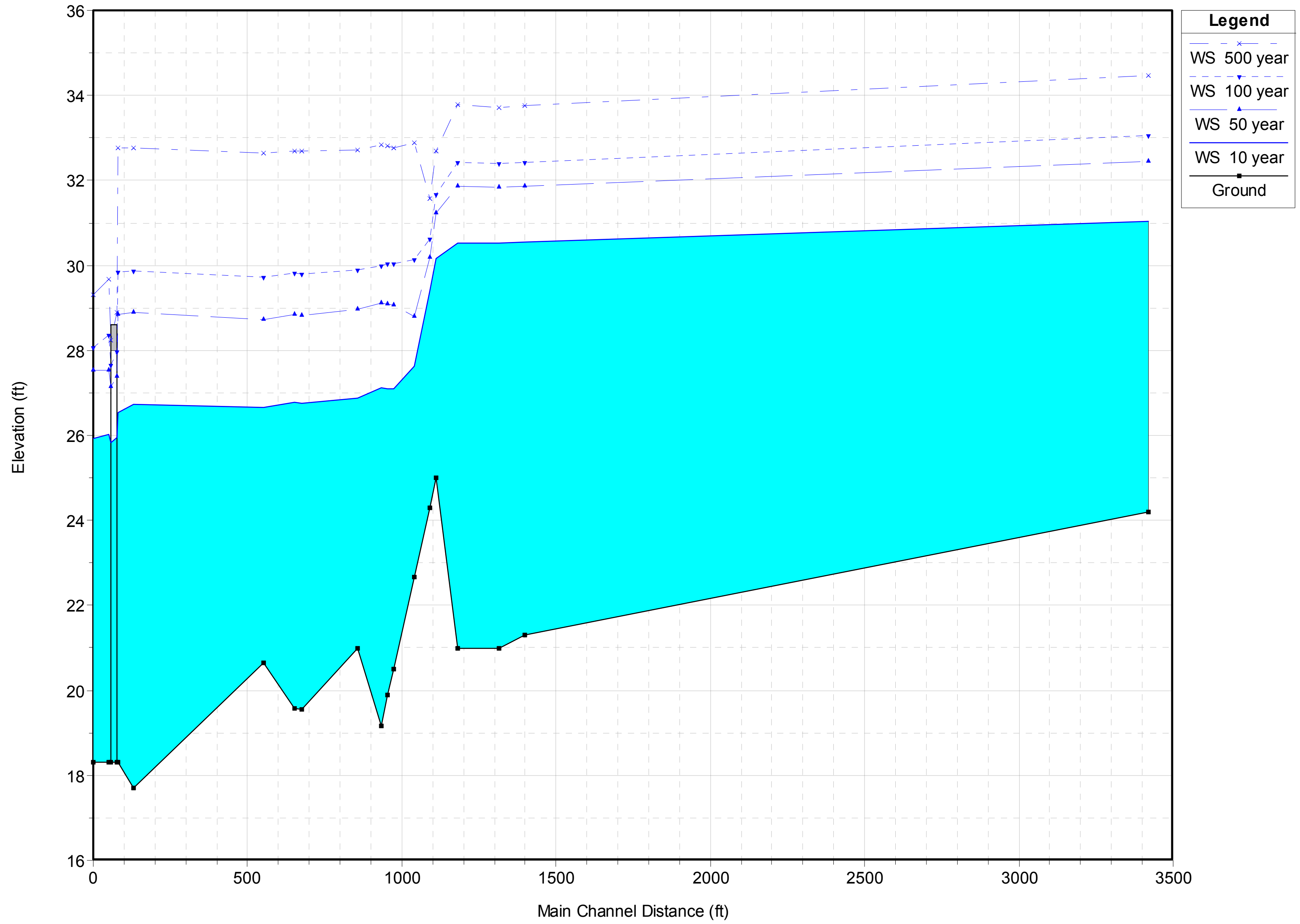


Figure 24 Rock Ramp Water Surface Profile, Peak Flow Rates

DETAILED EVALUATION OF SELECTED ALTERNATIVES

Denil Fish Ladder

Fishway Description

The Denil fish ladder would be located on the south embankment of the dam and would replace the existing ladder. The south embankment was selected over the north embankment because the ladder would be accessible for construction and maintenance from the Essex County Greenbelt Association, Inc. property. The existing trail will allow construction vehicles access to the site.

The total fishway length would be about 86 ft long and broken into three distinct sections, two Denil sections and a turning/resting pool. A plan and section of the Denil fish ladder configuration are shown on Figure 25 and Figure 26, respectively. The fishway entrance would be located on the south embankment near the existing fishway entrance and would have an invert level at El. 21.2 ft. To obtain this low entrance bottom elevation, the area in front of the entrance would need to be excavated. The fishway entrance and ladder sections would be constructed out of 12 inch thick concrete walls. The ladder sections would be installed at a 8H:1V (12.5%) slope and the lower ladder section would be about 20 ft long and include 12 baffles and the upper ladder section would be about 12 ft long with 8 baffles. The baffles would be spaced 20 inches on center and 30 inches wide. The turning pool would also act as a resting pool for fish moving up the ladder. The exit of the fishway would have a concrete exit channel approximately 40 ft south-west of the spillway, similar to the location of the existing fishway. The exit channel would have an invert at El. 24.9 ft.

The dam would include a notch to provide downstream passage for juvenile outmigrants during the late summer and fall. The notch would be about three feet wide by 12 inches deep located adjacent to the fishway. A gate in the exit channel would prevent outmigrating juveniles from descending the Denil fishway. During the spring migration period this notch could be used to provide attraction flow to the entrance of the fish ladder to enhance passage effectiveness.

Dam Modifications

The hydraulic analysis, which was presented in the previous section, indicates that the south existing embankment is overtopped for a 10, 50 and 100 year flood event. The Office of Dam Safety Inspections have also recommended improvements to the south embankment. Therefore, the fish ladder installation would include modifications to the dam embankment to prevent overtopping.

The average embankment height between the abutment and the existing ladder currently ranges between El. 28.9 ft and El. 30.0 ft. The height of the remaining dam embankment from the existing fish ladder to the south ranges between El 30.0 ft and El. 31.0 ft. The embankment would be overtopped by approximately 4 to 48 inches for 10 to 100 year flood, respectively. Therefore, for this study, Alden has assumed that the south embankment and abutment height would be raised to El. 34.0 ft to provide 1 ft of freeboard for the 100 year flood. Alternatively, the dam embankment could be modified by armoring the embankment with riprap to provide scour protection for overtopped conditions.

The USGS gage located approximately 150 ft downstream is a barrier to fish passage at low river flows. Therefore, this option includes notching the USGS gage to provide fish passage during low river flows. Alternatively, the USGS gage could be removed to provide upstream passage.

Hydraulics

The fishway would be designed for fish passage at water levels corresponding to expected river flows during the fish migration period. During low flow periods, minimum water depth in the fishway entrance would be two feet. At high river levels the entrance would have about 4.8 ft of water depth. The hydraulics conditions in the impoundment would not significantly change from existing conditions with the addition of a Denil ladder.

The USGS gage would be recalibrated once the center of the weir is notched. The notch will improve the accuracy of the gage during low flow conditions by concentrating the flow through a smaller channel and providing greater change in water level.

Construction

The construction of the fishway and dam modifications would require small cofferdams upstream and downstream of the proposed Denil fishway. These cofferdams will allow the fishway construction to be completed in "the dry". Alternatively, the impoundment could be drained by removing the steel gate in the existing spillway. The spillway gate may be inoperable, therefore for this evaluation we assumed cofferdams would be used. Hay bales and silt fences would be installed around the project construction limits. The existing path on the southern shore would be expanded and improved to accommodate heavy equipment.

A cofferdam would be installed spanning in an arch from the south dam abutment to a point on the southern impoundment shore about 70 ft upstream to dewater the area in the impoundment at the fishway exit. A cofferdam would also be installed in the tailwater around the fishway entrance location downstream of the dam. The cofferdams could be portable inflatable cofferdams or steel frames with plastic liners. Dewatering pumps would then drain the area behind the cofferdams. Contractors will need to monitor the weather for storms and make the necessary provisions to protect the construction site from high flows.

Once the site is dewatered the southern embankment could be cleared and grubbed and the existing fishway would be removed. Excavation for the new fishway, structural fill added and graded and installation of the new concrete fishway would be then be installed. The site would then be backfilled, embankment grade raised to El. 34.0 ft and upstream stone protection added to the upstream face of the dam embankment.

Notching the USGS gage would require an upstream and downstream cofferdam similar to those used during the construction of the fishway. Once the cofferdams are installed and the area dewatered, pneumatic hammers and saws would be used to remove the concrete to create a notch. After the demolition of the existing concrete, concrete anchors and reinforcing steel would be placed, wooden forms installed, and concrete poured to make the notch.

Installation of the new fishway, dam modifications and notching the USGS gage would be accomplished in approximately 10 weeks. Mobilization of equipment, clearing and grubbing access roads, installing hay bales and silt fences around the project limits and installing cofferdams would take approximately two weeks. Installation of the fishway and dam modifications would require approximately 5 weeks and notching the USGS gage would take another 2 weeks. Removing cofferdams, clean up, and demobilization would take about one week.

Operation and Maintenance

Prior to the beginning of the fish run period, the fish ladder would be inspected for potential damage to baffles, debris blockage, and sediment accumulation. Once operational, the fishway would require periodic inspection of the ladder to monitor debris buildup. After storms with significant runoff, the ladder and exit pool should be inspected and debris removed, as necessary.

Passage Effectiveness

The Denil ladder configuration is based on conventional design practice for fishways. This ladder design has been effectively used for passing alewife and blueback herring at many low head dams through the Northeast and Mid-Atlantic regions. The entrance to the fishway would be located as close to the spillway as possible, consistent with USFWS design requirements at other sites. At low river flows, fish should not have any problems finding the ladder since the entrance would be located in the pool at the base of the dam. At high river flows, fish might have to search for the fishway entrance, but likely would be able to locate it relatively quickly because of narrow river channel widths.

Although upstream passage for anadromous target species would be achieved with this alternative, some riverine fishes and American eel migrants (elvers and yellow eels) would not be capable of passing upstream due to limited swimming capabilities. Tesch (1977 - as cited in Clay 1995) reports that eels between 4 and 6 inches can swim at speeds up to 5 ft/sec. Larger eels would likely have the capacity to swim at speeds exceeding average velocities in the ladder (3 to 5 ft/sec) and some may therefore be able to ascend a Denil ladder by swimming. In addition, the ability of eels to ascend solid surfaces may facilitate some passage along the internal margins of the ladder. Nonetheless, a relatively simple ladder designed specifically for eels would pass this species more efficiently than a Denil ladder.

Wetlands and Aquatic Habitat and Resources

Water levels in the reservoir would not change from existing conditions; therefore, the addition of the Denil ladder would not result in any loss of wetland areas bordering the reservoir. However, construction activities would fill in a small wetland area adjacent to the fishway entrance. Also, potential impacts to downstream habitats resulting from sediment release during construction may occur.

Recreation Resources

Water levels in the impoundment would not change significantly; therefore the Denil ladder would not impact current boating conditions.

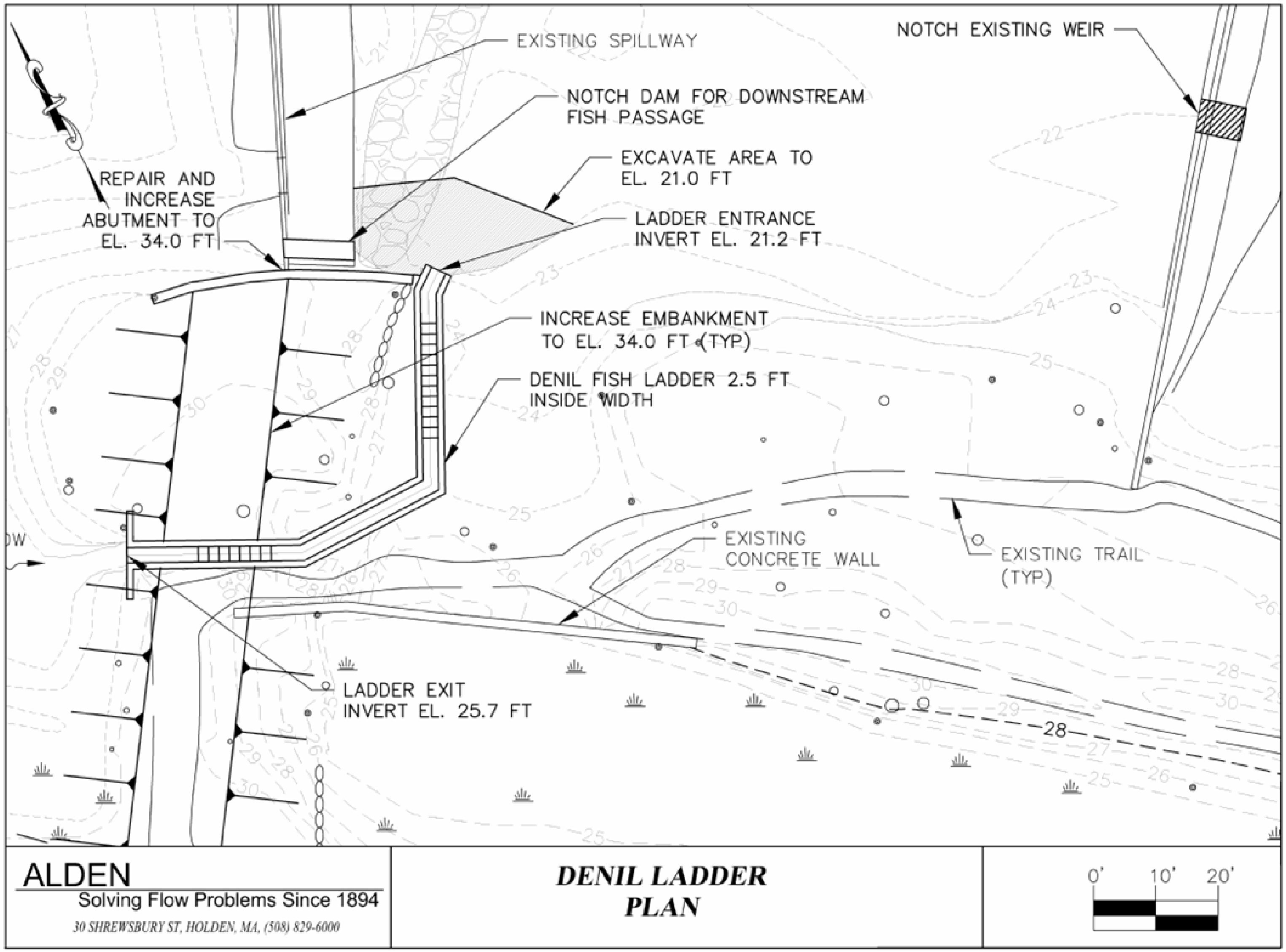


Figure 25 Denil Ladder - Plan

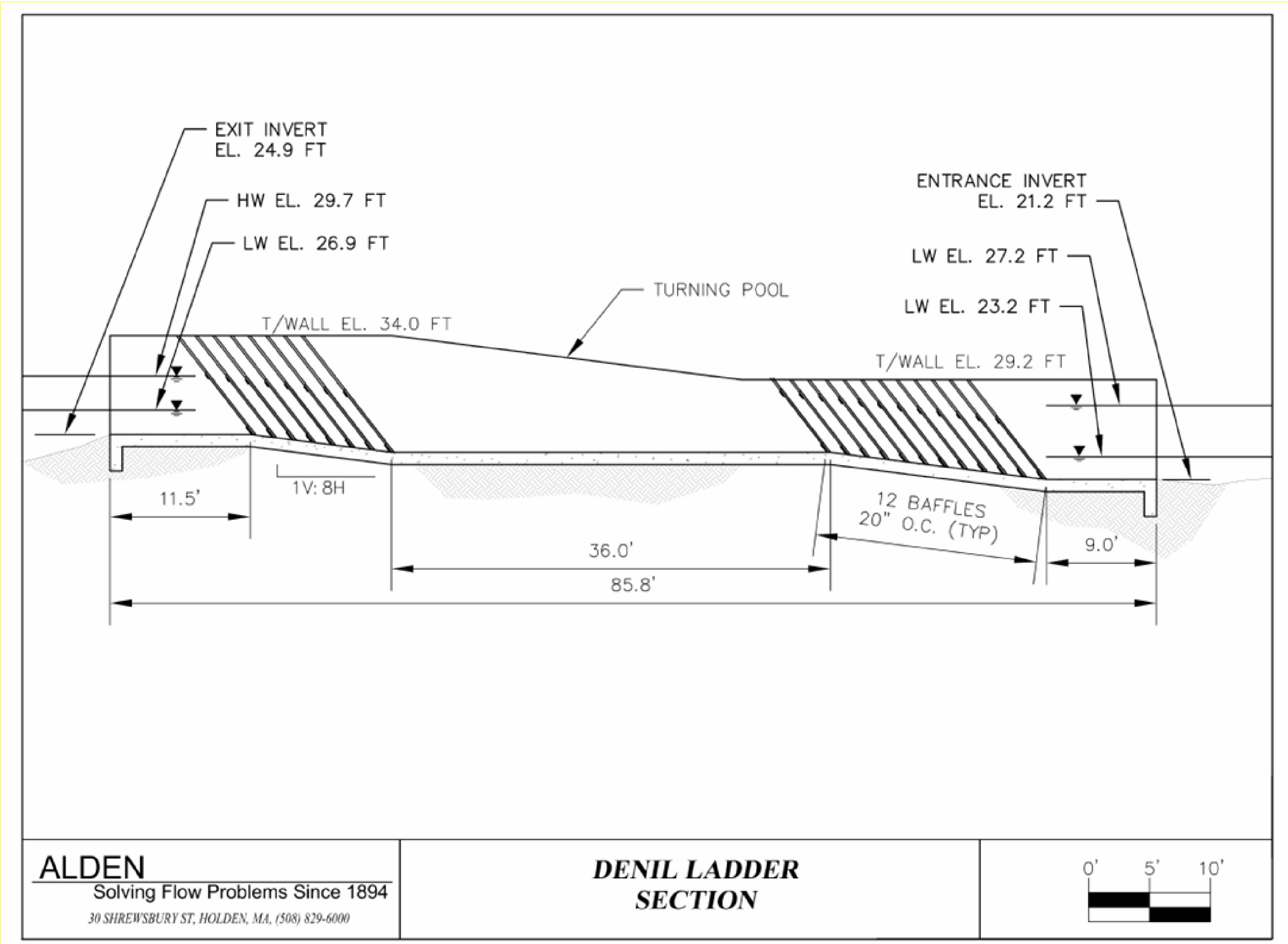


Figure 26 Denil Ladder Section

Fish Bypass Ramp, South Embankment

Fishway Description

A fish bypass ramp would be installed on the south dam embankment adjacent to the spillway, as shown on Figure 27. This fishway would be approximately 20 ft wide and 270 ft long, and would have slope sections of approximately 30H:1V between turning pools. The bypass would have 10 pools with a hydraulic drop of 6 inches per pool. The pools would be separated by large boulder sills. This design includes two long flat turning pools. The fishway pools and side slopes would be constructed with rocks and boulders. The fishway entrance would be located near the base of the dam downstream of the dam. The fishway entrance would have an invert at El. 21.3 ft and the exit channel invert would be at El 26.0 ft. The fishway exit channel could include an optional flow control structure consisting of a trapezoidal weir. The weir would have a 4 ft bottom width with 1H:4V side slopes and channels bolted to the downstream face to receive stoplogs. This would allow stoplogs to be installed to prevent damage during floods. Alternatively, a flow control weir structure could be constructed of large boulders. A typical section of the bypass channel is shown on Figure 28.

The fishway would be supported by a well graded, compacted gravel base with an underlying impervious polyliner membrane or clay layer. The membrane will reduce leakage and seepage to improve low flow passage conditions. The substrate material would increase in gradation to a lined channel with riprap approximately 6 to 24 inches in diameter. Boulder sills would create pools approximately every 15 ft. The boulders creating the sills or weirs would be separated by a 3 to 6 inch gap providing passage at low flow and passage for bottom orientated fish. The boulders would be approximately 3 to 5 ft in diameter, partially buried creating 3 ft high weir crests. The boulders would be pinned and locked in place with large rock and riprap. The upstream and downstream side of the boulders would be supported by riprap.

The fishway would provide downstream passage for the juvenile out migrants during the late summer and fall. The fishway would provide a minimum pool depth of 1.5 ft during low flow conditions.

Dam Modifications

The fish bypass ramp alternative would require the same dam and USGS weir modifications as described previously for the Denil ladder alternative. The south abutment and embankment would need to be raised to El. 34.0 ft and the USGS gage would be notched to provide fish passage during low flow conditions. Alternatively, the USGS gage could be removed and relocated to provide fish passage.

Hydraulics

The fishway would be designed for fish passage at water levels corresponding to expected river flows during the fish migration period. During low flow periods, all of the river flow would be routed through the bypass. At this low flow (10 cfs) the minimum water depth in the fishway entrance would be 6 inches. At a design high river flow rate of 1,597 cfs, the entrance would have approximately 1.8 ft of water depth. Flows in the bypass would range from about 10 cfs at river low flow up to about 100 cfs at the high design river flow. The hydraulics in the reservoir would not significantly change from existing conditions with the addition of the fish bypass ramp. At 10 cfs river flow, the water level in the impoundment with the fish bypass ramp would be about 1 inch lower than the current water levels.

For this evaluation, Alden has assumed that stoplogs could be installed in the exit channel of the fishway to prevent water entering the fishway during high floods. If the fishway did not include a stoplog or gate structure then the fishway would need to be designed to handle higher water levels which would increase the height, width and cost of the fishway.

The hydraulic design of the bypass channel was based on USFWS guidelines for pool and weir fishway and Fish Passes (FAO/DVWK 2002). The energy dissipation factor for the fishway ranges from 0.4 lbs/ft^3 at the design low flow to 4.0 lbs/ft^3 for the design high flow.

The USGS gage would be recalibrated once the center is notched. The notch would improve the accuracy of the gage during low flow conditions by concentrating the flow through a smaller channel and providing greater change in water level.

Construction

The area upstream and downstream of the bypass channel would require dewatering similar to the Denil fish ladder dewatering techniques. Hay bales and silt fences would be installed around the project construction limits. The existing path on the southern shore would be expanded and improved to accommodate heavy equipment.

Once the site is dewatered the southern embankment and bypass channel fishway location would be cleared and grubbed and the existing fishway would be removed. The fishway would require excavation of approximately the 800 cubic yards of soil. The fishway would be lined with an impervious membrane and filled with well graded compacted gravel. Boulders would be set to create weirs and the pools and side slopes lined with about 12 to 18 inches of rip rap. Approximately 250 tons of boulder size rock and 400 cubic yards of rip rap are required.

The USGS weir would be notched as described for the Denil ladder alternative.

Installation of the new bypass ramp fishway, dam modifications and notching the USGS gage would be accomplished in approximately 10 weeks. Mobilization of equipment, clearing and grubbing access roads, installing hay bales and silt fences around the project limits and installing cofferdams would take approximately two weeks. Installation of the bypass channel and dam modifications would require approximately 5 weeks and notching the USGS gage would take another 2 weeks. Removing cofferdams, clean up, and demobilization would take about one week.

Operation and Maintenance

Prior to the beginning of the fish run period, the fish bypass ramp would be inspected for debris blockage and sediment accumulation. Once operational, the fishway would require periodic inspection of the ladder to monitor debris buildup. After storms with significant runoff, the ladder and exit pool should be inspected and debris removed, as necessary.

Passage Effectiveness

The fish bypass ramp would be configured based on USFWS design practice for fishways and should be effective in passing alewife, blueback herring, American Shad, Lamprey and elver and yellow phase American eels. The design of the bypass channel fishway is consistent with the USFWS criteria of an energy dissipation factor than 3 lbs/ft^3 for effective fish passage. The entrance to the fishway would be located at the base of the spillway. Fish should not have difficulty finding the bypass ramp entrance at low river flow because all of the river flow will be going through the bypass. At high flows, fish would be able to move upstream past the ramp entrance towards the dam. Most riverine species currently residing in the Ipswich River would be capable of negotiating a fish bypass ramp.

Operation of the fishway would require periodic inspection to monitor debris buildup. After storms with significant runoff, the pools should be inspected and debris removed, as necessary.

Wetlands and Aquatic Habitat and Resources

Water levels in the reservoir would not significantly change (less than 1 inch) from existing conditions; therefore the addition of the bypass channel fishway would not result in any loss of wetland areas bordering the reservoir. However, construction activities would fill in a small wetland area adjacent to the fishway entrance. Also, potential impacts to downstream habitats resulting from sediment release during construction may occur.

Recreation Resources

Water levels in the impoundment would not change significantly; therefore, the bypass ramp would not impact current boating conditions. The configuration of the fish bypass channel would not allow downstream passage by canoes and kayaks because of the sharp bends and boulder weirs.

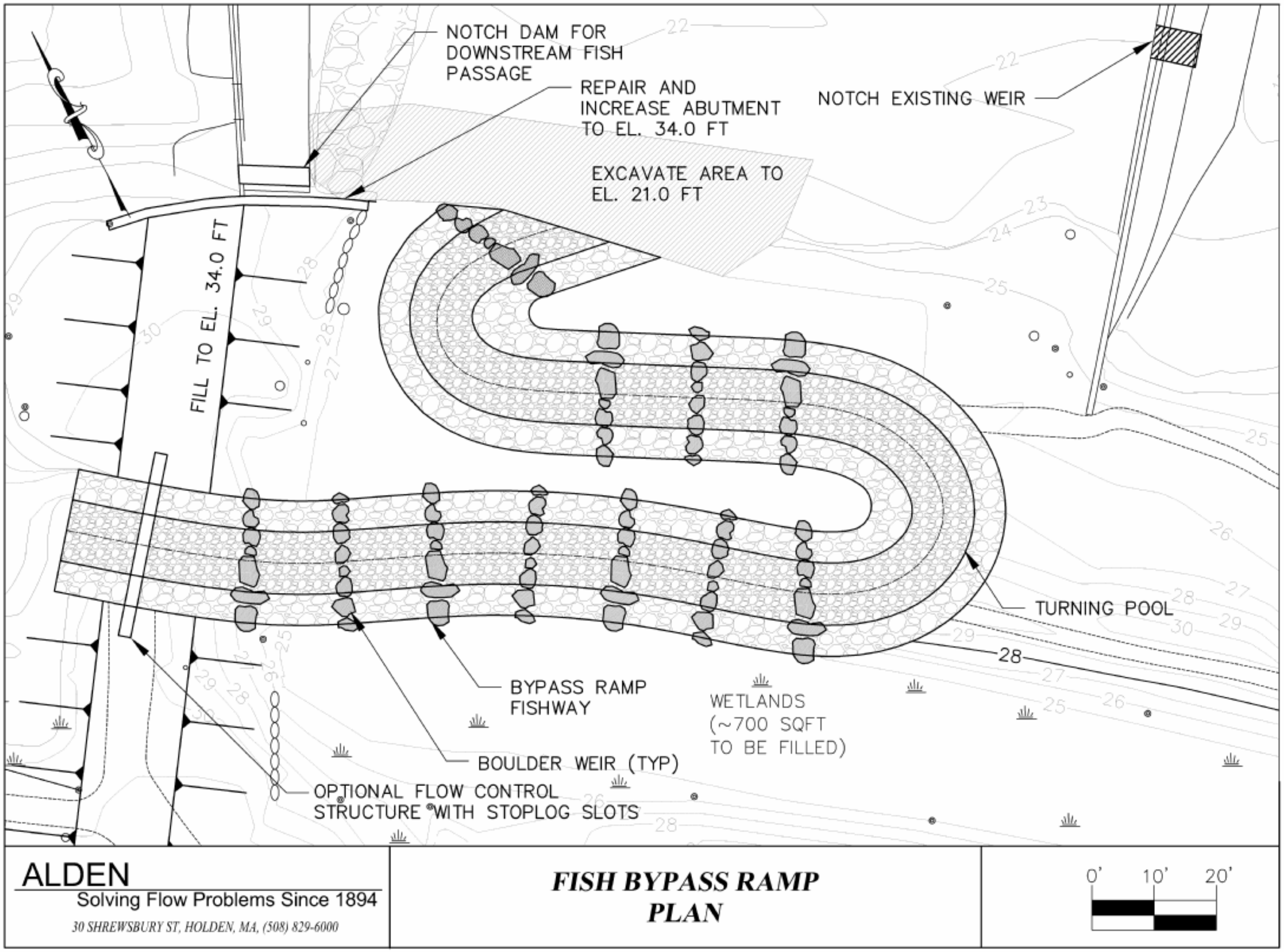


Figure 27 Fish Bypass Ramp Plan

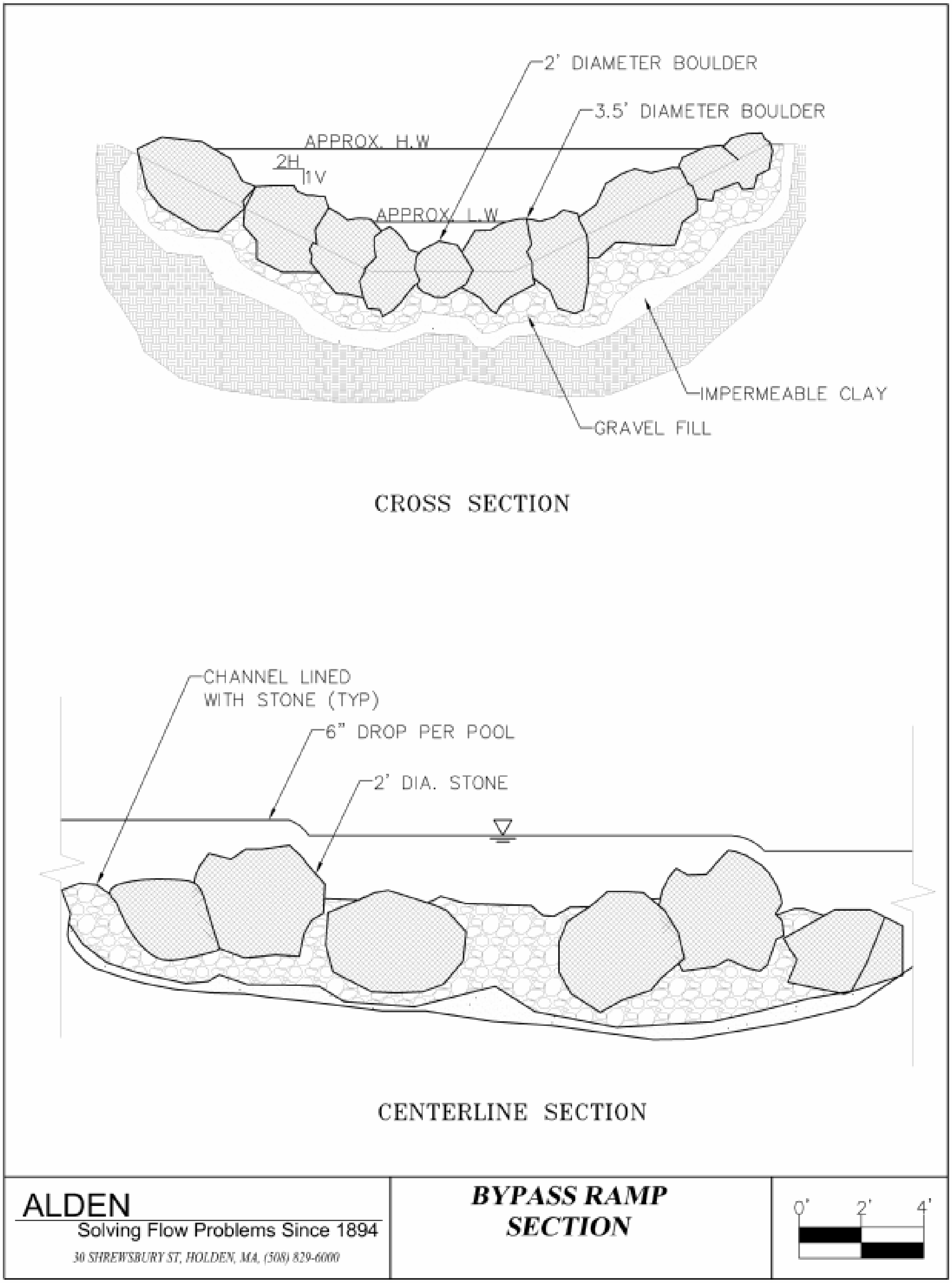


Figure 28 Fish Bypass Ramp Section

Rock Ramp

Rock Ramp Description

A rock ramp would be installed on the downstream face of Willowdale Dam spillway. The top of the ramp at the dam would have an invert level at El. 25.0 ft, which would also be the top of the modified spillway. The rock ramp would span the entire width of the river and extend about 165 ft in the downstream direction at a 30H:1V slope to a point about 10 ft downstream of the existing USGS gage, as shown on Figure 29. The downstream end of the ramp would terminate at the existing river bed at approximately El. 20 ft. The rock ramp would be roughened with large riprap and boulder weirs similar to the bypass channel. The ramp would have a total 10 pools and rock weirs with a hydraulic drop of 6 inches per pool and a centerline pool depth of 2 to 3 ft. This design should be sufficient to pass the target species and most resident fishes.

The rock ramp would include a center thalwag or low flow channel to increase fish passage efficiencies at low river flows. The dam would also be modified to concentrate low flows to the rock ramp low flow channel. The low flow channel would be 5 ft wide with 3H:1V side slopes and 20 inches deep. The rock ramp bed side slopes would be 20H:1V from the low flow channel to the existing river banks. The shallow slope concentrates deeper faster water near the center of the channel and provides shallower and slower water near the water edges. The rock ramp banks would have 3H:1V slope above 100 year flood level.

The rock ramp would be supported by a well graded, compacted gravel base with an underlying impervious polyliner membrane or clay layer. The membrane will reduce leakage and seepage to improve low flow passage conditions. The substrate material would increase in gradation to a lined channel with riprap approximately 6 to 24 inches in diameter. Boulder sills would create pools approximately every 15 ft. The boulders creating the weirs would be separated by a 3 to 6 inch gap providing passage at low flow and passage for bottom orientated fish. The boulders would be approximately 3 to 5 ft in diameter, partially buried creating 3 ft high weir crests. The boulders would be pinned and locked in place with large rock and riprap. The upstream and downstream side of the boulders would be supported by riprap.

The USGS gage would be relocated since the rock ramp extends beyond the current gage location. The new gage would be located at the dam. Piping would be installed along the upstream face of the dam and extend to a stilling well located on the improved south dam embankment. The stilling well would be located in a concrete vault with a steel cover. USGS would then develop a detailed discharge rating curve for the dam to calibrate head pond levels with river discharge.

Dam Modifications

The rock ramp would be located downstream of the existing spillway and would extend downstream of the dam at a gradual slope with stepped pools that create conditions acceptable for upstream fish passage. Rock fill would be placed immediately upstream of the spillway to provide a gradual run to the dam crest. Rock fill upstream and downstream of the dam provide additional stability to the dam. This alternative would require the same south embankment dam modifications as described previously for the Denil ladder alternative. The south abutment and embankment would need to be raised to El. 34.0 ft. The existing spillway would be lowered at the center to El. 25.0 ft and slope up to the existing abutments to El. 26.1 ft as shown on Figure 30.

The USGS gage would be buried or removed by the proposed rock ramp. A new gage could be located at the existing dam or at Willowdale Bridge downstream. For this analysis we have assumed the gage could be installed at the existing dam.

Hydraulics

The hydraulic analysis results for the rock ramp option were presented in the Hydrology and Hydraulics Section and Table 10 and Table 11. The results indicate that the ramp would slightly increase impoundment 100 year flood water levels (0.1 ft) and would decrease extreme low flow water levels by 1.6 ft.

The low flow channel in the center of the ramp would have the capacity for the entire river flow up to 100 cfs. For the extreme low flow conditions of 3 and 10 cfs, water depths in the low flow channel would range from 3 to 8 inches and velocities ranging from 0.6 to 3.5 ft/sec, if the channel was roughened without weirs (as modeled by HEC-RAS). The addition of stone weirs would create pools with depths of about 12 inches. At the design high river flow of 1,597 cfs the water depths in the ramp would range from 4 to 5 ft and velocities ranging from 4 to 8 ft/sec.

Construction

Construction of the rock ramp would require the river to be diverted around the project site so that construction could be conducted "in the dry". One method would be to divert water through a bypass channel. Alternately, the river could be pumped or siphoned around the project through large pipes. For this analysis and cost estimate, Alden has assumed the existing old mill race/canal could be utilized as a bypass channel and the existing dam would act as a cofferdam to keep the project site dry. A cofferdam at the downstream limits of the project would be required to keep water from backing up into the work area.

First, a temporary construction access road would be installed to accommodate heavy equipment. Hay bales and silt fences would be installed around the project limits. The old mill race would be prepared as a bypass channel. The canal would be cleared and grubbed and a diversion created to discharge water approximately 100 ft downstream of the USGS gage. A portable inflatable or steel frame with a liner would be installed as a cofferdam across the river downstream of the project limits. The head of the canal would then be breached to divert the river. Construction would take place during the low flow period from July through September to reduce the diversion flows.

Once the river has been diverted and the project site dewatered, construction would be conducted in "the dry" using excavators and bulldozers. Fill material would be trucked into the site consisting of well graded gravel, clay and riprap. Once the fill material is set at the proper slope, boulders would be set to create weirs and the pools and side slopes lined with about 12 to 18 inches of rip rap. Approximately 2,400 cubic yards of gravel, 900 tons of boulder size rock and 950 cubic yards of rip rap are required.

The dam spillway would be modified by removing one or two courses of the large granite blocks that make up the spillway and adding a new concrete cap in the form of a shallow “V” at the lowered elevation. Repairs to the south dam embankment would be similar to previous options.

For this evaluation, Alden assumed that the USGS weir would be removed and replaced with a new gaging station at the existing dam. A new pipe would be routed from the impoundment to a stilling well inside a new concrete vault to measure water depth. USGS would then develop a calibration or rating curve for the modified spillway.

Installation of the rock ramp, dam modifications and relocating the USGS gage could be completed in approximately 4 months. Mobilization of equipment, clearing and grubbing access roads, installing hay bales and silt fences around the project limits would take approximately two weeks. Installing cofferdams, preparing a diversion canal and diverting the river would take another 2 weeks. Modifications to the spillway and installation of the USGS gage would take approximately 2 weeks. Installation of the rock ramp would require approximately 8 weeks. Removing cofferdams, sealing the diversion canal and repairing the south embankment, clean up, and demobilization would take another 4 weeks.

Operation and Maintenance

Operation and maintenance of the rock ramp across the entire river would be similar to fish bypass ramp alternative previously presented.

Passage Effectiveness

The rock ramp would be configured based on USFWS design practice for fishways and should be effective in passing alewife, blueback herring, American shad, Lamprey and elver and yellow phase American eels. Most riverine species currently residing in the Ipswich River would be capable of negotiating a fish bypass ramp.

Operation of the fishway would require periodic inspection to monitor debris buildup and damage. After storms with significant runoff, the pools should be inspected and debris removed, as necessary.

Wetlands and Aquatic Habitat and Resources

Water levels in the impoundment would change from the existing conditions with the rock ramp alternative. The ramp would require a lower spillway crest to limit flood flow water levels. However, lowering the spillway would also lowers the water levels during non-flood flows. Water levels in the impoundment would be reduced by 4 inches with 319 cfs up to 19 inches with 3 cfs river flow with the rock ramp installed. The change in water levels would impact wetlands and riparian habitat bordering the impoundment typically inundated during average and low flow conditions. The duration of inundation of wetland areas will be reduced and wetland area may move slightly down slope towards the new water surface.

Recreation Resources

Normal water levels would be reduced for average and low river flows in the impoundment. The lower water levels would reduce the surface area that is accessible by boaters. The Foote Brothers may also have to extend their docks to reach the waters edge during low flow conditions. The rock ramp is outfitted with a low flow channel that could be designed as a canoe chute. A canoe chute would allow boaters to access the lower reaches of the Ipswich River. A portage could also be installed to allow boaters around the rock ramp.

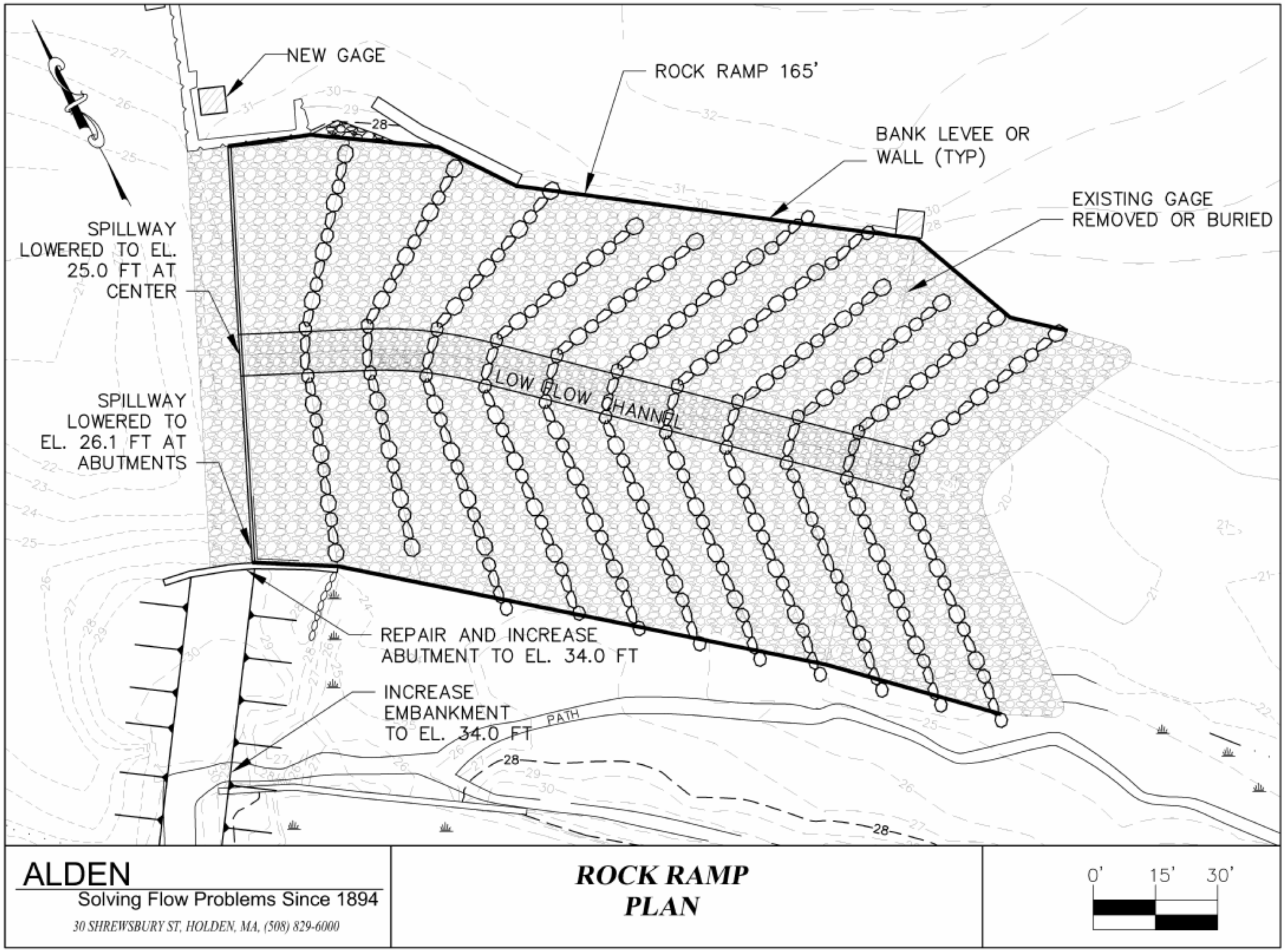


Figure 29 Rock Ramp Plan

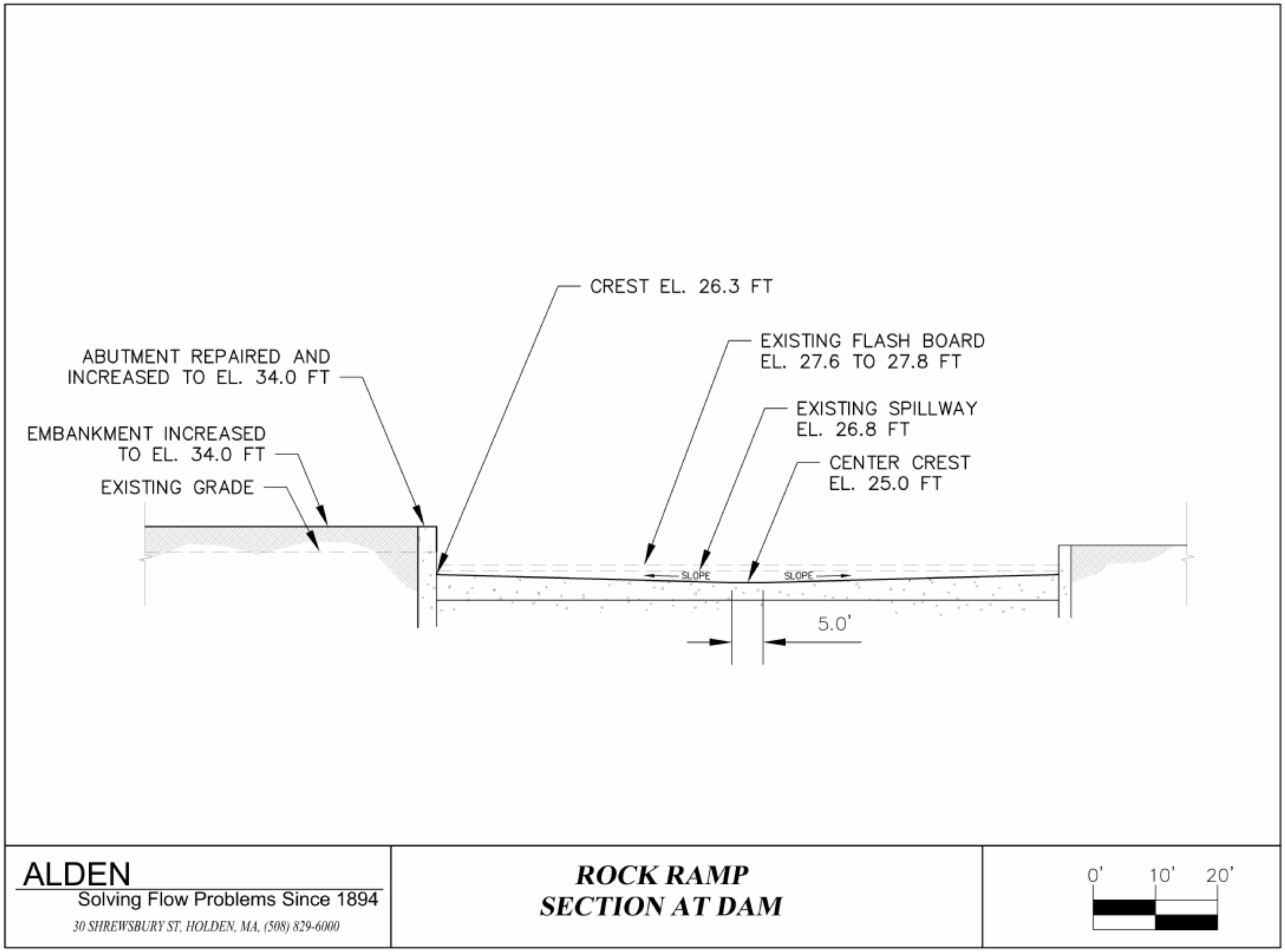


Figure 30 Rock Ramp Section at Dam

Dam Removal

Dam Modifications

The dam removal alternative would remove the physical barriers that prevent upstream fish passage and would reconnect fish populations to the upstream reaches of the Ipswich River. Dam removal would include removing the spillway portion of the dam, the USGS weir, and the stone wall weir. A small wedge of sediment located on the upstream face of the dam would also be removed or regraded down to the natural river bed armor layer, if present. Areas where armor stone is not encountered would be lined with rock to prevent erosion and head cutting. The existing north abutment would remain to support Foote Brothers property and would require additional riprap fill for support. The south abutment would be removed and the new bank stabilized. A plan of the spillway breach is presented on Figure 31.

The USGS gage would also be removed and a new location suitable for measuring river discharge would need to be identified. For the purposes of this evaluation, Alden has assumed the river constriction at Willowdale Bridge would be a suitable location for the new USGS gage. Piping for the new USGS gage at the bridge would be installed just upstream of the bridge and extend to a stilling well located on shore. The stilling well would be located in a concrete vault with a steel cover. USGS would develop a detailed discharge rating curve to correlate water levels upstream of the bridge with river discharge.

Hydraulics

The results of the HEC-RAS hydraulic analysis were reviewed and presented in the Hydrology and Hydraulics Section and presented in Table 9. The criteria selected for determining barriers, as previously discussed are:

- Maximum velocity of 7 ft/sec which is the approximate bust speed of adult herring 6 to 11 inches in length (USACE 1991).

- Vertical drops of no greater than 0.5 ft.

- Minimum water depths of 6 inches.

The analyses of the dam breach with design fish passage flow rates indicate that there would not be any velocity barriers to fish passage in the river reach modeled. The majority of the velocities were below 4 ft/sec for the river reach modeled. River station at 975 ft just upstream of the USGS gage had the highest velocities at 5.6 ft/sec for 319 cfs and 6.8 ft/sec for 1,597 cfs river flows. Velocities in the river channel through the Willowdale dam breach section and impoundment were less than 4.0 ft/sec for fish passage design flows, well below the 7 ft/sec fish swimming speed criterion.

Water levels in the impoundment were reduced by 4 ft from El. 27.9 ft at the dam to El. 23.6 ft (NGVD 29) for 319 cfs (spring average flow rate) and by 6 ft for the low flow of 3 cfs. Water levels at the upstream boundary of the hydraulic model were only reduced by 1.5 ft from El. 28.0 ft to El. 26.5 ft (NGVD 29) at a 319 cfs flow. During the late summer and fall (August through November) when the average river discharge is 73 cfs, the water level would be lowered by 4.8

ft in the impoundment from El. 27.2 ft to El. 22.5 ft (NGVD 29). Water levels at the upstream boundary of the model (station 3401 ft) would be expected to drop by 1.8 ft from El. 27.2 ft to El. 25.4 ft (NGVD 29) for a river discharge of 73 cfs.

Sediment

Relatively little sediment has accumulated within the impoundment due to Willowdale dam. Survey bathymetry indicates bottom elevations in the impoundment as low as El. 20.8 ft, which is lower than the river bottom immediately downstream of the dam at El. 21.8 ft. Average impoundment bottom levels within the river channel and downstream between the dam and USGS gage are about the same at El. 22.0 ft. However, a wedge of material on the upstream face of the dam is present. The wedge starts about 30 ft upstream of the dam at El. 22.0 ft and increases in height to El. 25.0 ft at the dam.

The relatively small amount of sediment in the impoundment is likely due to high velocities (2 to 3 ft/sec) within the impoundment during peak flow events. The impoundment is contained on the north by Topsfield Road and on the south by a steep bank without presence of a flood plain to help dissipate peak river flow energy. These conditions create high velocities through the impoundment that would scour out any accumulated sediments. Sediment samples were not gathered for this study, but the survey indicates a gravel bottom substrate through the impoundment. Sediment deposits would be located near the banks of the impoundment adjacent to the dam outside the main channel of the river.

The sediment wedge upstream of the dam could be part of the original dam construction, or it could have been deposited as bed load material accumulating at the dam. If the material were deposited as bed load, Alden would expect to have found more sediment in the impoundment where the velocities in the channel would have been lower than the velocities at the spillway. More sediment would have resulted in a shallower bottom angle approaching the dam than indicated on the bathymetric surveys. Because the slope of the substrate material upstream of the dam is approximately 10H:1V, Alden has assumed that this substrate material was part of the original dam construction. The total volume of the material creating this wedge is estimated to be about 480 cubic yards. For the purposes of the dam removal alternative we assumed this material would be removed and located upland or off site.

Construction

Removal of the dam would be conducted during the low flow season in the late summer to ease construction efforts. Breaching the spillway would first require the reservoir to be dewatered and accumulated sediments to be removed. A temporary construction access road would be installed to accommodate heavy equipment. Hay bales and silt fences would be installed around the project limits. For this study, we assumed the spillway stoplogs would be removed to dewater the impoundment. Alternatively, the river could be diverted through a bypass channel as described for the rock ramp option to dewater the project area. Once the impoundment has been dewatered cofferdams would be installed around one-half of the spillway and the dam structure and sediments removed. Once the first half of the dam has been demolished, the river would be diverted through the removed portion of the spillway and cofferdams installed around the other half of the spillway. The dam and sediments in the other half of the project would then be removed.

The spillway would be removed using excavators and heavy equipment. The spillway would be excavated down to the natural river bed armor stone, if present. Material from the spillway breach could be used to stabilize the breach side slopes, channel bottom and river banks for the new river channel through the impoundment. The north abutment wall would be supported by large riprap or additional concrete reinforcement to support the Foote Brothers property. The sediments could be deposited to an upland disposal site or re-graded on site. The new river channel banks through the impoundment may require armoring to prevent excessive erosion and contain river bank sediments.

Breaching the spillway would be accomplished over a period of 10 weeks. Mobilization of equipment, clearing and grubbing access roads and installing hay bales and silt fences around the project limits would take approximately two weeks. Dewatering the impoundment and installing cofferdams around half of the spillway would take another week and removing half the spillway and sediments, and stabilizing the abutment would take about 2 weeks. Removing the other half of the spillway and stabilizing the abutment, would take another 3 weeks. The USGS gage would be removed and relocated concurrently with the spillway removal. Removing the cofferdams, cleanup and demobilization would take approximately 2 weeks.

Operation and Maintenance

Removal of the dam would not require any river channel maintenance for fish passage and would eliminate all operational and maintenance activities associated with a fishway and the existing dam. However, for the first two to three years until vegetation becomes established the river channel should be monitored for signs of head cutting and excessive bank erosion and repaired as required.

Passage Effectiveness

Willowdale Dam acts as a physical barrier preventing anadromous and riverine fishes from migrating upstream to historic breeding areas and habitat. Removing this physical barrier by breaching the spillway would allow migratory and riverine species to pass upstream. The hydraulic conditions after breaching were reviewed for the existence of velocity barriers and shallow water depths, as discussed previously, and no such barriers were found. Therefore, the spillway breach alternative should be an effective method for allowing anadromous fishes to reach upstream spawning areas and the catadromous American eel to access rearing habitats in the Ipswich River. Additionally, downstream movement by juvenile river herring, shad and silver phase American eel would not be impeded. Resident riverine fish species would also be able to move freely upstream and downstream during all river flow conditions.

Wetlands and Aquatic Habitat and Resources

A detailed survey of the entire impounded and existing wetland area was not available for this evaluation to determine the amount of wetland area impacted. However, in general terms water levels in the reservoir would change from the existing levels at El.28.0 ft to El. 23.7 ft after the spillway breach for average river flow rates. Lowering the water level below the low flow periods will affect the existing wetlands within and bordering the impoundment in one of two ways: (1) draining the wetland and moving the source of hydrology (e.g., soil saturation or inundation): (2) changing the hydrologic regime such that the level or duration of inundation or saturation is reduced. Due to the lower water levels after the dam breach the conversion of wetland habitat is expected. In the upper reach of the impoundment, migration of the existing wetland down slope towards the new water surface will occur. In the lower portion of the impoundment, the shrub wetland along the steep slopes will be converted to woody upland species and the area formally inundated will re-vegetate with trees, shrubs, and persistent emergent species. The area along the new channel will re-vegetate with persistent emergent species and wood shrubs typical of the river system. The removal will restore pre-dam wetland habitat that was submerged by the impoundment.

Extreme low river flow conditions in late summer when upper portions of the Ipswich River nearly runs dry and consists of isolated segmented pools could occur in the river reaches in the vicinity of Willowdale Dam if breached. Currently, the dam impoundment keeps the river flooded during low flow periods providing refuge habitat during extreme low flows. However, recent water agreements for the Towns of Wilmington and Reading are expected to limit the frequency of extreme low water events and increase the low river flow rates.

The new riparian areas within the impoundment should be monitored for erosion and for the establishment of invasive species. Native shrubs and trees that can be planted from live stakes (Alders, Willows and Viburnums) should be installed along the banks of the new channel in the impoundment to provide additional bank stabilization and reduce the potential for the establishment of invasive species. Common invasive species include the following:

- Purple loosestrife (*Lythrum salicaria*)
- Common reed (*Phragmites australis*)
- Japanese knotweed (*Polygonum cuspidatum*)

Japanese knotweed (*Polygonum cuspidatum*) is an aggressive invasive that prefers sunny upland areas. This species of invasive plant, and possibly others, may colonize any area of newly exposed soil.

The management of invasive species should be addressed in the development of this alternative. However it is not reasonable to expect the complete control or eradication of the species from the river system. The goal should be to limit the spread of these plants to allow diversity of native plant species to become established.

Breaching of the dam would be a significant benefit to migratory species and resident riverine fishes. The dam breach would result in there being no upstream or downstream barriers to river herring, shad, and American eel. Consequently, abundant habitat of the dam location would be available to all three of these species. Unlike other alternatives, there would be no impediments to downstream migrations from dam breaching. Also, removal of the dam would decrease fragmentation of habitat and resident fish populations by allowing most species to move freely upstream and downstream of the current dam site.

Restoration of flow, temperature, and sediment regimes to the section of the Ipswich River upstream and downstream of the dam site should result from breaching. This would improve habitat quality and availability for many of the fish species currently present in the vicinity of the dam. The removal would restore pre-dam habitat for fluvial species. However, loss of aquatic habitat from the dam breach may affect the abundance and distribution of some species currently residing in the backwater area of the impoundment. Most fish affected by habitat loss would likely disperse to other stream reaches, resulting in minimal overall impacts to fish populations within the reaches of the Ipswich River upstream and downstream of the current dam location. Impacts to downstream habitats during construction may occur due to limited sediment releases.

Recreation Resources

Lower water levels would substantially reduce the water surface area available to boaters and increase average river channel velocities upstream of the dam which would change the boating conditions. This change of conditions from pond to river would still provide opportunities to boaters. The dam removal would provide unobstructed upstream and downstream access to the river and remove the navigation and safety hazard of the spillway. During extreme low flow periods the river could become segmented limiting boating opportunities.

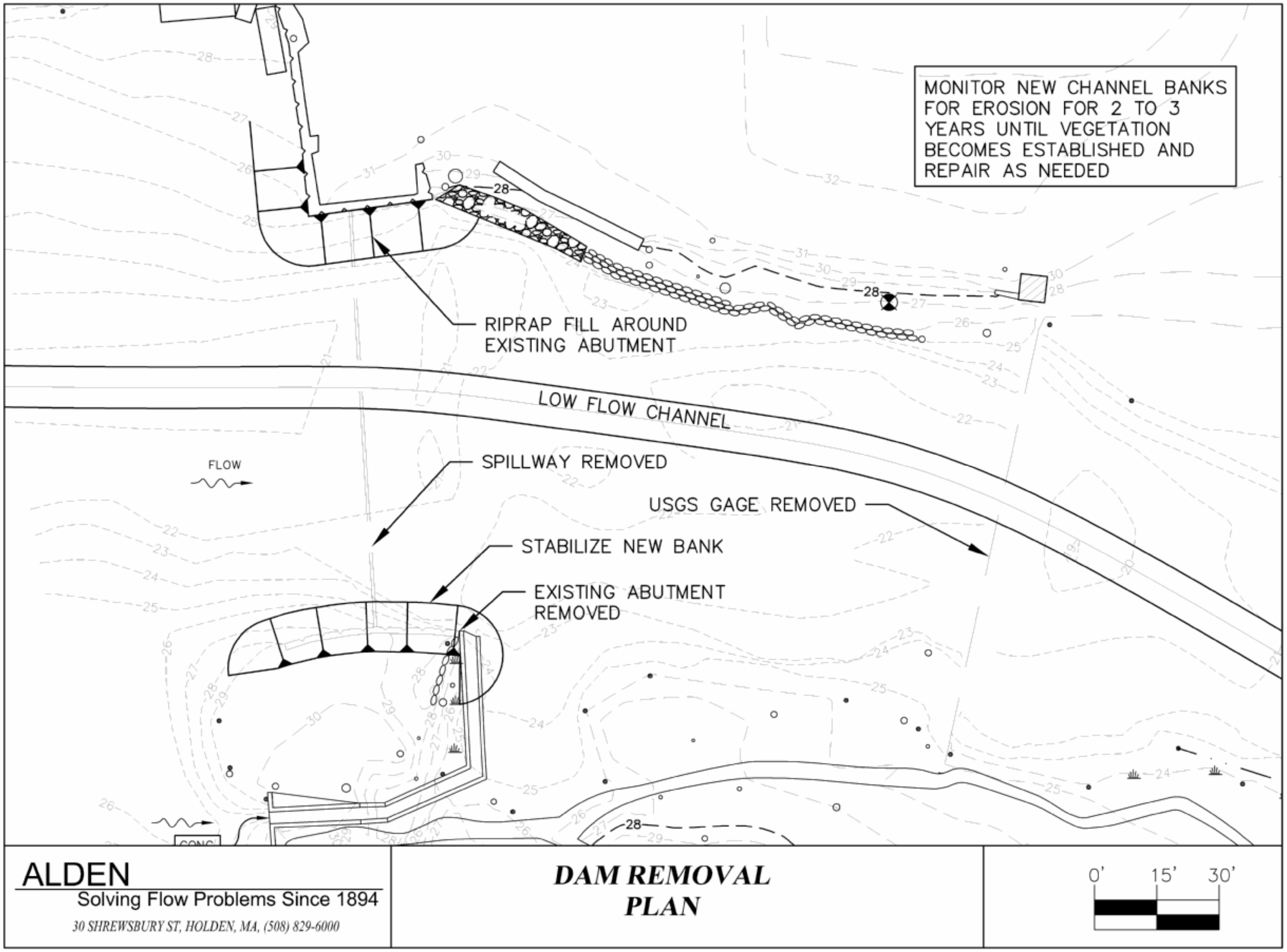


Figure 31 Dam Removal Plan

NO ACTION ALTERNATIVE

"No Action" alternative assumes the proposed fish passage project would not be implemented at the site. For this scenario, the current conditions at the site are assumed to continue unchanged and are included in the evaluation to provide a baseline for comparison to proposed alternatives.

Willowdale Dam is an earthen embankment with granite abutments and spillway. The total length of the dam is approximately 150 ft and the spillway is about 100 ft. The dam has a hydraulic height of 3 to 4 ft. A sluice gate is located near the south spillway abutment which is approximately 6 ft wide and 4 ft deep. Flashboards 10 inches high are installed on the spillway. The average water depth in the impoundment is about 4 to 5 ft. Remnants of an old mill head race canal are located downstream of the south dam embankment.

The dam is in fair to poor condition (DEM 2002). There is evidence of erosion and overtopping on the south dam embankment and around the existing fishway. Dam inspections were conducted by the Office of Dam safety in 2002 and identified deficiencies and recommendations. The hydrologic and hydraulic analysis indicates the dam would be overtopped for the 10-year, 50-year and 100-year flows. The earthen dam embankment does not have adequate erosion and scour protection to withstand overtopping. The dam is at risk to breach for the 10-year, 50-year and 100-year flood condition, which is a safety concern.

A concrete notch style fishway is located on the south dam embankment. The fishway is about 3 ft wide and 60 ft long, with a slope of 0.09 ft/ft. The fishway is in poor condition with visible evidence of deterioration and has reportable low efficiencies at passing fish.

A USGS gage is located approximately 150 ft downstream of the dam. The gage consists of a concrete weir about 110 ft long with a sloping crest to the center. The total height of the weir is about 2.5 ft. The USGS weir is in fair to poor condition with visible evidence of deterioration and possible undermining determined from the presence of scour holes upstream and downstream of the gage. The gage also acts as a barrier to fish passage during low river flows.

Willowdale Dam is an upstream barrier to alewife, blueback herring, shad, American eel, and resident riverine fishes and the existing fishway is ineffective at passing fishes upstream. Failure to provide some form of upstream passage at the Willowdale Dam will continue to prevent anadromous and catadromous species from accessing historic spawning and/or nursery areas within the Ipswich River drainage. This will prevent restoration efforts from extending the current range of these species. Failure to remove the dam or provide upstream passage will continue the fragmentation of habitat and freshwater fish populations.

Willowdale Dam would continue to provide slow moving backwater for boating enthusiasts to enjoy. However, the dam in its current condition is at risk of failing for a 10, 50 and 100 year flood event if improvements are not made to the dam embankment and abutments. After a Phase I inspection of the dam is conducted the Office of Dam Safety would determine the required repairs and maintenance required by the dam owner. Based on Alden's dam inspection and review of previous inspection reports the required repairs and maintenance will likely include the following:

- Remove vegetation from south embankment

- Armor south abutment and embankment for scour protection for high flows, or increase height to prevent overtopping.
- Increase spillway capacity to pass the 100 year flood

ESTIMATED COSTS OF ALTERNATIVES

Cost Estimates were developed for each of the fish passage alternatives. The estimates are based on quantities developed from conceptual designs for each alternative and from historical data from other projects. The cost data were adjusted for identifiable differences in project size, operations, and best professional judgment. The estimates are intended to provide budgetary costs and to identify the relative cost differences between alternatives. The cost estimates should be refined once a preferred alternative is chosen and detailed design has been completed to reflect the selected construction methods.

Alden’s cost estimates typically reflect the following assumptions:

- Present day prices and fully contracted labor rates as of May 2006.
- Forty-hour work week with single shift operation.
- Direct costs for material and labor required for construction of all project features.
- Distributable costs for site non-manual supervision, temporary facilities, equipment rental, and support services incurred during construction. These costs have been taken as 85-100% of the labor portion of the direct costs for each alternative.
- Indirect costs for labor and related expenses for engineering services to prepare drawings, specifications, and design documents. The indirect costs have been taken as 10% of the direct costs for each alternative.
- Allowance for indeterminates to cover uncertainties in design and construction at this preliminary stage of study. An allowance for indeterminates is a judgment factor that is added to estimated figures to complete the final cost estimate, while still allowing for other uncertainties in the data used in developing these estimates. The allowance for indeterminates has been taken as 10% of the direct, distributable, and indirect costs of each alternative.
- Contingency factor to account for possible additional costs that might develop but cannot be predetermined (e.g., labor difficulties, delivery delays, weather). The contingency factor has been taken as 15% of the direct, distributable, indirect, and allowance for indeterminate costs of each concept.

The costs do not include the following items that will affect estimates of the total capital costs:

- Costs to perform additional laboratory or field studies that may be required, such as hydraulic model studies, soil sampling, and wetlands delineation and mitigation.
- Costs to dispose of any hazardous or non-hazardous materials not previously identified that may be encountered during excavation and dredging activities.
- Costs for administration of project contracts and for engineering and construction management incurred by The Division of Marine Fisheries.
- Archeological survey or monitoring.

- Escalation
- Permitting costs

The estimated project costs for the selected alternatives are presented in Table 12 through Table 15. Capital costs for the alternatives range from $161,000 to breach the spillway to $544,000 to install a rock ramp. The Denil fish ladder, fish bypass ramp, and rock ramp options include dam repair costs to south dam embankment and abutment. These repairs may be required by the Office of Dam Safety for the no action alternative. Repairs have been estimated to cost about $43,000 and are listed as a line item for the Denil ladder, bypass channel and rock ramp cost estimates. A summary of the estimated installation for each alternative are presented in Table 16.

Table 12 Denil Fish Ladder Estimated Costs

Item	**Estimated Cost ($ x 10^3)**
Direct Costs	
Mobilization and Demobilization	19
Site Preparation	15
Cofferdam	22
Site Work	13
Fish Ladder Concrete Structures	87
USGS Weir and Downstream Passage Notch	3
Fish Ladder Trash Rack, Gates and Baffles	6
Repair South Dam Embankment	43
Direct Costs (May 2006 $)	$208
Indirect Costs	21
Total Construction and Indirect Costs	$229
Allowance for Indeterminates/Contingencies	57
Total Estimated Project Costs (May 2006 $)	$286

Table 13 Fish Bypass Ramp Estimated Costs

Item	Estimated Cost ($ x 10^3)
Direct Costs	
Mobilization and Demobilization	18
Site Preparation	15
Cofferdam	19
Flow Control Exit Structure	20
Bypass Ramp Structure	71
Trash Rack and Gates	4
USGS Weir and Downstream Passage Dam Notch	3
Repair South Dam Embankment	43
Direct Costs (May 2006 $)	$193
Indirect Costs	19
Total Construction and Indirect Costs	$212
Allowance for Indeterminates/Contingencies	53
Total Estimated Project Costs (May 2006 $)	$265

Table 14 Rock Ramp Estimated Costs

Item	**Estimated Cost ($ x 10^3)**
Direct Costs	
Mobilization and Demobilization	36
Site Preparation	17
Cofferdam	19
Bypass River	11
Modify Spillway	13
Rock Ramp Structure	237
Replace Gaging Station at Dam	19
Repair South Dam Embankment	43
Direct Costs (May 2006 $)	$395
Indirect Costs	40
Total Construction and Indirect Costs	$435
Allowance for Indeterminates/Contingencies	109
Total Estimated Project Costs (May 2006 $)	$544

Table 15 Dam Breach Estimated Costs

Item	**Estimated Cost ($ x 10^3)**
Direct Costs	
Mobilization and Demobilization	11
Site Preparation	15
Cofferdams	19
Breach Dam	22
Stabilize Abutments	8
Stabilize Channel	6
Remove USGS Gage	14
Replace Gaging Station at Bridge	22
Direct Costs (May 2006 $)	$117
Indirect Costs	12
Total Construction and Indirect Costs	$129
Allowance for Indeterminates/Contingencies	32
Total Estimated Project Costs (May 2006 $)	$161

Table 16 Summary of Estimated Costs

Alternative	Total Project Costs
Denil Fish Ladder	$286,000
Bypass Ramp Fishway	$265,000
Rock Ramp	$544,000
Dam Breach	$161,000

SUMMARY

All four of the proposed fish passage alternatives are feasible and would meet the project's fish passage goals. Each alternative would provide effective fish passage for the target species at Willowdale Dam.

Description of Alternatives

The Denil ladder, bypass ramp, and rock ramp would include modifications to the south dam embankment to prevent overtopping during flood events. The embankment would include clearing and grubbing trees and stumps from the embankment, raising the embankment height to prevent overtopping, installing scour protection and stabilizing the south abutment.

A Denil fish ladder would be located on the south embankment approximately where the existing fish ladder is located. The ladder would be 2 ft wide, with a slope of 8H:1V with internal baffles. The ladder entrance would be located near the base the spillway and channel modifications would improve attraction flow conditions at the entrance to the fishway. The fish ladder would include a downstream passage pipe to provide downstream passage of juvenile out migrants during the late summer and fall. The USGS gage located downstream of the ladder would be notched to provide fish passage during low river flow conditions.

The fish bypass ramp would be installed on the south embankment between the abandoned head race canal and the river. The ramp would be approximately 270 ft long, 20 ft wide at a 30H:1V slope. The ramp would have 10 pools created by large boulder weirs with a 6 inch hydraulic drop per pool. The entrance to the ramp would be located approximately 50 ft downstream of the dam. River channel modifications near the base of the spillway would improve river attraction flow conditions for the entrance to the fishway. The bypass ramp would be lined with riprap and large stone with a trapezoidal cross sectional shape. The USGS gage located downstream of the ladder would be notched to provide fish passage during low river flow conditions.

A rock ramp would extend from the spillway at a 30H:1V slope downstream approximately 165 ft. The spillway would be modified by lowering the spillway at the abutments by 6 inches and the center by 22 inches so that flood water levels are not increased. The ramp would be lined with riprap and have 10 boulder weirs creating pools. The center of the ramp would have a low flow channel to provide sufficient water depth for fish passage during low flow conditions. The USGS gage would be removed and at the dam.

The proposed spillway breach would restore the river width to approximately 100 ft at the existing spillway. Removing the spillway would include excavating substrate material behind the dam, removing the granite block spillway, and stabilizing the existing abutments and river channel, and monitoring post removal conditions of the river. The USGS gage would be removed and replaced at the Willowdale Bridge just downstream or another suitable location.

Passage Effectiveness

If properly designed, each of the alternatives is expected to be effective in providing upstream passage for alewife, blueback herring, and shad. The Denil ladder is based on USFWS design criteria. These ladders have been installed for passing anadromous migrants at numerous low head dams throughout the Northeast and Mid-Atlantic regions. The fish bypass ramp design is also based on USFWS design principles and should provide effective upstream passage for the targeted species and some resident fishes. The rock ramp design is also based on USFWS design principles and uses the entire river flow which would improve effectiveness relative to the ladder and bypass channel alternatives. Bypass ramps and rock ramps are newer techniques that are still in the developmental stages for many fish species, including herrings, shads, and salmonids. However, unpublished evidence indicates bypass ramps are effectively passing river herring at some sites in New England (Alex Hero, USGS, personal communication). These designs require periodic maintenance and inspection to identify damage and to clear of debris to assure proper and effective operation.

The dam removal alternative would restore the river slope and hydraulic conditions similar to pre-dam conditions. The average velocities for the fish passage design flows would be well below the velocity barrier threshold values. The dam removal alternative would reconnect the downstream and upstream reaches of the Ipswich River for all aquatic life, while the other fish passage alternatives are specifically designed for the targeted species (blueback herring, alewife and shad) and may not be effective for passing some resident species.

Impacts to Wetlands and Aquatic Habitat

Impacts to aquatic habitat are expected to be negligible with the Denil ladder and bypass ramp alternatives. Temporary disturbance to wetlands during construction would be minimized by using appropriate erosion and sediment controls. The rock ramp alternative would lower impoundment water levels during low flow by 1.6 ft and may slightly alter the existing wetland boundaries. Dam breaching would create significant water levels changes (4 ft change), reducing normal pond levels from El. 27.9 ft to El. 23.7 ft. Existing open water habitat would be replaced by a restored stream channel and associated wetland habitat that was present prior to the dam's construction.

Recreation

The Denil fish ladder and bypass ramp would not affect existing boating activities within the impoundment. The rock ramp alternative would lower water levels during the low flow periods by 1.5 ft, which would reduce the water surface area and may require the Foote Brothers to relocate their boat docks. However, the rock ramp alternative includes a low flow channel that could be designed as a canoe chute so that boaters could access the lower reaches Ipswich River.

The dam removal alternative would lower water levels which would reduce the available water surface area to boaters. The river channel velocities would also increase which would change the boating conditions. The new conditions would provide unobstructed upstream and downstream access to the river and remove the navigation and safety hazard of the spillway. During extreme low flow periods, the river could become segmented limiting boating opportunities. Howevr, this risk would be diminished with the recent water supply agreements by the Towns of Reading and Wilmington.

Costs

The cost to install a Denil ladder is estimated to be $286,000 and construction would take approximately 10 weeks. The cost to install a fish bypass ramp is $265,000 and would take approximately 10 weeks to complete. The rock ramp installation is estimated at $544,000 and would take approximately 16 weeks to complete. The Denil ladder, fish bypass ramp and rock ramp include costs to repair the south dam embankment and spillway abutment. The repairs may also be required for the no action alternative and would cost about $43,000. The dam breach alternative is estimated to cost $161,000 and would take approximately 10 weeks to complete.

Cost Summary of Fish Passage Alternatives

Alternative	Total Project Costs
Denil Fish Ladder	$286,000
Bypass Ramp Fishway	$265,000
Rock Ramp	$544,000
Dam Breach	$161,000

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