Robert Street Dam Removal - Restoring Migratory Fish Passage on the Raritan River, New Jersey

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***Abstract* -** The Robert Street Dam was successfully removed from the Raritan River in central New Jersey to restore migratory (anadromous) fish passage. This reconstructed concrete gravity dam had a structural height of approximately 7.5 feet, a crest length of 255 feet with a width of 23 feet, which included a 17.5-foot wide rock-backfilled section between two parallel rows of waler-supported steel sheet piles driven into bedrock that encased the original circa 1915 dam. To remove the dam, numerous technical and permitting challenges had to be resolved, including inadequate bridge load capacity that precluded heavy equipment access to the site. Technical obstacles that were overcome during the dam removal included managing the work around frequent upriver reservoir releases, the laborious extraction of over 300 individual sheet piles using two different hydraulic vibratory driver/extractors, and conveyance of over 700 tons of concrete and 70 tons of steel offsite over the five-week removal period.

I. INTRODUCTION

This dam removal project originated from a Natural Resource Damages (NRD) Settlement between the New Jersey Department of Environmental Protection (NJDEP) and one of North America's largest petroleum/chemical business concerns (Responsible Party) for potential historical impacts to river sediment, including in the Raritan River in central New Jersey, from four industrial facilities that were formerly owned by subsidiaries of the Responsible Party. To resolve potential sediment NRD issues with the State of New Jersey (with NJDEP acting as the Natural Resource Trustee designee), the Responsible Party agreed to conduct a damage assessment of the surface water bodies adjacent to the former industrial sites with the ultimate goal of implementing a remedy to compensate for the presumed interim loss of the injured natural resources.

When the potential natural resource injury (i.e., potential damage to sediments caused by the industrial site discharges) was found to be on par with the level of effort to implement several dam removal projects, the NJDEP and the Responsible Party concluded that dam removals on the Raritan River would be an effective method to settle the potential NRD liability; thus, an amenable and amicable settlement was reached. A 2012 Association of State Dam Safety Officials (ASDSO) conference paper [1] described how the concept of dam removals on the Raritan River was gaining momentum at the same time NJDEP and the Responsible Party were negotiating the NRD settlement agreement.

Although not as well documented as the Hudson or Delaware Rivers in terms of historical shad populations, the Raritan River once supported a commercial seine-haul fishery, but it was immediately recognized during the initial 1870s inspections by the Commissioners of Fisheries of the State of New Jersey that the primary cause of steep fish population declines along the eastern seaboard was “the erection of dams impassable by the anadromous fishes returning to their spawning grounds…as they have been cut off from these ranges, has depletion followed in every river” [2]; at this same time, it was ascertained “that no spawning grounds for the shad exist in the Raritan River” [3]. In a comprehensive evaluation of rivers and streams throughout New Jersey conducted one hundred years later, the spawning run for American shad in the Raritan River was declared extinct [4]. In addition to blocking spawning runs of anadromous fish, dams limit dispersal of resident freshwater fish species, cause crowding just downstream of the dam structure, and produce differences in biodiversity between upstream and downstream locations. The natural river process of transporting and depositing gravels, sand, nutrients, and woody debris is also significantly hampered. Additionally, dams alter riverine habitats by producing lake-like conditions upstream of the structures, which can favor undesirable species (e.g., carp), cause siltation of spawning and feeding habitats, and trigger deleterious effects on water quality, such as decreased dissolved oxygen concentrations [5].

The Raritan River watershed, which includes the North and South Branches of the Raritan River and major tributaries such as the Millstone River, Stony Brook, Bound Brook, Green Brook, South River, and Lawrence Brook, encompasses 1,100 square miles and composes New Jersey’s largest watershed and longest interior river system located solely within the state’s borders (**Figure 1**).

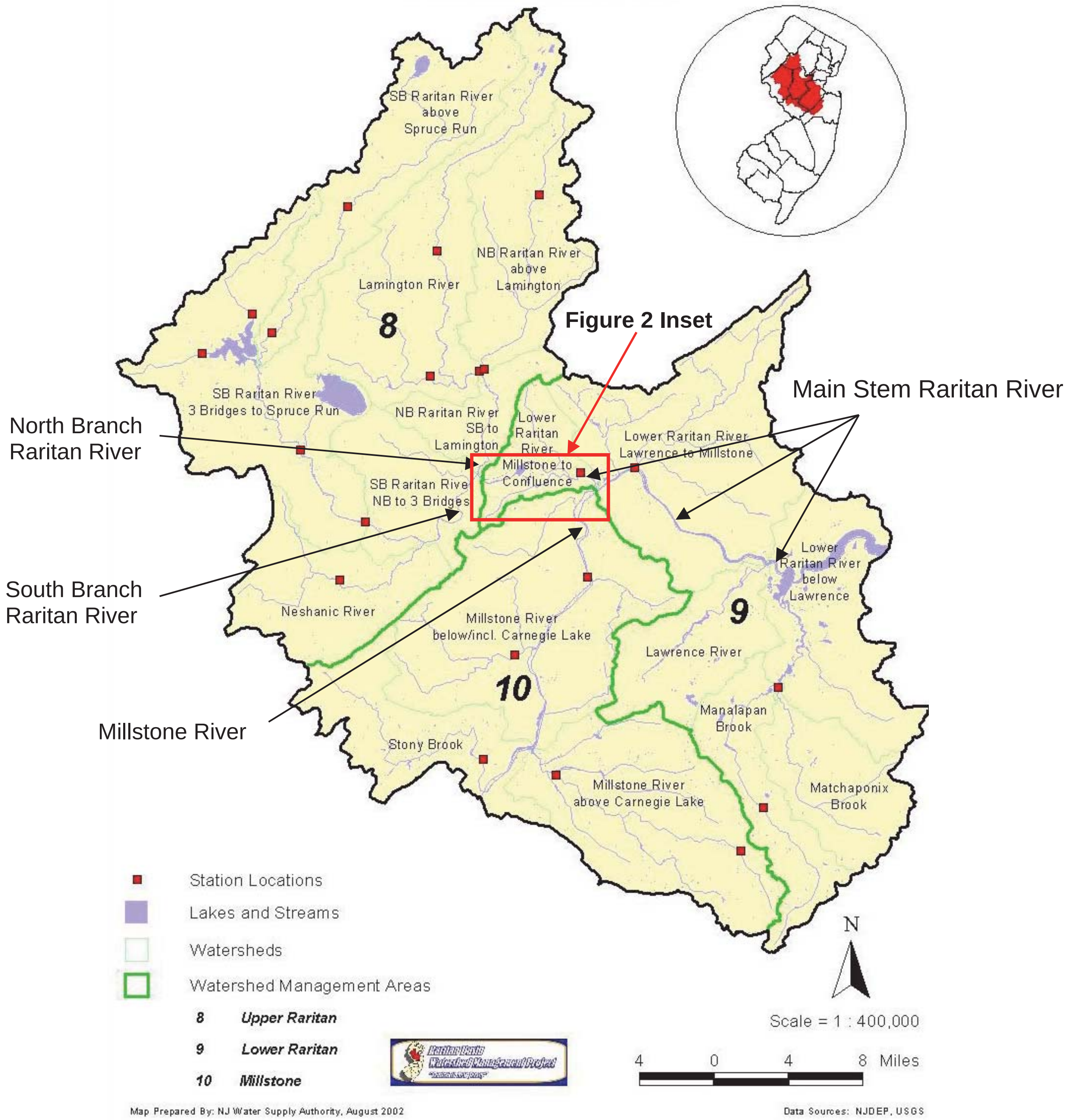

Figure 1. Raritan River watershed map, showing the 1,100-square-mile extent of the Raritan Basin. Copyright ©2002, New Jersey Water Supply Authority Watershed Protection Programs Division.

There are some two dozen dams (although many of these structures are technically weirs, the term "dam" will be used hereafter) of varying size and classification along the main stem of the Raritan River and its major tributaries that block passage of anadromous (i.e., migrating up rivers from the sea to spawn) fish from reaching the middle and upper reaches of the watershed. Along with American shad (*Alosa sapidissima*), the anadromous fishes of greatest concern in New Jersey include the hickory shad (*Alosa mediocris*), alewife (*Alosa pseudoharengus*), and the blueback herring (*Alosa aestivalis*). The top three dams on the removal priority list (and not coincidentally, the three lowermost dams blocking the main stem of the Raritan River) were the Calco Dam (Raritan River Mile [RM] 20.9), the Nevius Street Dam (RM 27.0), and Robert Street Dam (RM 27.9). These lowhead dams, which have been blocking anadromous fish passage since the early 1900s, became the three obstructions slated for removal in this initial Raritan River dam removal effort (**Figure 2**). The most technically challenging dam removal was the Robert Street Dam, discussed hereafter.

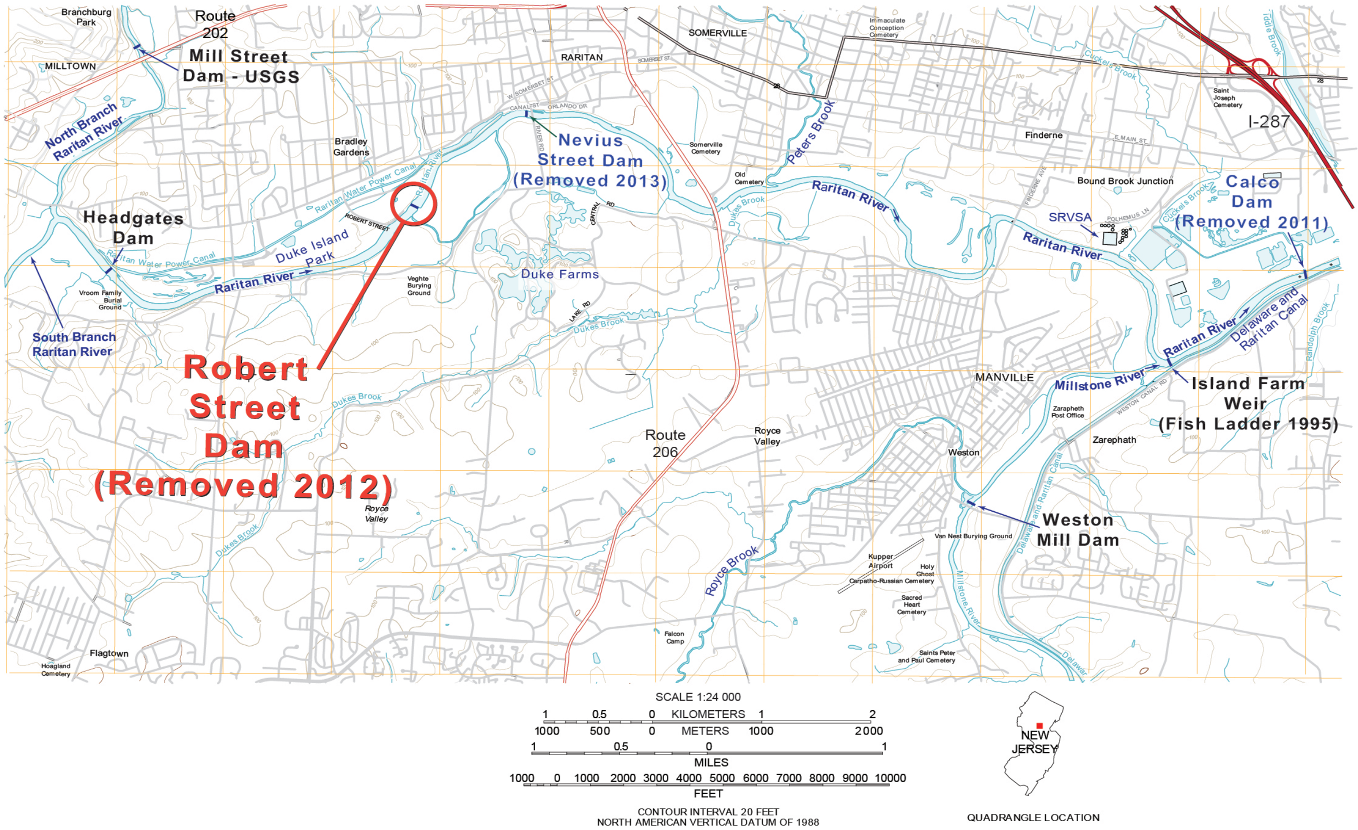

Figure 2. Locations of the Calco Dam (RM 20.9), Nevius Street Dam (RM 27.0), and Robert Street Dam (RM 27.9) moving upriver (westward) along the main stem of the Raritan River in central New Jersey. Following the removal of these dams, only the Headgates Dam two miles above the Robert Street Dam remains as an obstruction to migratory fish passage on the main stem of the Raritan River.

II. Robert Street Dam Description

The Robert Street Dam is located near the eastern end of Duke Island in Bridgewater and Hillsborough Townships, Somerset County, New Jersey. The original dam at this location was constructed circa 1915, but the purpose of this structure (referred to historically as the Dead River Dam and referred to hereafter as the "original" dam) and the entity that funded its construction remains unknown. In assessing the location of the original dam relative to an extensive sidechannel on the south side of the river, and the remnants of what appears to have been a debris deflection boom at the mouth of the sidechannel, it is most likely that this original dam served to impound water for irrigation purposes for former agricultural fields. These fields are now being restored back to wetlands habitat for the preservation of wildlife and enhanced floodplain function.

The original dam had a crest length of 250 feet and was approximately six feet in height with a concrete apron that extended approximately eight feet farther downriver. No records of this dam were on file at NJDEP Dam Safety Section (Dam Safety), but after months of diligent inquiries of adjacent property owners and engineering firms that were working in this area in the early 1960s, two photographs and a site plan of the original dam were acquired. The site plan was part of a December 1963 dam failure structural engineering assessment [6] and the inspection notations on this drawing include "dam overturned," "dam settled and badly deteriorated," "numerous structural cracks," and "large structural crack." Review of this information indicated that about 100 feet of the dam had settled and deteriorated because of water seepage and scouring of the underlying foundation material. This scour was most pronounced on the north end of the dam, which had caused a 15-foot section of the dam to overturn (**Figure 3**).


Figure 3. The original dam at the present-day Robert Street Dam location circa 1963 in a state of deterioration, subsidence, and failure; the left photo was taken from the south bank (river flow is from left to right) and the right photo was taken from the north bank where a section of the dam had overturned. Photos courtesy of Goodkind & O'Dea Consulting Engineers.

The owner of the dam at that time, the Park Commission of Somerset County, funded a substantial 1964 reconstruction of the dam for recreational boating, presumably to create an impoundment adjacent to the newly-opened Duke Island Park upriver of this location. Upon completion, the reconstructed dam had a crest length of 255 feet and had a width of 23 feet (**Figure 4**).


Figure 4. The reconstruction of the Robert Street Dam location in 1964; the left photo was taken from the south bank (river flow is from left to right) and the right photo was taken from the north bank. It is evident from these photos that the river was diverted around the construction site; present-day observations indicated that this was most likely accomplished via a bypass channel along the south bank (background of right photo). Photos courtesy of NJDEP Dam Safety.

Because the Dead River Dam and the Headgates Dam (located two miles upriver) had both failed in the space of just four years from undermining, cutoff walls became the key feature of the reconstruction effort. During the 1964 reconstruction, the original dam structure was encased between two parallel rows of waler-supported steel sheet piles, spaced 17.5 feet apart, which were driven into bedrock to an undocumented depth (**Figure 5**). The horizontal waler beams were composed of two 9-inch by 2.5-inch steel channels bolted together back-to-back to create ad hoc I-beams, and these walers were then bolted to the sheet piles using ¾-inch bolts. A total of 16 one-inch diameter solid steel tie-rods, spaced 16.35 feet apart, were installed to secure the upriver and downriver rows of sheet piles together (and the original dam was notched in locations where the structure interfered with the installation of these tie-rods).

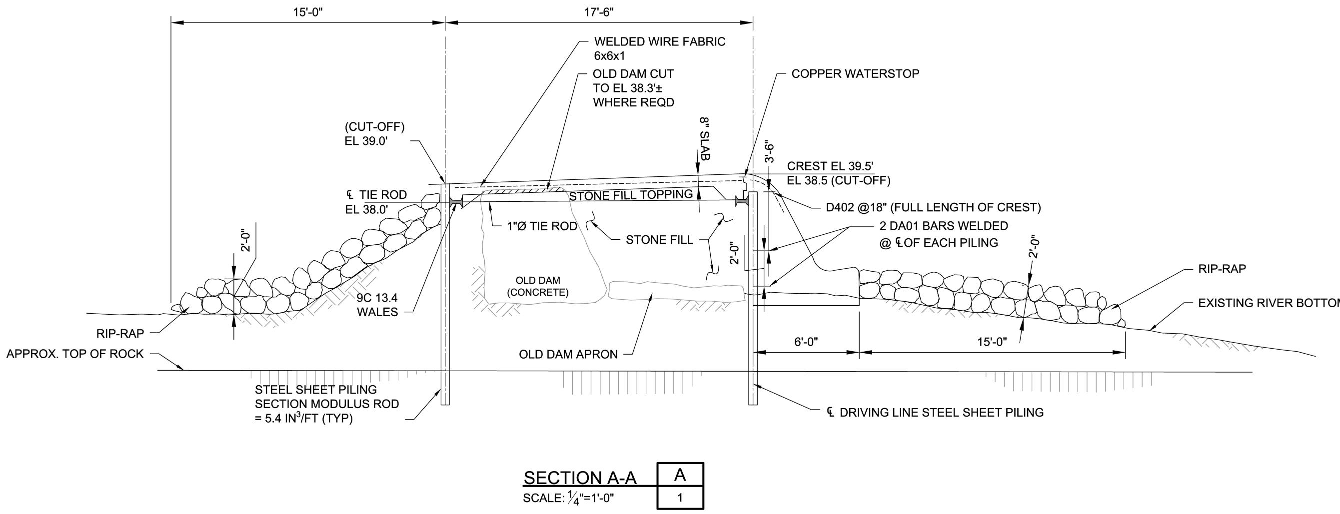

Figure 5. The author's redrawn Robert Street Dam as-built profile showing the encasement of the original "Old Dam" and "Old Dam Apron" between parallel rows of steel sheet piles; river flow is from left to right.

The upriver portion of the reconstructed dam had a 15-foot wide, 2-foot thick armored riprap slope of about 45 degrees although virtually all that material had been scoured away and deposited downriver of the dam by the time the assessment work began on this project; the downstream slope of the concrete spillway was approximately 70 degrees. According to available design drawings [7], the Robert Street Dam has a designed structural height of approximately 7.0 to 7.5 feet depending on whether the original dam apron was still present to serve as the base of the reconstructed dam (**Figure 5**). Photographs taken eight years after the 1964 completion of the dam indicated that the river had during flood stages scoured out the fill material behind the dam abutment walls on both shorelines so at some point after 1972, a riprap-entrained concrete cap was poured to stabilized the new fill that was emplaced landward of the abutments.

The design of the J-shaped base of the dam spillway created a powerful reverse roller and substantial hydraulic jump just a few feet downriver (**Figure 6**). At least one documented fatality occurred at the dam on June 17, 1989, and several other drowning victims found farther downriver may have been caused by entrapment in the Robert Street Dam reverse roller. Discussions with the Somerset County Duke Island Park rangers revealed that they have performed several rescues and resuscitations on individuals who were either fishing off the dam, or using it to cross the river when they slipped off and fell into the reverse roller. As such, it was not lost on the negotiators of the NRD settlement that there would be substantial public safety benefits to this dam removal in addition to eliminating a troublesome attractive nuisance at Duke Island Park.

Figure 6. Pre-dam removal image of the Robert Street Dam at Raritan RM 27.9 as viewed from the north bank of the river (left). There was at least one documented fatality of a boater who became trapped in the reverse roller at the base of the spillway. Deer swept off the dam while attempting to cross the river on the dam have also perished in the reverse roller (right). Copyright ©2016 John W. Jengo

A comprehensive field reconnaissance and photographic documentation of the Raritan River below and above the Robert Street Dam was conducted by kayak during the planning stages of the dam removal. One consistent finding was the contrast between the reaches of free-flowing river below the dam versus the development in the summer months of acres of thick filamentous mat algae in the 1.4-mile long Robert Street Dam impoundment, which negatively affected river water quality (e.g., decreased dissolved oxygen concentrations) above the dam (**Figure 7**). Eliminating these stagnant water conditions was another aspect of the dam removal that swayed public opinion in support of the project.

Figure 7. Clear water in the undammed reaches of the Raritan River reveal a clean sand, gravel, and cobble river bed substrate (left). The lake-like conditions upriver of the dams (right, above the Robert Street Dam) abetted the development of thick filamentous mat algae in the summer months, which triggered deleterious effects on water quality and aquatic life. Copyright ©2016 John W. Jengo

III. Primary Dam Removal Regulatory Requirements

Conference presentations [8] and a recent ASDSO paper [1] described the substantial and complex permitting effort that was implemented to receive ownership and permitting approvals to remove the Robert Street Dam. Reference [1] detailed the level of effort in confirming ownership of the dam, executing demolition and access agreements with the two adjacent property owners, performing hydraulic modeling, collecting sediment grain size and sediment contaminant data, surveying of the river bed, impounded bed load, the dam, and flood plain topography, meeting with stakeholders and environmental groups, addressing state Historical Preservation Office concerns regarding potentially affected archaeological and historical resources, pre-application interactions with NJDEP's Division of Land Use and Dam Safety permit writers, coordinating with Somerset County on the use of bridges and roadways to access the dam and to convey dam debris off-site, issuing public notices and landowner notifications, and performing engineering tests to assess the preferred access route to the dam.

It is worth revisiting; however, that the primary project objective and Dam Safety permit requirement was to re-establish the natural river bed gradient through the former dam location per the engineering plans submitted in the Dam Safety Permit application (in addition to ensuring that the dam removal would not adversely affect flooding conditions downstream during the 10, 50 and 100 year storms). Those engineering plans were informed by detailed survey transects at 4,250 feet (R1 transect), 2,230 feet (R2 transect), 900 feet (R3 transect), 275 feet (R3A transect), 200 feet (R4 transect), 50 feet (R4B transect), and 1 feet (R4A transect) upriver of the dam and 60 feet (R4C transect), 260 feet (R5 transect), 650 feet (R6 transect), and 1,250 feet (R7 transect) downriver of the dam (those transects surveyed within 275 feet of the dam are shown on **Figure 8)**. The spacing between the individual survey points on each transect varied between 10 and 20 feet depending on the variability of the river bed elevation features that were being profiled.

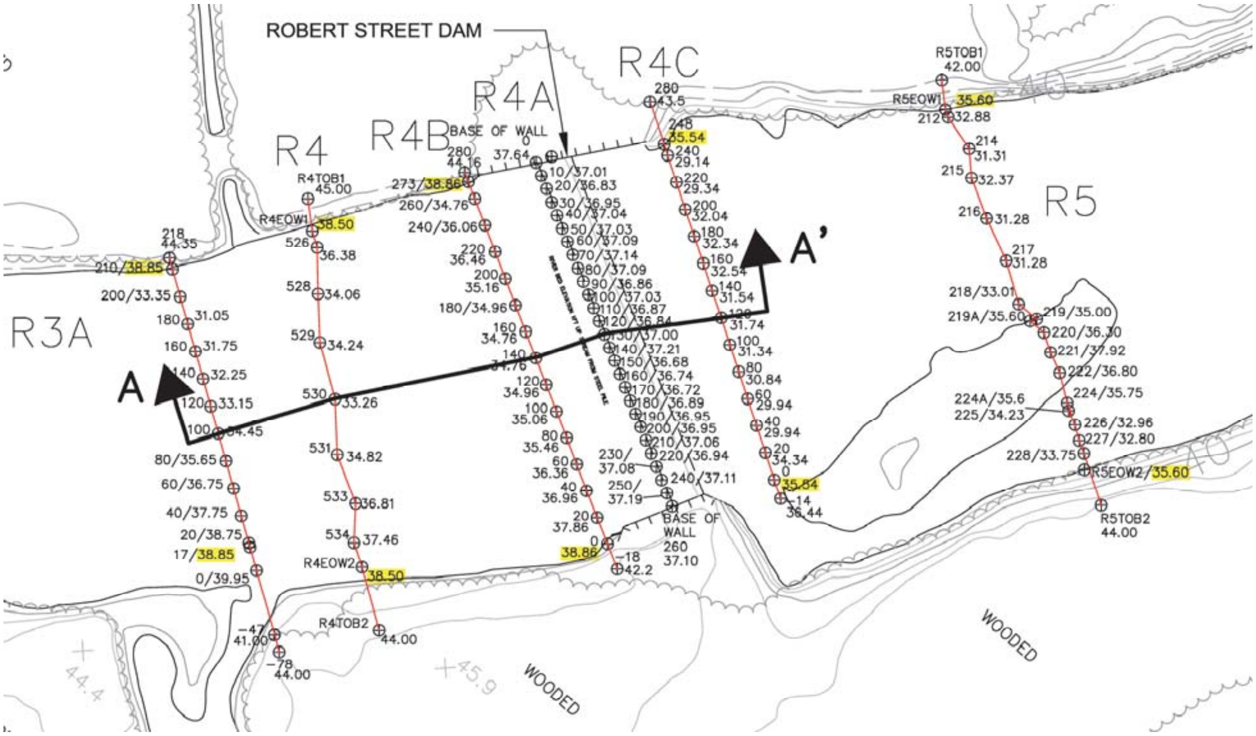

Figure 8. Plan view of the Raritan River survey transects nearest the Robert Street Dam.

Using the acquired surveying data, pre-dam removal and proposed post-dam removal river bed gradient profiles through the dam site were developed to allow Dam Safety to review and approve this critical aspect of the river bed restoration plan. That plan entailed the elimination of both the dam and the mounded sediment bedload behind the dam to create a sufficient river channel geometry that lacked obstructions and hydraulic jumps to provide anadromous and resident fish passage under normal river flow conditions (**Figure 9**).

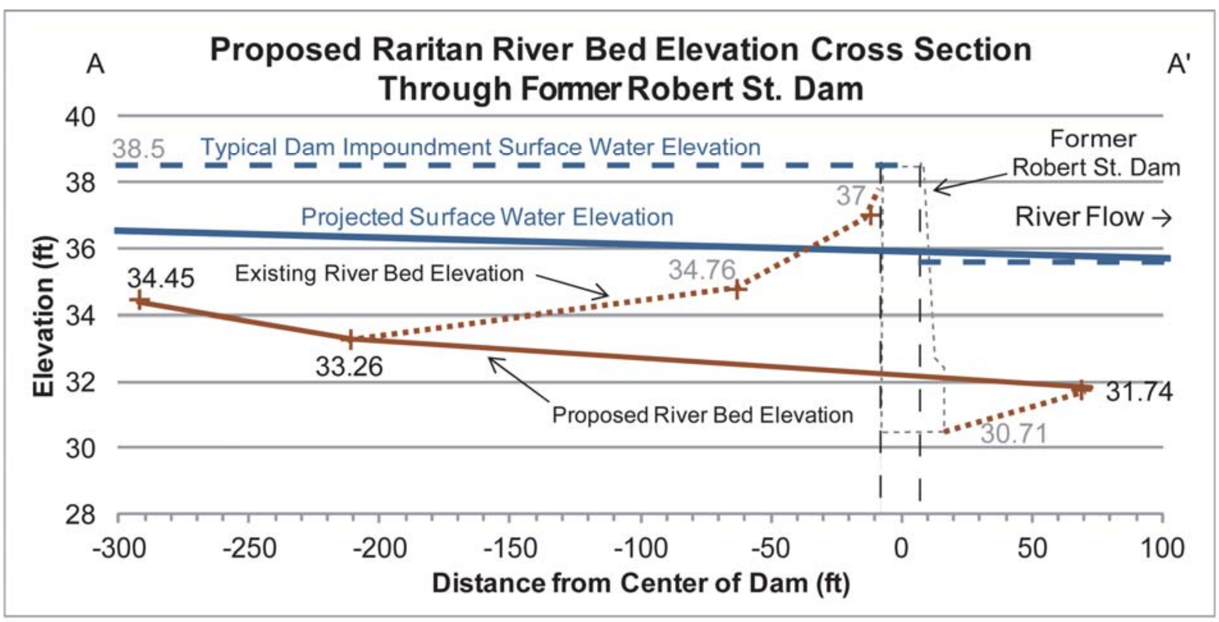

Figure 9. Pre-dam removal (dashed brown line) and the proposed post-dam removal (solid brown line) river bed elevation profiles and the projected post-dam removal surface water elevation (solid blue line) through the Robert Street Dam site.

The river bed survey data was also used in the planning of the mobilization activities. Using the survey transects as a guide, the most promising routes from various prospective access points to the dam was explored by kayak to determine water depths at various river flows to determine the safest routes for the demolition equipment.

IV. EXAMPLES OF TECHNICAL CHALLENGES

A. Fish and Wildlife Restrictions - Bald Eagle Nest

Typically, the most challenging aspect of the NJDEP Dam Safety, Land Use, and Fish & Wildlife permits are the various permit timing restrictions. When all the different permit timing conditions were combined initially, they left only a narrow window to perform the dam removal. After coalescing the Land Use Permit prohibitions, including March 15-June 15 (trout-stocked waters), March 1-June 30 (anadromous species spawning runs), and May 1-July 31 (warm-water fish nest building and spawning), along with the overlapping timing restriction under the Endangered and Non-Game Species Program because of the presence of the American bald eagle and great blue heron (December 15-July 31st), the earliest start date for the Robert Street Dam removal was August 1st. Unfortunately, the anticipated duration of the demolition work (six weeks) would push the dam removal completion into mid-September, but only one year earlier, Hurricane Irene struck New Jersey on August 28th, which was followed by Tropical Storm Lee 10 days later. These storms created flooding conditions so severe that the river's discharge was elevated above its historical median daily discharge for the next 3.5 months (e.g., the discharge on August 28 peaked at 80,400 cubic feet per second (cfs) as compared to the 292 cfs median of daily mean for that day). A repeat of those events would have seriously interrupted the planned removal of the Robert Street Dam; therefore, in our multiple permit applications, we proposed a start date of July 16th.

Just a few months before mobilization, the project team received a draft Land Use permit condition that the Robert Street Dam removal could not begin until August because the dam was within 750 feet of a bald eagle nest. The NJDEP was concerned that the noise associated with the dam removal could disturb the fledging eaglets at the nest site and that the work would affect their continued use of the nest during their post-fledging period. Land Use also opined that human figures in the vicinity of the dam would have the same disturbing effect. Unfortunately, this proposed delay would jeopardize the successful completion of the dam removal and put personnel working in the river at risk, particularly because the dam could only be accessed and worked on safely during the low flow conditions that exist predominantly in July and into early August. After considerable research, we submitted the following technical basis to Land Use to support our contention that it would not be harmful to the eaglets to initiate the dam removal in July:

- The United States Fish & Wildlife Service (USFWS) Bald Eagle Management Guidelines Federal Guidelines were consulted to determine an acceptable distance away from a bald eagle nest for noise-making activities. The dam project was well beyond the 330-foot (100 meters) vegetated buffer recommended by USFWS and was also outside the 660-foot buffer for non-vegetated areas. Because work on the dam would be conducted 750-1,000 feet away from the nest, compliance with this USFWS guidance was assured, particularly because the work area is not visible from the eagle's nest, which is often referenced in USFWS guidance as the primary factor that most influences an eagle's response to human activity.

- The dam demolition site is additionally buffered from the nest by forested vegetation. The excavation contractor tested the noise level of the excavators in an open field at 750 feet and measured a 65.2 dB level, essentially equivalent to conversational speech. It was anticipated that the actual noise experienced at the eagle nest with the vegetation buffer would be below 40 dB, the level of a typical bird call.

- The eagle nest was located within 950 feet of a busy County road (River Road) and in close proximity to an active auto wrecker facility and neither of these man-made intrusions were buffered from the nest by vegetation. The constant stream of vehicle traffic on River Road, the dissonant, high decibel noise from the auto wreckers, and a high voltage power line right-of-way adjacent to the nest posed a far greater and constant threat to the eagle nest than the dam removal work, which would only be occurring during the weekday daytime hours.

We subsequently rejected a proposed Land Use counteroffer to wait to commence the work until a NJDEP observer determined that the eagle fledging period was complete because it was not practical to defer the implementation of the complex logistic milestones that are necessary to properly execute a dam removal. These milestones included making the required property owner notifications, reserving a time period for the dam removal contractor (which had to be done months in advance), arranging for Department of Transportation (DOT) and Duke Island Park access to mobilize the heavy equipment on pre-determined days, and having the optimal river discharge conditions to access the river, demolish the dam, and to provide a safe escape route. Fortunately, through a series of high level negotiations with representatives of the NJDEP Office of Natural Resource Restoration (ONRR) and Division of Land Use, a compromise with NJDEP Land Use was reached just weeks before needing to lock in specific dates for the equipment mobilization. The compromise allowed equipment mobilization to the dam site to begin on July

18th with the commencement of the dam removal on July 23rd, only a one-week delay from the original proposed start date of July 16th.

B. Dam Site Access and Conveyance of Debris Off-Site

The Raritan River is surprisingly inaccessible considering the river flows through a highly populated area. As such, identifying appropriate river access and a suitable staging area became a fundamental challenge in planning the Robert Street Dam removal. The closest property available for use as a staging area and access route to the dam was on Duke Island, reachable most directly by a narrow 1982 Glue-Lam wooden deck bridge (crossing the historic Raritan Water Power Canal) whose maximum permitted load (20 tons) was well short of the capacity needed to support the crossing of the two pieces of demolition equipment (a CAT 330C L and Deere 3530D LC excavators weighing in at 78,000 pounds each). This bridge would be actually be utilized for two purposes: (1) as a mobilization route for the dam demolition equipment and (2) as a conveyance route for the off-site disposal of dam demolition debris. As such, a separate geotechnical effort was implemented to characterize the bearing capacity of the bridge abutments and canal banks to determine if a temporary bridge could be constructed over the existing bridge; this work involved advancing split spoons and Shelby tubes in the areas where the temporary bridge would be supported by the ground surface and conducting a series of geotechnical analyses on the acquired soil samples.

The data obtained from the geotechnical sampling were used to calculate soil bearing capacity, which was then compared to the loads exerted by the bridge and the demolition equipment. The results of the geotechnical evaluation indicated the necessity of constructing additional structural support for the temporary bridge. Two 30-inch diameter concrete piers would need to be installed on both sides of the bridge to a significant depth and then a cantilever system constructed to support the temporary bridge, which was wider than the existing bridge. However, all the soil enhancements and load distribution remedies to support the transit of the demolition equipment were deemed too costly and infeasible to implement and could not entirely eliminate the risk of structural damage to the existing bridge. In addition, the amount of time necessary to install this new infrastructure exceed the limited bridge closure time (36 hours) that would be granted by one remaining commercial entity on the island. As such, a series of options to work around the limited capacity of the bridge were developed, as described in the two subsections below.

<u>Options of Demolition Equipment Mobilization</u>

Having established the insufficient load capacity of the Robert Street Bridge (and rejecting the option to construct a temporary bridge) for the transport of the 40-ton demolition equipment, other river access options were explored. Because access to the dam on the south side of the river was precluded because of the bald eagle nest and restrictions associated with that property under the Wetlands Reserve Program, the best alternative route into the river was located over 3,000 feet upriver through Duke Island Park. However, this route was not without its own inherent risks and concerns, principally the ground surface impact of the transit of the 40-ton demolition equipment. The route the equipment would need to follow would include (i) crossing a bridge over the Raritan Power Canal, (ii) tracking across paved walking paths and grassy playing fields, (iii) driving along a narrow, 2,850-foot long paved walking path through a long forested tract, and most concerning (iv) entering into and then moving downriver in the dam impoundment to bypass the point where the walking path crossed a small wooden pedestrian bridge. Travel down the impoundment would continue until exiting the river at a boat ramp at the foot of Robert Street; from there, the excavators could track down to the end of Robert Street (formerly known as Edgewater Avenue when this area was a residential housing development) and onto another Duke Island Park paved walking path to reach the north embankment of the dam (**Figure 10**).

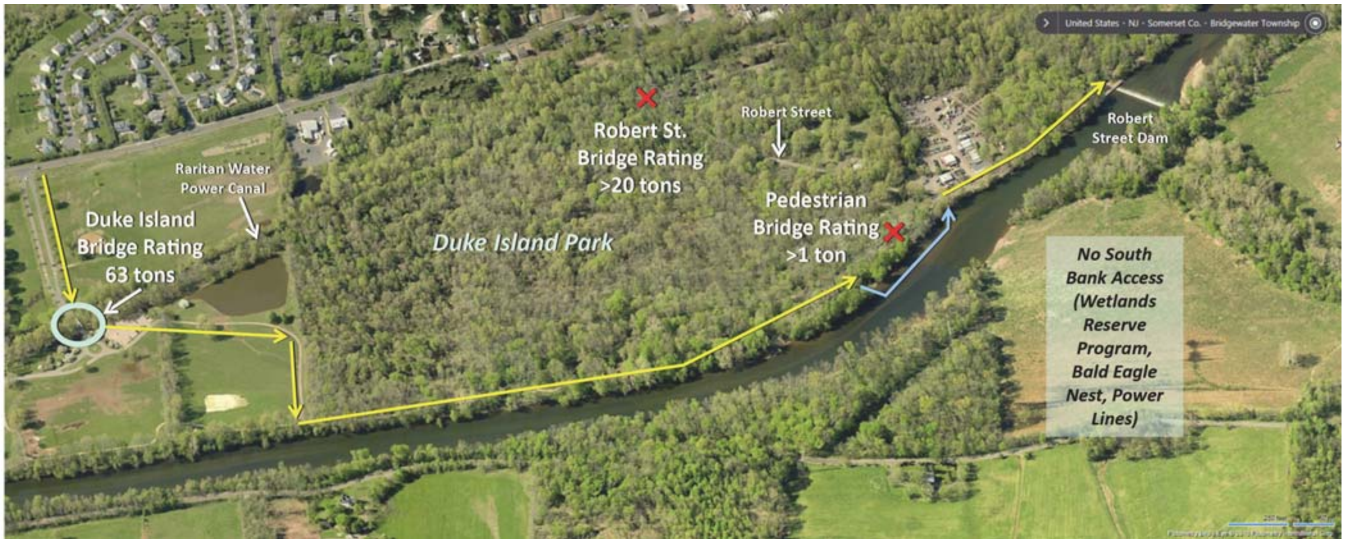

Figure 10. The mobilization route of the dam demolition equipment through Duke Island Park. The key success factor was utilizing the park bridge to cross the Raritan Water Power Canal, the only bridge onto Duke Island that had the operating capacity to support the transit of the 40-ton excavators. The route through the dam impoundment along submerged sand bars is indicated by the blue arrow.
Aerial photograph is Copyright ©2016 Microsoft Corporation

The assumed entry and exit point in the river was intensely reconnoitered at different river flows in the months prior to equipment mobilization and the depth of the water was measured at 5-foot spacings. This bathymetry reconnaissance, when paired with river discharge measurements from the USGS Manville Gage located 4.5 miles downriver, indicated that equipment transit in the river would need to occur at flows less than 250 cfs (to ensure shallow water depths) and would require a careful mark-out of the sole narrow route on in-river sand/gravel sand bars that could support the equipment loads. Another factor that had to be considered was the use of the Raritan River as a water supply “pipeline” by the New Jersey Water Supply Authority (NJWSA). To augment the drinking water withdrawals taking place at the Island Farm Weir approximately six miles downriver from the Robert Street Dam, the NJWSA can release millions of gallons of water on a daily basis from the Spruce Run and Round Valley Reservoirs upriver on the South and North Branches of the Raritan River. As such, releases that could noticeably increase the cfs discharge in the river also had to be monitored along with the normal discharge of the river to determine when it was safe to mobilize into the river and conduct the subsequent dam removal work.

<u>Options of Debris Conveyance</u>

The option of loading concrete debris via backhoes to a truck staged at the north end of the Robert Street Bridge was explored (to avoid having the trucks cross the bridge); however, the owner of the bridge (Somerset County) was not in favor of this option. Several of the more problematic issues were the potential interference with park visitors and commercial traffic, the frequency of the backhoes driving along Robert Street to and from the dam where people may be walking (Robert Street is a commonly used pathway for visitors to complete a hiking loop through Duke Island Park), and the nonconforming use of a Township thoroughfare for loading. The more amenable option was to use the bridge for the conveyance off-site of demolition debris provided that the weight of the trucks could be carefully managed. Several straightforward calculations (**Table I**) were made to determine how much the trucks could be loaded to stay under the maximum permitted load of the bridge (20 tons).

Table I. Load calculations to determine the maximum permissible haul truck payload of concrete and metallic debris to stay under the load capacity of the Robert Street Bridge.

Load	Weight (Kips)	Weight (Tons)
Max Gross Wt. of Truck (incl. Payload)	40 Kips	20 tons
Empty Weight of Truck	24.2 Kips	12.1 Tons
Max Permissible Payload of Truck	15.8 Kips	7.9 tons

Using this calculation, and upon receiving approval from the Somerset County Bridge Engineers, it was agreed that a truck scale would be brought on-site and used to weigh the trucks prior to crossing the bridge. Although lightening the load of the trucks in this manner to below 7.9 tons of debris would at least double the amount of trips to convey debris off-site, this option was considerably less expensive and more feasible than the temporary bridge and all the ancillary work to create additional load support of that structure, as discussed above.

V. Dam Removal Equipment Mobilization

On two consecutive mornings of the equipment mobilization and prior to the park's opening (to avoid inferences with the public), the CAT 330C L and Deere 3530D LC excavators were offloaded from their lowboy carriers on the far side of the Duke Island Park bridge (which had an operating rating of 63 tons, which was not sufficient to support both the weight of the excavators and their lowboy transports). The excavators were driven across the bridge (the bridge asphalt was protected by laying out 72-foot long re-purposed conveyor belts under the excavator tracks), across grassy fields, and then down paved walking paths for 2,850 feet until that route ended at a wooden pedestrian bridge (**Figure 11**). It was assumed that upon entering the river, the excavators would sink in the soft mud along the impoundment edges before reaching the in-river sand bars. As such, loads of large rocks were brought in and dumped at the edge of the embankment to create sufficient resistance when the excavators angled into the river (two large dead trees were also maneuvered into position to stabilize the mud bottom).

Then, when the discharge of the river fell below the targeted cfs flow, the excavators were mobilized into the river. Following the previously marked out route, the excavators tracked along a series of shallow, submerged sandbars that kept the water level of the river from reaching the cab of the excavators until a boat ramp located 975 feet upriver of the dam was reached. A load of stone was placed at this ramp for increased traction and our Land Use permit allowed that imported material and in-river sediment to be re-contoured by the excavators to build an adhoc causeway to cross a 40-foot wide stretch of deeper water between the last sand bar and the boat ramp (**Figure 11**). Based on bathymetry data acquired during the river bed survey work, it was surmised that this channel was formed during the 1963 breach of the former Dead River Dam, which formed a deeply incised channel reaching over 1,000 feet upriver of the dam along the north shoreline.

Figure 11. The dam demolition excavators were driven through Duke Island Park on several paved walking paths (left) to a point where the excavators were brought into the river to travel along shallow sand bars to reach a boat ramp 975 feet upriver of Robert Street Dam (right). Copyright ©2016 John W. Jengo

The staging and loading area on the north shore was temporarily fenced to provide security for the demolition equipment and to restrict public access to this area of intense activity. Because the paved walking path was coopted for use by haul trucks to convey debris off-site, a temporary walking trail was created around the fenced area to allow park visitors to pass by the work area safely.

VI. Robert Street Dam Removal

A. Robert Street Dam Removal Planned Sequencing

Per a Dam Safety permit requirement, HEC-RAS modeling was performed to determine the width of the initial breach (25 feet) and the maximum allowable river discharge (300 cfs or less) when the initial breaching could occur (the term "initial breach" in this Dam Safety context refers to actions that begin the release of impounded water from above the dam while the term “final breach” means the complete removal of the dam). The initial breaching was proposed to be located on the far southern (right) bank of the Robert Street Dam to produce the desired impoundment drawdown and water flow velocity through the breach. This initial breach, and expansion of the breach across the entire width of the river to achieve the final breach, was planned to proceed as follows:

1. The concrete dam crest and 8-inch thick concrete approach apron installed as part of the 1964 dam reconstruction would be demolished and removed to expose the sheet piling and horizontal walers (the braces tieing the rows of sheet piles together);
2. The horizontal walers would be cut where they were attached to the sheet piles to facilitate the removal of the sheet piling, and the 1-inch steel tie rods between the two rows of sheet piles would also be cut and removed;
3. The stone backfill between the sheet piles would be excavated and removed. If this material was run-of-river gravel size, it will be stockpiled for future use for river shoreline restoration. If the material was angular trap rock between the size of R-4 to R-6, it would be stockpiled for use in dam abutement wall support;
4. An appropriate section of the downriver sheet piling would be extracted and a corresponding section of upriver sheet piling would then be removed, along with any mounded sediment bedload;
5. The remnant of the former dam between the extracted sheet piles would then be demolished and removed down to the bed of the original gradient of the river;
6. Once all the sheet piling, rock fill, and the original dam had been removed completing the final dam breach across the river, the river channel would be reconnected through the former dam alignment; and,
7. Lastly, the previously exavated R-4 to R-6 sized rock fill would be emplaced as abutement wall support.

Throughout the dam removal process, concrete debris, rebar, tie-rods, extracted sheet piles and miscellaneous metal (e.g., copper water stops installed at the contraction joints between the individual approach apron slabs) would be conveyed to the north shoreline where this material would be transferred to haul trucks for off-site disposal. The truck scale discussed previously would be employed to ensure that the total weight of the trucks did not exceed the 20-ton operating capacity of the existing Robert Street Bridge.

B. Robert Street Dam Removal Actual Sequencing

On the appointed day of the initial dam breaching, the river discharge was at 204 cfs, nearly 100 cfs lower than the maximum permitted flow specified in the Dam Safety Permit. Using a temporary rock ramp that was emplaced at the northern dam abutment several days earlier, the excavators were mobilized into the river and over to the south end of the dam using the concrete approach apron as an ad-hoc causeway (**Figure 12**).

Figure 12. To avoid damage to the natural river embankment, loads of stone were dropped into the river to construct a temporary ramp extending outward from the north shore dam abutment (left); this ramp was used throughout the project to bring the excavators in and out of the river (right). Copyright ©2016 John W. Jengo

A CAT Hammer model H140D S mounted on the excavator arm was employed as the primary tool to break apart the concrete. The H140D S had an operating weight of 5,180 pounds and was capable of generating 300-600 blows per minute with an operating pressure of 2320 psi (**Figure 13**).

Figure 13. The initial breakup of the dam crest and concrete approach apron of the Robert Street Dam using the CAT Hammer model H140D S (left) with the objective of opening a 25-foot wide initial breach on the south end of the dam (right). Note the horizontal waler (sticking upright in the right photo) that had been pulled free from the downriver row of sheet piles (lower right). Copyright ©2016 John W. Jengo

Although the dam removal commenced following the proposed Step 1 and Step 2 removal sequence, modifications were needed almost immediately because of the difficulty of extracting the sheet piles. Prior to the commencement of work, the depth and number of sheet piles fortifying the Robert Street Dam was unknown. As such, the demolition contractor planned to break apart the concrete approach apron and dam crest in order to expose the upper 1-2 feet of the sheet piles. The excavator bucket would then grapple onto the sheet piles and rock them back and forth to detach the sheets from their connections with adjoining sheets prior to lifting the sheets up and out of the river. It became apparent on the first few sheet piles that this approach was time consuming, tended to distort the upper sections of the sheets, and was generally ineffective in dislodging the sheet piles in an efficient manner (**Figure 14**).

Figure 14. The approach of hammering the dam crest directly above the downriver sheet pile resulted in large concrete sections being dislodged in a single piece, simplifying their removal from the river (left). The effort to rock sheet piles back and forth and lifting them with the excavator bucket was time consuming and was generally ineffective in dislodging the sheets in an efficient manner (right). Copyright ©2016 John W. Jengo

To accomplish the initial breaching in the time allotted, and given the onset of severe thunderstorms forecasted in the afternoon that would terminate work early on this first day, the downriver sheet piles were bent forward to commence the dewatering of the upriver impoundment. When several sheet piles were finally removed the following day, they were measured to be 13 to 14 feet long, with at least four feet of bedrock naturally cemented to the lowermost portion of the sheets (**Figure 15**). Based on the project team’s estimate on the total number of sheets (approximately 300) composing the upriver and downriver sheet pile rows, the dam removal contractor ceased operation on sheet pile removal and initiated a rental of a hydraulic vibratory driver/extractor (vibratory extractor) for use in the extracting the sheet piles.

Figure 15. The level of effort required to remove sheet piles with the excavator bucket (left) indicated that a different extraction approach was needed. While awaiting the delivery of a hydraulic vibratory driver/extractor, unremoved sheets were bent forward in the initial breach to commence the dewatering of the upriver impoundment (right). Copyright ©2016 John W. Jengo

While awaiting the delivery of the vibratory extractor, the contractor continued to break apart the concrete approach apron and dam crest to expose the top of the downriver row of sheet piles working from the south bank to the north bank (**Figure 16**). This work revealed that ½-inch thick rounded rebar was used to provide cantilever support to the overhanging dam crest.

Figure 16. Work proceeding on the breakup and removal of the dam crest across the dam (left) to expose the downriver row of sheet piles (right). Copyright ©2016 John W. Jengo

The work to uncover the top of the downriver row of sheet piles in preparation for vibratory extraction exposed the infrastructure of the Robert Street Dam and revealed how the dam was reconstructed in 1964 (**Figure 17**). The original dam was easily distinguishable by its reddish-pink coloration (a probable result of incorporating native Raritan River bedload as aggregate) and the sporadic distribution of both ⅝-inch round and ½-inch square rebar. R-4 to R-6 rock fill had been emplaced to fill the remaining space between the two rows of sheet piles and to bring the filled surface up to a consistent elevation (made necessary by the differential subsidence that had occurred to the original dam). Approximately 12-inches of bedding gravel (referred to as “stone fill topping” on the original design drawings) was laid down to create a level bed to support the concrete pour of the 8-inch thick concrete approach apron, which incorporated a dense web of ¼-inch rounded steel wire mesh.

Figure 17. View of the infrastructure of the Robert Street Dam, the ¼-inch rounded steel wire mesh-supported concrete approach apron underlain by bedding gravel (left), which covered both the pinkish-colored original dam and R4 to R6 rock fill between the parallel rows of sheet piles (right). Copyright ©2016 John W. Jengo

Evaluation of the sheet piles indicated that they were contiguous U-sheet piles with Union straight web section interlocks positioned at both flange ends (**Figure 18**). Although most of the upper contacts of the sheet piles were filled with concrete, the sheets were not grouted together at depth. The sheets, marked "Bethlehem" (undoubtedly sourced from Bethlehem Steel) had a section width of approximately 20-inches, with a 6-inch section depth, and varied slightly in thickness between ⅜-inch to ½-inch. The weight of a typical 13-foot long sheet (after cemented rock fragments were cleaned off) was 360 pounds.

Figure 18. The downriver row of sheet piles awaiting extraction after the concrete dam crest and concrete approach apron had been removed (left). The sheet piles were identified as U-sheet piles with Union straight web section interlocks (right). Copyright ©2016 John W. Jengo

Two types of vibratory extractors were ultimately used to extract the sheet piles. After five days of use (with the first two days dedicated to removing the downriver and upriver sheet piles in and around the initial breach), the first vibratory extractor (MKT Manufacturing, Inc.'s Model V-2ES) was found to be working beyond its capacity to vibrate and lift the sheets, and a failure occurred in the power unit when attempting to extract a particularly recalcitrant sheet. Although the sheets were not grouted into bedrock, naturally occurring cementation with the siltstones and mudstones of the Triassic-age Passaic Formation had locked the sheet piles so tightly in place that ultimately the bedrock had to be shattered to release the sheet pile from the subsurface (**Figure 19**).

Figure 19. Use of MKT Manufacturing, Inc.'s V-2ES vibratory extractor in the initial phases of the sheet pile extraction (left). Nearly every extracted sheet pile had fragments of bedrock attached (right), which indicated that naturally occurring cementation with the siltstones and mudstones of the Triassic-age Passaic Formation had served to firmly lock the sheet piles in place. Copyright ©2016 John W. Jengo

A decision was made to replace the MKT unit, which would be delivered to the site in 24 hours. In the meantime, work continued on excavating the original dam and rock fill between the sections of the extracted upriver and downriver sheet piles down to the pre-dam river bed elevation and deepening/widening the dam breach to complete the dewatering of the upriver impoundment (**Figure 20**).

Figure 20. View of the initial dam breach looking toward the north bank (left) and from downriver to upriver from the south bank (right). Copyright ©2016 John W. Jengo

As expected from the pre-dam removal river bed survey (**Figure 8**), the shallow river bed on the south side of the river was broadly exposed after the impoundment water level was permanently lowered. A broad swath of filamentous mat algae and other aquatic plants were stranded and carpeted the former river bed margins (**Figure 21**). It was not necessary to remove this material or seed the exposed river bed because prior dam removal experience on the Raritan River had indicated that this algae and plant material would degrade quickly and the exposed river bed would begin to vegetate naturally within a few weeks.

Figure 21. The exposed Raritan River bed following the final dewatering of the Robert Street Dam impoundment, looking upriver at stranded filamentous mat algae (left) and looking downriver at other stranded aquatic plants toward the dam site (right). Copyright ©2016 John W. Jengo

Upon delivery to the site, a more powerful International Construction Equipment (ICE) Model 11-23 vibratory extractor was then employed for the duration of the project. Utilization of the ICE 11-23 enabled most sheet piles to be extracted in only one to three minutes, with most of that time needed to ramp up the vibration of the sheet piles to break the seal with the adjoining sheets; this would often result in the interlock heating up to such a degree that it glowed bright red (**Figure 22**). The sheet extraction time; however, was swift compared to the effort to carry and stage the power unit in close proximity of the extraction points, along with the necessary hydraulic hose "wrangling" (each 100-foot section of hose weighed 850 pounds) to keep the hose properly positioned, unkinked, and protected from the exposed sharp metal surfaces of the sheet piles, walers, and the steel wire mesh of the demolished concrete approach apron.

Figure 22. The ICE Model 11-23 vibratory extractor was ideally suited to extract the remaining Robert Street Dam sheet piles (left) and overcome the resistance of the interlocks, which often superheated during the extraction procedure (right). Copyright ©2016 John W. Jengo

A comparison of the two vibratory extractor models (**Table II**) suggests that the ICE-11-23 model's increased eccentric movement, maximum line pull capacity, the total suspended weight of the extractor with clamps and hoses (5,590 pounds) and the clamping force and pressure (4500 psi) along with a more robust power unit were the most critical upgrades.

Table II. Comparison of the specifications of two vibratory extractor models used to extract steel sheet piles in the Robert Street Dam removal project.

Manufacturer	MKT Manufacturing, Inc.	International Construction Equipment (ICE)
Vibratory Extractor Model	**V-2ESC**	**11-23**
Eccentric Movement	550 in-lbs	1100 in-lbs
Frequency	1,800 cycles per minute (30 Hz)	2,100 vibrations per minute (35 Hz)
Amplitude	0.75 in	0.92 in
Force	25 tons Driving	69 tons Centrifugal
Max Line Pull	16 tons	40 tons
Weight (w/o Clamps & Hoses)	3,300 lbs	4,300 lbs
Height	48	61 in
Throat Width	14.75 in	12.8 in
Clamping Force	16 tons	85 tons
Power Unit	**HP-85T3**	**CAT 3116TA**
Engine	85 HP	220 HP
Operating Speed	2,200 RPM	2600 RPM
Drive Pressure	2,500 psi	5,000 psi
Drive Flow	30 gpm	71 gpm
Length	96 in	126 in
Height	69 in	79 in
Weight	2,500 lbs	9,310 lbs

Recurring problems arose with the heavy use of the vibratory extractors, with the cumulative loss of several days downtime on sheet pile extraction. Issues with oil leaks at hose connections (eco-friendly biodegradable hydraulic oils were utilized for all in-river equipment so there were no harmful releases to the river), hose kinking, fuel filter clogging, and the dislodging of clamps could have been prevented had these rental units been better maintained by the rental agency. In future projects, it would be imperative to implement routine maintenance visits to keep the equipment operating to eliminate downtime for repairs and part replacements.

Use of the vibratory extractors necessitated making an adjustment to the planned dam removal sequencing outlined above. Firstly, the rock fill and the original dam between the sheet piles was kept intact after the removal of the concrete approach apron for use as a stable platform for (i) the excavators to remove the remaining dam crest and expose the top of the sheet piles, and (ii) the vibratory extractor power unit and excavator to remove the downriver row of sheet piles. Then, during the subsequent excavation of the rock fill and the original dam, some of that material was emplaced *upstream* of the upriver row of sheet piles to create a causeway/working platform for the excavators to facilitate the subsequent removal of the upriver sheet piles, which also required moving the access/egress ramp on the north embankment off the dam (**Figure 23**). The reason was self-evident – a stable platform was needed to stage the nearly 5-ton power unit of the vibratory extractor and have the excavator with the vibratory extractor positioned astride the sheets that were being pulled (in addition, this temporary platform was also utilized to stage the compressor for the CAT hammer).

Figure 23. Staging the excavator on the rock backfill of the original dam to remove the remaining dam crest to expose the downriver row of sheet piles nearest to the north abutment (left); concrete and excavated rock fill material was then emplaced as a temporary causeway/working platform upstream of the upriver row of sheet piles (left side of right photo). Copyright ©2016 John W. Jengo

With this revised sequencing into place, the last remaining sheet piles were extracted (**Figure 24**), although one or two of the sheet piles were left in place nearest the base of the abutment walls for support. This final extraction effort did require returning to several sheet piles to cut away upper sections that were distorted or shredded by the initial excavator extraction attempts. This was necessary to fashion a clean, straight surface at the top of the sheet piles to grapple with the extractor clamps, which had a fairly narrow throat width. The dam removal then concluded when the remaining original dam remnants and rock fill was excavated and removed from the river, progressing from the far south bank of the river to the near north bank.

Figure 24. The final downriver sheet pile extraction (left) and final upriver sheet pile extraction (right). In the right hand photo, note that the access/egress ramp was moved upriver off the dam from its original position shown in Figure 12. Copyright ©2016 John W. Jengo

VII. DAM DEBRIS REUSE AND DISPOSAL

A. Rock Fill Debris

The size of the rock fill between the sheet piles that encased the original dam, which generally ranged from R-4 through R-6, was ideally suited for reuse as riprap to stabilize the dam abutments, which was one of the conditions that the land owners on both sides of the river had stipulated. The reuse of the rock fill provided both structural support for the abutments and protection from the scouring action of the river along the newly-exposed base of the walls (**Figure 25**).

Figure 25. After excavation, the salvaged R-4 through R-6 sized rock fill was segregated (left) and stockpiled for use in stabilizing the former Robert Street Dam abutments (right). Copyright ©2016 John W. Jengo

B. Concrete Debris

Although it may have been possible to petition Dam Safety to reuse the dam concrete debris on-site, which is common practice in states such as Pennsylvania, the aesthetics were unappealing in a project that was attempting to restore the river back to its natural state (in addition to safety concerns because the concrete dam crest contained rebar and the concrete approach apron was riddled with ¼-inch rounded steel wire mesh). As such, it was always part of the project to convey and dispose of this concrete material off-site.

Throughout the project, concrete debris was conveyed to the north bank by using both excavators in a “bucket brigade” fashion. After the concrete debris had been stockpiled at the north bank and “downsized” by the excavator equipped with the CAT hammer (during times when that equipment was not needed for in-river dam demolition), the debris was directly loaded into haul trucks. A total of 96 round trips were needed to convey 702 tons of concrete debris off-site, while staying below the Robert Street Bridge load capacity (the average net weight of the concrete per load was 7.3 tons). When one of the excavators could remain dedicated to loading the haul trucks, two trucks were employed on certain days that allowed a maximum of 14 trips off-site per day. The material was hauled to a New Jersey Approved Class B Recycling Facility (Vollers’ recycling facility in Branchburg, New Jersey), a 12-mile roundtrip from the dam site, to be recycled (**Figure 26**). The recycled concrete would ultimately be crushed and then reused in roadways, driveways, and building pads rather than take up valuable space in local landfills.

Figure 26. Loading of dam concrete debris into one of the haul trucks for transport off-site (left). The concrete debris was brought to a New Jersey Approved Class B concrete recycling facility for crushing and subsequent reuse (right). Copyright ©2016 John W. Jengo

C. Metallic Debris

Over 70 tons of steel, primarily the extracted sheet piles and waler beams, were conveyed off to Klein Recycling in Hillsborough Township, New Jersey, an 11.5-mile round trip from the dam (but in the opposite direction of the concrete recycling facility), for ferrous metal recycling (**Figure 27**).

Figure 27. Loading some of the 300 individual steel sheet piles onto a trailer for transport off-site (left). The steel sheet piles were brought to a local facility (right, foreground) for ferrous metal recycling. Copyright ©2016 John W. Jengo

VIII. Robert Street Dam Site Restoration

The Robert Street Dam removal project was the largest dam removal in the Raritan River watershed to date and was a highly visible effort that received significant local and regional press coverage, many interested observers, and intense regulatory scrutiny. Such public exposure helped justify a particularly diligent restoration effort and the addition of unanticipated tasks, namely the retrieval of all manner of debris that was exposed when the dam impoundment was drained. Empty tanks, rope, hose reels, bicycles, and numerous car and truck tires and ancillary automobile parts and other debris were retrieved and disposed of properly off-site, courtesy of Somerset County. In addition, as the river clarity improved and flows decreased in mid-August in the final days of the project, the river bed was canvassed each day to manually retrieve small pieces of concrete and steel wire mesh (**Figure 28**). By the end of the project, all anthropogenic material greater than a few inches in size had been removed from the river bed.

Figure 28. Retrieval of unrelated debris that emerged from the dewatered dam impoundment (left) and meticulous collection of small pieces of concrete along the demolished dam alignment (right) was performed during the restoration phase of the Robert Street Dam removal. Copyright ©2016 John W. Jengo

Lastly, to create a smooth shoreline transition, emergent gravelly sand beaches on both sides of the river were supplemented with the bedload that was excavated from behind the dam and then contoured to connect and blend with the salvaged R-4 to R-6 rock fill that had been emplaced to support the former dam abutments (**Figure 29**).

Figure 29. Mounded gravelly sand bedload from behind the dam was moved to the shorelines, which were contoured and graded to blend in with the excavated dam rock fill on the south (left) and north (right) river banks that had been emplaced to support the former dam abutments. Copyright ©2016 John W. Jengo

Our extensive experience with the behavior and sediment load carried by the Raritan River and its frequency to flood at all times of the year suggested that in just a few years, fine-grained material would blanket the riprap and fill in the interstitial spaces in the rock fill stabilizing the abutments, which would then promote the growth of vegetation. As such, only a minimal amount of river bed gravelly sand was emplaced to "knit" together the abutment riprap. As predicted, periodic flooding events over the next 12 months following the dam removal deposited enough river mud to in-fill the riprap so that these areas were completely vegetated the following summer (see **Figure 30** and **Figure 31** below).

The excavators were demobilized from the site using the same route through Duke Island Park (as described earlier). The exit was made considerably easier by the lower water levels in the former impoundment; in fact, the same route through the impoundment where water levels were up to the excavator cabs were now dry tracks along the newly exposed shoreline. Areas on the north shore that were impacted by the week of mobilization and the subsequent five weeks of intense site activities, which included staging of the vibratory extractor and power unit, periodic refueling visits, use as a truck scale weighing area, and the stockpiling/loading of the concrete debris and steel sheet piles, were scraped free of loose debris and gravel, covered with screened top soil, and seeded. Any damage to the Duke Island Park paved walking paths (approximately 90 feet) used by the excavators in both accessing and demobilizing from the dam site were also subsequently repaired. Lastly, riprap that had been entrained in the concrete abutment cap that had been a tripping hazard ever since it was poured sometime after 1972 were chipped down to grade with the hydraulic hammer as a safety measure for park visitors.

IX. Conclusion

The removal of the Robert Street Dam, in conjunction with the removal of the Calco Dam and the Nevius Street Dam downriver, eliminated the physical barriers to anadromous fish passage along nine miles of the main stem of the Raritan River between RM 20.9 and RM 29.9 and the lower 1.5 miles of the Millstone River tributary. These projects restored access to historically significant spawning grounds for American shad (*Alosa sapidissima*), hickory shad (*Alosa mediocris*), blueback herring (*Alosa aestivalis*), and alewife (*Alosa pseudoharengus*) in New Jersey's largest interior watershed and river system (**Figure 30**).

Figure 30. A before (left) and after (right) view of the Robert Street Dam facing west (looking upriver) from the north bank of the river. In the photo on the right, note the growth of vegetation that has completely covered the abutment-supporting riprap as compared to the same view in the right-hand photo in Figure 29. Copyright ©2016 John W. Jengo

Post-dam removal observations have verified the elimination of the filamentous mat algae and stagnant water conditions behind the former Robert Street Dam and have shown that the natural river process of transporting sediment, woody debris, and nutrients has been fully restored (**Figure 31**).

Figure 31. A before (left) and after (right) view of the Robert Street Dam facing southeast across the former dam alignment and impoundment from the north bank of the river. Copyright ©2016 John W. Jengo

The re-establishment of flowing water and emergence of shallow sand bars and beaches along the river's edge are now providing the diversity of habitats necessary for fish species and other species such as the American eel, bald eagle, great blue heron, and great egret to survive and thrive. The elimination of a significant public safety hazard has also increased recreational use of the river, including kayaking, canoeing, and fishing (**Figure 32**).

Figure 32. A before (left) and after (right) view of the Robert Street Dam facing west (looking upriver) from the south bank of the river. Copyright ©2016 John W. Jengo

In addition to the direct ecological benefits, the removal of the Robert Street Dam and other Raritan River dams have triggered feasibility studies and planned dam removals farther upriver on the Raritan River such as the Headgates Dam at RM 29.9, the Weston Mill Dam on the Millstone River, and the design of a nature-like fishway at the Island Farm Weir on the Raritan River at RM 22.0 to replace a suboptimal fish ladder. The success of the dam removals thus far, particularly the use of NRD compensation funds to address large-scale dam removals too complex and costly to be funded readily by Non-Governmental Organizations (NGOs), offers a model for funding dam removals on other river systems throughout the country, particularly if industries with potential sediment NRD liabilities can be matched with suitably scaled dam removal projects. Dam Safety officials can contribute immensely to this effort by continuing their proficient and diligent work in identifying derelict, abandoned, and nonessential dams as worthy candidates for removal to facilitate migratory fish passage.

X. Acknowledgements

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