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FISH PASSAGE AT HADLEY FALLS: PAST, PRESENT, AND FUTURE

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ABSTRACT

Upstream and downstream passage of anadromous fish species has long been an important issue for the hydro-power industry. Over the years the objectives, policies, and techniques for fish passage at hydroelectric facilities have evolved significantly. This paper examines the evolution of fish passage and protection over the past 120 years at Hadley Falls on the Connecticut River in Holyoke, Massachusetts. Fish passage and protection effectiveness at this site, recent fish passage facility improvements, and the evolving environmental and regulatory concerns that are currently being evaluated for potential future downstream passage improvements is discussed.

SITE DESCRIPTION

The City of Holyoke Gas and Electric Department (HG&E) in Massachusetts owns the Holyoke Hydroelectric Project (Project) (FERC No. 2004). The 43.8 megawatt (MW) Project is located on the Connecticut River in Hampden, Hampshire, and Franklin counties, Massachusetts. The southwest end of the Project's dam is located in the City of Holyoke and the northeast end of the dam is located in the Town of South Hadley, with the majority of the Project's structures and all of the generating facilities located in the City of Holyoke. The 30 feet (ft) high, 985 ft long masonry and concrete dam is located at a physiographic feature know as Hadley Falls. Here the elevation of the riverbed drops almost 60 ft over a short distance, making the site ideally suited for hydropower usage. The dam is topped by five 3.5 ft high inflatable rubber bladder sections which impound a 2,290 acre reservoir with a normal maximum surface elevation of 100.6 ft National Geodetic Vertical Datum (NGVD). A 25 ft wide bascule gate is located at the southwest end of the dam between the spillway and the intake for the Hadley Falls Station. Hadley Falls Station (30 MW), located on the impoundment at the southwest end of the dam, is the largest of the hydroelectric generating stations included in the Project (43.8 MW total). The Project has a three-level canal system with a 6,600 cubic feet per second (cfs) hydraulic design capacity, which extends through the lower areas of the city and provides water for industrial use and hydropower generation. The Holyoke Canal System begins with the canal gatehouse structure located between the intake for the Hadley Falls Station and the west shore. The gatehouse discharges into the First Level Canal (about 6,500 ft long) and from there the flow is routed through the Second and Third Level Canals and then back to the Connecticut River. The Project includes six hydroelectric generating stations (one at the dam and five in the canal system). The canal system also provides water to sixteen other hydroelectric generating stations. HG&E currently owns 13 of these stations and the other three are privately owned. The Holyoke Canal System was listed in the National Register of Historic Places in 1980.

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The Connecticut River is the longest river in New England, originating 2,625 ft above sea level in the Fourth Connecticut Lake and accumulating water from several major tributaries as it flows south at a slope of about 6 ft per mile. The waterway serves as the boundary between New Hampshire and Vermont, then runs through Massachusetts and Connecticut before emptying into Long Island Sound, over 400 miles from its source. Located 86 river miles upstream of the Long Island Sound, the dam at Hadley Falls which is known as the Holyoke Dam is the first barrier that anadromous fish encounter during their upstream spawning migration. An area of about 8,309 square miles is drained by the river at the Holyoke Dam. Flows in the Connecticut River at the Project average about 17,000 cfs but seasonal extremes range from more than 80,000 cfs in spring to less than 5,000 cfs in late summer.

FISH SPECIES

The Connecticut River in the vicinity of the Project has a highly diverse fish community that includes resident, diadromous, and endangered species (Holyoke Water Power, 1997). Populations of many species are abundant, reflecting good water quality and a diversity of habitats. Many smallmouth and largemouth bass are present, including a number of large specimens. Large channel catfish are also resident. The forage base is abundant, with numerous small herrings, minnows, and sunfishes available to predators. Panfish are common, although generally not large-sized, except for an occasional brown bullhead, white perch, or yellow perch. American eel, gizzard shad, common carp, and white sucker also comprise a considerable portion of the fish biomass. Fish species such as Atlantic salmon, American shad, blueback herring, striped bass, shortnose sturgeon, lamprey and American eel use the fish lifts and louver bypass array to move through the Project.

A program to restore an extirpated population of Atlantic salmon to the Connecticut River has been ongoing for over 30 years. This restoration effort has been one of the main drivers of fish passage enhancements throughout the Connecticut River. Annual catches of returning salmon at the Project have ranged from 529 in 1981 to 41 in 2001. Most salmon that return to the river are captured at the Project and transported to a federal hatchery for spawning stock. Only one of ten salmon is released from the upstream fish passage facility at the Project to proceed upstream. The remainder are trapped at the Project and transported to adult holding facilities where they are kept until spawning season when they are used to provide hatchery stock. Salmon fry from the hatchery are released into various Connecticut River tributaries where they develop for two to three years in natural habitat before they reach the smolt stage and emigrate. Downstream migration to the sea occurs in spring when the water temperature reaches about 10° C. Downstream passage is provided for the smolts at the Project.

American shad migrate into the Connecticut River during late March or April, reaching the upstream fish passage facility at the Project during late April or early May. Commercial gillnet fishermen harvest shad in the lower river from near its mouth to Glastonbury, CT (river mile 39) and sport fishing for shad is a major attraction, especially in the first 2 miles downstream of

Holyoke Dam and downstream of the remnants of the Enfield Dam (river mile 53). During the run, water temperatures at Holyoke Dam range between 12° and 20° C; and river flow is generally declining from the spring peak, though spates occasionally occur.

Most shad are lifted over the Holyoke Dam and allowed to continue upstream migration, where fishways at the Turners Falls, Vernon, and Bellows Falls hydroelectric projects also provide a means to enhance upstream passage for migrating species. Some shad are trapped at the Project and transported in trucks by state and federal agencies to upstream reaches of the Connecticut River, or to other river basins. After spawning, adult shad swim back downstream, primarily during daylight hours in June and July, and may survive to spawn more than once.

Young-of-the-year (YOY) shad are abundant in many locations upstream of Holyoke Dam throughout the summer. Presumably, they provide a forage base of some importance for predatory fish in the impoundment of the Project and upstream to Turners Falls Dam. Although some YOY shad may move downstream through the Project at other times, the seaward migration out of the Connecticut River occurs from September through November, peaking when water temperature is 9° to 14° C. The young migrate to areas in the North Atlantic from the Maritimes to Florida and remain at sea for four to six years before returning to their native river to spawn.

Blueback herring enter the Connecticut River to spawn at about the same time as American shad. Peak blueback movement often occurs slightly after peak shad movement. They are not an important sport or commercial species in the Connecticut River, although some are captured for use as bait in coastal fisheries. Blueback herring tend to spawn on hard substrates in swift-flowing tributaries of the lower Connecticut River at temperatures of 14° to 25° C. Presumably some spawning also occurs in the mainstem Connecticut River upstream and downstream of Holyoke Dam, where swift-flowing habitats with hard substrate are available. The adults migrate back downstream immediately after spawning, and are capable of returning to spawn in subsequent years. The numbers of blueback herring along the entire East Coast has experienced a dramatic decline over the past decade. Numbers lifted at the Project peaked in 1985 when over 600,000 were lifted to a low of 151 fish lifted in 2004.

Striped bass is an anadromous species that supports substantial recreational fishing in the Connecticut River downstream of the Holyoke Dam, but commercial fishing is not permitted. This species is native to Atlantic coastal waters from the Maritimes to the southeastern United States. Major spawning areas include the Hudson River and tributaries to Chesapeake Bay, however, spawning has not been documented in the Connecticut River. Striped bass is a major sport species throughout most of its range and was once of commercial importance until downward population trends forced a moratorium on commercial fishing for striped bass.

Adult striped bass in freshwater habitats feed largely on other fish, and have been shown to feed on river herring, American shad, and American eel. The recent declines in Connecticut River populations of these species may be due to the resurgence of the Atlantic coast striped bass population. Striped bass first appeared in the fishlift at the Project 1979.

Lamprey is another anadromous species that spawns in the Connecticut River and its tributaries. This species inhabits the Great Lakes and coastal North America and Europe, spawning during spring in shallow areas of moderate current with sand, gravel, and rubble substrate. It is not of recreational or commercial value in the Connecticut River, although specimens are frequently collected at the Project and elsewhere for research and educational purposes. During the spawning run, adults undergo considerable physiological change and deterioration, and die after spawning. Downstream migration occurs in fall and spring, but primarily in the spring. Although lamprey may spawn downstream of Hadley Falls Dam, it is unlikely that substantial spawning occurs in the impoundment because spawning does not occur in soft sediments.

The American eel is a catadromous species whose young enter the Connecticut River to feed and mature, then return to the sea to spawn as adults. They are an important commercial species in many areas, though no substantial commercial fishery for this species exists in the Connecticut River. At the Holyoke Dam, upstream migrating juvenile eels are most abundant from mid-August through September. The eels then live upstream for a number of years before maturing into the silver eel stage when they migrate back to the sea to spawn. This downstream migration is usually at night during the fall. The Project does have facilities to enhance upstream passage of American eel.

The shortnose sturgeon is currently both state (MA) and federally listed as an endangered species. Since the original listing, substantial information about the shortnose sturgeon population of the Connecticut River has been obtained, leading to periodic scrutiny of the endangered listing. In the Connecticut River, shortnose sturgeon appeared to be divided into two populations: one landlocked between Turners Falls and Holyoke Dam, and the other below Holyoke Dam to Long Island Sound. Between 1980 and 2005, 112 shortnose sturgeon have been lifted at the Holyoke Dam. While hundreds of individuals were identified below the dam from 1993-1995, only between 1 and 6 were passed in any one of these years. In 1996, a record number of 16 shortnose sturgeon were passed above the Holyoke Dam (Kynard 1998).

Recent unpublished work indicates there may be more interaction between these two populations than previously believed. Estimates of total adult abundance calculated in the early 1980's range from 297 to 516 above Holyoke Dam and around 800 in the downstream population. More recent tagging studies have indicated that populations in the lower river have increased to as many as 1,000 individuals (Savoy 2005).

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HISTORY OF UPSTREAM FISH PASSAGE AT HADLEY FALLS

Over the years several dams have been constructed at Hadley Falls and most of the owners of these dams were committed to providing fish passage for the anadromous species present in the Connecticut River. The first large project constructed at Hadley Falls was the navigation canal in South Hadley in 1794. The construction of the dam for this project blocked runs of anadromous fish in the Connecticut River upstream of Holyoke. In the same year the Massachusetts Legislature passed an act prohibiting the catching of any shad or salmon within 100-rods of the dam. In 1796 petitions were brought in the General Court concerning the dam obstructing the passage of shad. The following year a petition was brought to the Court of Common Pleas in Northampton requesting fishing damages. No action was taken on the petition.

In 1800 and 1801, the owners of the dam met with committees of citizens from Northampton and Easthampton who complained about the dam backing up water on their properties. As a result the westerly end of the dam was torn down leaving only a wing dam from the east bank to the mid stream. Thus fish were again allowed an unobstructed upstream passage.

In 1815, a new dam was built downstream of the original one. In 1819, an indictment was issued by the Supreme Judicial Court on Northampton for obstructing the free passage of waters to the ocean. A not guilty plea was entered and returned by a jury. However, as a result of this litigation the owner agreed to build a fishway. This was accomplished by building an oblique wing dam below and near the dam on the east side. This arrested the water from the main dam, producing an eddy, in which fish could find a quiet stopping place after passing the rapids below. Opposite this wing dam, a passage hole was made in the main dam where fish could “dart” into the pond above.

In 1824, a freshet carried away the dam built in 1815 and a new one was built in its place. The owner was promptly indicted for and found guilty of preventing upstream fish passage. As a result of this litigation the dam was altered again to allow passage. However, it must be realized that these early dams were low dams that could likely be breached sufficiently to allow fish passage (Barrett 1983).

In October, 1849, a timber crib dam was constructed at Hadley Falls, to divert water for use in the canal system in Holyoke. The dam extended from shore to shore, and again upstream fish migration was prevented.

In 1866, the Commonwealth of Massachusetts enacted legislation requiring the construction of devices to permit free passage of shad and salmon on the Connecticut River. In 1873, a wooden fish ladder was constructed on the northeast end of the dam in the town of South Hadley. However, no fish ever entered this ladder and in 1895 the Massachusetts legislature passed an Act which exempted Holyoke Water Power (HWP) from the need of maintaining a fishway.

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The granite block dam that is currently used by the Holyoke Project was built in 1900, about 150 ft downstream from the previous timber crib dam. In 1938 the Act of 1895, which exempted HWP from maintaining a fishway was repealed. In 1940, a second fish ladder was constructed on the northeast end of the dam in South Hadley. Again like its predecessor no fish ever entered this ladder.

On September 9, 1949, HWP who was the dam owner at the time, received a license from the Federal Power Commission (now known as FERC) for the Holyoke Project. The license authorized the construction of a new hydroelectric unit at the dam and in 1950 Hadley Falls Unit 1 was completed. As part of the Federal Power Commission license, HWP was required to "construct, maintain and operate such fish protection devices and shall comply with such special conditions in the interest of fish life as may be prescribed hereafter by the Commission upon recommendation of the Secretary of the Interior."

After investigation it was soon found that there were no fishways for shad on the east coast. On the west coast there were generally two types of fishways, the ladder and the lock. It was decided early on that some scheme other than a ladder should be tried. Rather than using an open lock system like those used to raise and lower boats, it was decided to concentrate efforts on a pressure lock system (See Figure 1). This was a completely new approach to the subject of fish passage, using untried principles. The pressure lock scheme involved luring the shad in the tailrace of the Hadley Falls Station into a corral area. From there they would be transported by pressurized pipe to the pond above the dam. In 1951 there was a considerable amount of original research done on the characteristics of shad both in the field and in the laboratory. There was little known at the time about how to get the fish into the corral area. There were experiments with mirrors, lights and electric currents. In the end, it was found that with sufficient amounts of attraction water at high enough velocities the shad would move into the corral area. The pressure lock system was

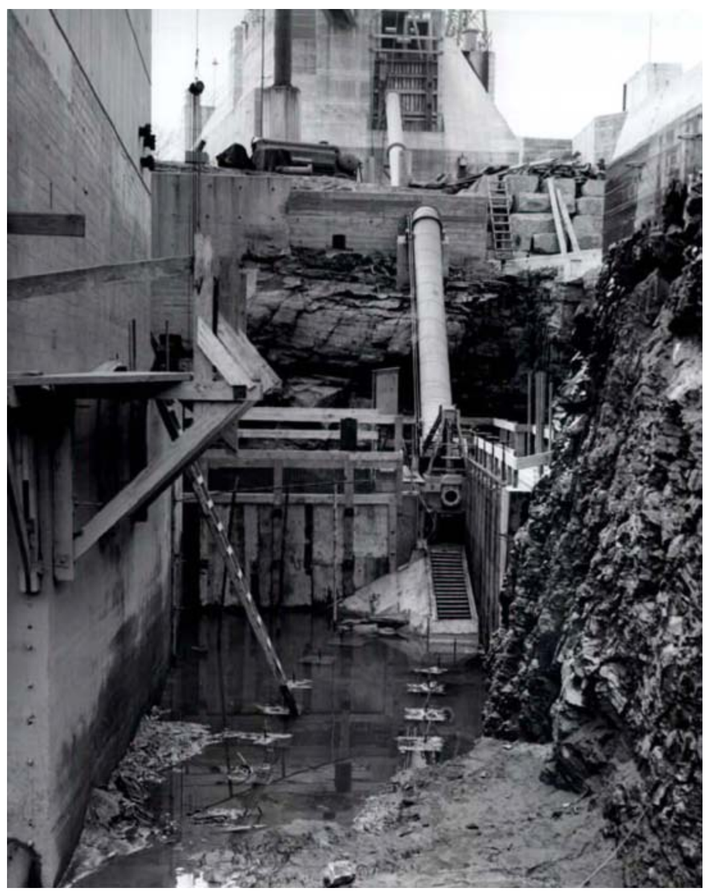

FIGURE 1 LOOKING UPSTREAM AT THE DEWATERED PRESSURE LOCK SYSTEM

first tried in the spring of 1952 and it was estimated that 511 fish were passed. HWP continued developing the system in 1953 and 1954. At the end of the three years of experiments it was determined that the pressure lock system was not a satisfactory solution to the fish passage needs and a new approach would be tried.

A fishlift facility was constructed at Hadley Falls Station in 1955. Attraction water flow was used to attract upstream migrants in the tailrace into a collection area, similar to that used for the pressure lock system. Once in the collection area they were crowded into a large bucket or hopper which raised the fish to a transfer station at an elevated walkway connecting the powerhouse and headworks (See Figure 2). From here they were hand netted and placed in a large tub with wheels that could be manually moved to the headworks where the fish were dumped into an exit channel and free to swim upstream into the impoundment (See Figure 3). Some 4,899 shad were transported over the dam during a 35-day period in 1955. This was the first significant passage of shad above the Holyoke Dam in over one hundred years and the first successful fishlift in the country. In honor of the event, the Department of the Interior awarded HWP its first Conservation Service Award.

FIGURE 2 LOOKING DOWNSTREAM AT THE FISHLIFT

FIGURE 3 RELEASING FISH INTO THE EXIT CHANNEL

Although fish lifting operations at the Holyoke Dam started in 1955, the numbers of shad passed annually remained below 40,000 from 1955 to 1968. Improvements to the original facility increased the number of shad lifted to more than 100,000 by 1975 and to 350,000 in 1976. The increased numbers in 1976 were a result of construction of a second lift to pass fish swimming up the bypass reach to the spillway and an elevated fishway exit flume extending from the existing exit channel in the headworks to the fishlift towers. The exit flume included a counting and trapping station and the installation of this exit flume meant that the fish could be discharged into the impoundment above the dam without manual labor.

In 1992, over 720,000 adult American shad passed upstream through the fishlift complex at the Holyoke Project ; this is the highest annual total to date. The highest number of salmon passed in a year was 368, also in 1992. The lifts also pass other anadromous fish upstream, including blueback herring (over 630,000 in 1985), striped bass, lamprey, American eel, and shortnose sturgeon.

In 2001, HG&E purchased the Holyoke Project and one of the significant improvements made prior to the purchase was the installation of an inflatable rubber dam to replace the wooden flashboards. The rubber dam plays an important role in the overall project operation including upstream fish migration by preventing the head pond fluctuations that occur when flashboards fail and increasing control over spillway flows. This improved spillway flow control minimizes upstream migratory delays during periods of high river flow that previously would have caused flashboard failure and it reduces the stranding of shad at the dam apron. Additionally, the increased stability of the head pond allows the water surface elevation in the fishway exit flume to be maintained at a consistently higher level.

RECENT UPSTREAM FISH PASSAGE IMPROVEMENTS

The construction of the new state of the art automated upstream fish passage facility at Hadley Falls Station began in the summer of 2004 and ended in the spring of 2005. This project was a renovation and expansion of the existing facility and was intended to increase fish passage effectiveness and reduce operation and maintenance costs (Kleinschmidt Associates, 2002). The new facility is designed to pass the target fish populations specified by the Connecticut River Atlantic Salmon Commission and required in the 1999 FERC License: 1,000,000 American shad, 1,000,000 blueback herring, 6,000 Atlantic salmon, 500 shortnose sturgeon, and an unspecified number of American eel. The new fishway consists of the same major components that comprised the previous fishway. These include three entrances, two collection galleries, two crowders, two elevators, an elevated exit flume with viewing windows and fish trapping stations, a counting room, a trap and transport facility, and other various gates and supporting mechanical equipment. The existing fishlift towers and all ancillary equipment were removed and replaced with a single tower structure which accommodates both the spillway and tailrace hoppers (See Figures 4 & 5). All of the major components of this new fishlift facility are integrated through a new PLC that is located in a new control room on top of the exit flume. The fishlifts can be operated automatically or manually and a video system allows the facility to be monitored from the control room. The video system has two cameras mounted near the top of the fishlift tower for viewing the hoppers and two cameras mounted near the base of the tower for viewing the crowder bays.

FIGURE 4 LOOKING UPSTREAM AT THE FISHWAY PRIOR TO RENOVATION IN 2004

FIGURE 5 LOOKING UPSTREAM AT THE FISHWAY AFTER RENOVATION IN 2004

The tailrace fishway provides upstream passage for migrants that come up the tailrace attracted by the powerhouse discharge. Each of the two tailrace fishway entrances is designed to discharge flows up to 120 cfs, for a total of 240 cfs. The crowding channel at the base of the tailrace fishlift retained its existing layout, with a crowding bay length of approximately 35 ft. The fishway equipment and structures in the tailrace area were raised approximately 18 inches to provide for 12 inches of free board at operations of 40,000 cfs total river flow. The former tailrace fishlift tower and 10 ton hoist were enlarged to accommodate a new hopper with greater volume. The previous hopper had a volume of 230 cubic feet and a cycle time of 10 minutes allowing the fishlift to operate at a rate of approximately 23 cubic feet per minute. The volume of the new hopper is 330 cubic feet and it also has a cycle time of 10 minutes allowing the new fishlift to operate at a rate of 33 cubic feet per minute. The new hoist has a variable speed drive with a capacity of 20 tons. The updated tailrace fishlift discharges fish in the same manner as before, at the downstream end of the exit flume and in line with the axis of the flume.

The spillway fishway provides upstream passage for migrants coming up the riverbed through the bypass reach to the base of the dam. Prior to the construction of the spillway fishway in 1976, upstream passage was accomplished solely through the tailrace lift facilities. During passage seasons, the Project was operated to optimize upstream passage conditions in the Hadley Falls tailrace. The spillway lift and associated facilities were built to supplement the tailrace fishway during periods of high river flow when spill occurred over the dam. Based on these operating conditions, anticipated usage and space constraints, the spillway fishway was constructed smaller than the tailrace facilities, having approximately 80% of the capacity. In the mid 1980s, flows in the bypass were increased to improve downstream passage. The additional water attracted more upstream migrants to the base of the dam and usage of the spillway lift facilities began to increase. The resource agencies recognized the potential for passage at the spillway and prescribed conditions in the new license and WQC that called for: (1) zone-of-passage (ZOP) flows in the bypass for upstream passage and, (2) increasing the capacity of the spillway lift facilities. The modified spillway fishway fulfills the requirements of these conditions. The existing attraction water system was modified to accommodate flows up to 200 cfs for the existing spillway fishway entrance. The entrance was not altered, but both the transport and crowding channels were significantly expanded. The spillway transport channel was lengthened from 30 ft to approximately 80 ft and the crowding channel length was increased from the existing 10 ft to approximately 35 ft. The former spillway fishlift tower and 8 ton hoist was enlarged to accommodate a new hopper with greater volume. The previous hopper had a volume of 182 cubic feet and a cycle time of 6.5 minutes allowing the fishlift to operate at a rate of approximately 28 cubic feet per minute. The volume of the new hopper is 330 cubic feet and it has a cycle time of 7.2 minutes allowing the new fishlift to operate at a rate of 46 cubic feet per minute. Similar to the tailrace hoist the new spillway hoist has a variable speed drive with a capacity of 20 ton. The updated spillway fishlift discharges fish at the downstream end of the exit flume and in line with the axis of the flume. This is a change from the previous layout, in which the spillway fishlift hopper discharged fish into the flume perpendicular to the length of the flume.

There are a number of facilities that are common to both fishways. The first is the attraction water system, which provides water for all of the fishway entrances. The source of the majority of the attraction water is the low-level outlet gate structure on the First Level Canal known as No. 1 Overflow. In 2002, racks with one inch clear opening and sufficient surface area to keep the entrance velocities below 2 feet per second were installed upstream of two of the three gates at No. 1 Overflow to prevent fish (target species shortnose sturgeon) and debris from entering the attraction water system. The existing attraction water supply system was not altered and can provide the required 440 cfs to the existing attraction water distribution structure. However, the attraction water distribution structure was modified to provide 200 cfs to the spillway fishway entrance and 240 cfs to the tailrace fishway entrances. One new 2.5 ft wide steel slide gate was installed between the two existing gates at the distribution structure to supplement the hydraulic control of the attraction water for distribution through the spillway and tailrace fishways. Additional attraction water is supplied by the discharge from the exit flume. This comes from the existing 24 inch exit flume discharge pipe located in the existing section of the exit flume and from the new 24 inch exit flume discharge pipe located in the new section of the exit flume.

The exit flume at the top of the fishlifts is another structure common to both fishways. The exit flume is an elevated concrete flume, which passes through and is an integral part of the Hadley Falls Station headworks structure. The width of the exit flume was expanded to accommodate the new location of the spillway fishlift adjacent to the tailrace fishlift at the downstream end of the flume. The exit flume is somewhat triangular in plan view, wider at the downstream end with a total width of about 30 ft and narrower at the upstream end with a minimum width of 7 ft. Located within the exit flume through the headworks structure, were three existing weirs originally designed to reduced the width of the exit flume to approximately 3 ft. These weirs were needed during times of high pond level fluctuation while the fishway was operating. The addition of the rubber dam stabilized the head pond and these weirs were longer required. So, the weirs were removed to increase the width of the exit flume through the headworks from 3 ft to 7 ft.

Within the elevated exit flume the fish trapping and counting facilities were replaced and improved. The existing fish trapping station was replaced and a second fish trapping station was added downstream of the first station. The two trap system required the installation of a new viewing/counting window at the second fish trapping station. This in turn made it necessary to increase the size of the counting room where the fish are monitored as they leave the fishway. The existing counting room was removed and replaced with a new steel framed room more than doubling the size of the previous structure.

During the upstream fish passage season shad and other species are occasionally trapped and transported upstream and to other river systems. Previously this was accomplished by trapping fish in the flume and netting them into a cart filled with water. This cart was then wheeled over the top of the flume and lowered by hoist to a platform below. From there the carts were emptied into awaiting trucks. To conduct this practice more efficiently, a new fish trapping and hauling facility was installed (See Figure 6). This facility is located beneath the elevated exit flume and adjacent to the fish elevator towers. It consists of a new access platform, a new hopper discharge chute, a new 12 ft diameter stainless

FIGURE 6 TRAP & HAUL FACILITY

steel sorting tank, a new 8 ft diameter stainless steel holding tank, and a new fiberglass holding tank. The hopper discharge chute conveys fish from the spillway hopper to the 12 ft diameter sorting tank and this sorting tank is connected with a gated flume to the 8 ft diameter holding tank. This holding tank has a 12 inch diameter discharge pipe that is used to load fish into tank trucks for transportation.

DOWNSTREAM FISH PASSAGE AT HADLEY FALLS

There are a variety of fish which pass downstream through the Project throughout the course of the year. These include adult anadromous species returning from their spawning run, juvenile anadromous species migrating to the sea, and adult catadromous American eel traveling to the sea to spawn. The first provisions for downstream fish passage at the project began in the late 1970's at Boatlock Station, one of the first canal units. It was understood that many of the outmigrating fish would enter the canal system because of the large quantity of water flowing into it. However, the trash racks would prevent their passage through the waterwheels. Development of the "Boatlock Bypass" included an electroshocker, which was designed to immobilize adult shad near the mouth of the bypass and cause them to be swept into a 2 ft diameter steel bypass pipe leading to a raceway and eventually to the Hadley Falls Station tailrace.

In 1992, HWP installed a permanent louver facility in the First Level Canal to guide downstream migrants entering the canal system. The louver array is approximately 450 ft long at an angle of 15° to the approach flow in the canal. The 15° angle of the louver array was a result of laboratory testing that showed relatively high diversion rates. The clear spacing between the vertical slats of the louver array is two inches. This presents a physical barrier to larger fish and the angle of the vertical slats in relation to the direction of flow creates an effective behavioral barrier to smaller fish. The louver facility was originally designed to guide and pass Atlantic salmon smolts, juvenile and adult American shad, and blueback herring, all of which migrate close to the surface. Therefore, the panels of vertical slats in the louver array only extended down half the depth of the canal. As part of the louver facility a 3 ft diameter steel bypass pipe and a wedge-wire ramp from the bottom of the canal up to the bypass pipe entrance were installed at the downstream end of the louver array. The bypass pipe returns fish to the Hadley Falls Station tailrace. There is a bypass collection facility with a sampling table located at the discharge of the bypass pipe. This is used primarily to enumerate Atlantic salmon smolts during the spring migration.

In 2002, the louver array was extended to the full-depth of the canal (See Figure 7) in order to provide guidance for bottom-oriented species as well as surface-oriented species. In addition to extending the depth of the louver panels, the former polyethylene slats in the louver panels were replaced with steel slats. Timbers were used to block the space between the canal bottom and the steel frame supporting the louver panels.

To evaluate the effectiveness of the full-depth louver array to pass salmon smolts and juvenile shad and herring, in 2004 HG&E measured flow velocities at strategic locations along the full-depth louver array and compared the results to velocities measured during the partial-depth louver guidance tests conducted in 1992. Velocity profiles taken along the full-depth louvers were compared with profiles compiled for the partial-depth louvers. Similar profiles were found at all tested flow regimes indicating that the full-depth louver effectiveness relative to guidance and passage of Atlantic salmon smolts and juvenile shad and herring is similar to that of the partial-depth louvers.

FIGURE 7 LOUVER ARRAY IN FIRST LEVEL CANAL

In addition, HG&E was required to test the effectiveness of the full depth louver facility for guiding downstream movement of shortnose sturgeon and American eel. This included evaluation of the behavior of downstream migrating shortnose sturgeon and American eel at the ramp and entrance to the bypass pipe at the downstream end of the louver array. HG&E conducted Louver Field Studies of the release-recapture type during the fall of 2004 (American eel) and the spring of 2005 (shortnose sturgeon). In these studies 30 cultured juvenile shortnose sturgeon and 60 American eel were marked and released into the canal just below the gatehouse about 300 ft upstream of the louver array. They were recaptured in the bypass collection facility. Radio telemetry tags were used to monitor fish movement along the louver array and through the bypass system. Antennas were placed at several depths (surface, mid-depth and bottom) along the length of the louvers, at the ramp to the bypass entrance, at the bypass entrance, and downstream of the louvers in the First Level Canal. Sampling was conducted both day and night. Flow through the canal during testing was varied to determine the best passage flow for shortnose sturgeon. Flows of 1,000 cfs, 2,000 cfs, and 6,000 cfs were tested. Results indicated that both American eel and shortnose sturgeon were effectively guided by the full-depth louver array.

Beginning in 1989, other measures to enhance downstream passage of Atlantic salmon smolts and juvenile American shad and blueback herring were tested at the Project in the area of the Bascule gate (See Figure 8), which is located between the spillway and the Hadley Falls Station intake (Kleinschmidt Associates 2003). If river flow is below the hydraulic capacity of the Project then no water is passed over the spillway, thus making the bascule gate and the Hadley Falls Station turbine intake the only means of egress for downstream migrants that do not enter the canal system.

HWP evaluated the effectiveness of a boom, a louver array, and a skirted boom and guide wall designed to guide fish to the Bascule gate. These barriers presented operational difficulties and did not enhance fish passage, so none of them were deployed permanently.

FIGURE 8 BASCULE GATE

In 1994 Alden Research Laboratories, the Conte Anadromous Fish Research Center, and HWP, fitted the Bascule gate slot with an insert also known as the Alden Weir. The purpose of the insert is to enhance downstream fish passage by eliminating an area of rapid change in water velocity near the crest of the gate. The gate discharges to the bypass reach at a point adjacent to the spillway fishlift entrance.

In 1995, HWP evaluated the effectiveness of facilities that included three modifications at Hadley Falls Station: an overlay blocking the uppermost 8 to 10 ft of the Hadley Falls Station intake racks; a guide wall extending upstream of the Bascule gate pier to create surface flow toward the gate; and the Alden Weir. These facilities were effective, and, with some adjustments, have served to guide fish to the gate insert and pass fish downstream at the Holyoke Dam from 1995 to the present.

In the mid 1990's HWP evaluated the mortality rates of clupeids passing through the Hadley Falls Station intake. This was accomplished by attaching a self inflating balloon to live fish specimens and releasing them at the intake. After passing through the units the fish are brought to the tailrace water surface by their attached balloons allowing them to be captured and examined. Surviving specimens were observed for several days afterward to evaluate delayed mortality. The results of the testing showed a survival rate of between 100% and 89%. (Harza 1993).

HG&E is currently testing in the laboratory what effective measures can be taken to keep anadromous fish, shortnose sturgeon and American eel from being impinged or entrained at the Hadley Falls Station intake racks.

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