



Lehigh River Fish Passage Improvement Feasibility Study

Easton Dam (PADEP Dam I.D. No 48-012)
Chain Dam (PADEP Dam I.D. No 48-013)
Northampton County, PA

Prepared By

KCI Technologies, Inc.

March 2013



American Rivers
Rivers Connect Us®



Easton Dam 1943



Easton Dam 2011



Chain Dam 1965



Chain Dam 2011

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Executive Summary

Background and Introduction to Feasibility Study - The Lehigh River has been used and enjoyed by countless generations, from the first Native Americans to settle upon its banks; to the many industrialists who used it to produce iron, cement and steel; to the recreational boaters, anglers, and wildlife enthusiasts who love the River today.

The Lehigh River watershed drains 1,345 square miles of eastern Pennsylvania, encompasses portions of 108 municipalities, contains more than 2,000 miles of tributary streams, and drains portions of ten counties. The watershed is home to more than half-a-million people. The headwaters of the Lehigh River are located deep in the Pocono plateau at Lehigh Marshes, just north of Gouldsboro in Wayne County. From there, the River winds its way 103 miles to its confluence with the Delaware River in the City of Easton in Northampton County.

The Lehigh River has an extensive industrial past; most notably it was used to transport coal from the Eastern Middle and Southern coalfields of Carbon and Luzerne counties to burgeoning markets in Philadelphia and New York. Throughout the nineteenth and the first half of the twentieth century the Lehigh River suffered tremendously and was once described as “black flowing lava.” In the 1970s the passage of the Clean Water Act began the environmental movement that has since led to dramatic improvements in the ecological health of the River.

But the Lehigh still faces enormous challenges, one of the most significant of which is the existence of large dams that that adversely affect water quality and aquatic and riparian habitat, prevent the natural movements of many resident and migratory fish species, exacerbate flooding and erosion, and are significant public safety hazards.

The dams constructed on the Lehigh River during the 1800s have resulted in the near extirpation of American shad (*Alosa sapidissima*) and other migratory fishes, including hickory shad (*Alosa mediocris*), blueback herring (*Alosa aestivalis*), and alewife (*Alosa pseudoharengus*), from the Lehigh. The American shad is an anadromous fish that lives much of its life in the Atlantic Ocean, but must migrate into freshwater rivers and streams to spawn. Before the dams were constructed shad were an extremely abundant and were critical components of the Lehigh River ecosystem. Creation of the dams stopped shad migration into the Lehigh River. Removing dams will allow shad and other migratory fish to return to the Lehigh and will allow resident fish to move freely through the River. Restoration of American shad was the primary impetus for undertaking this project, but the many potential social and environmental benefits that could result would extend far beyond fish.

For over 30 years, the Pennsylvania Fish and Boat Commission, Wildlands Conservancy, and their partners have been attempting to restore American shad to the Lehigh River through a combination of stocking and trying to provide fish passage at existing dams. The Easton and Chain Dams, which are the focus of this study, have existing fishways (installed in 1994), but monitoring indicates that passage is far from sufficient enough to support the restoration of the fishery and establish a self-sustaining population of American shad. All options to improve fishway efficiency from an engineering and operations perspective have been exhausted. The goal of this feasibility study is to determine how to allow substantial numbers of migratory fish into the Lehigh River while ensuring that the Delaware and Lehigh Canals remain watered.

Project Description - At both the Easton Dam, owned by Department of Conservation and Natural Resources and the Chain Dam, owned by the City of Easton, KCI evaluated the following set of options for fish passage:

- Partial Vertical Removal with Nature-like Fishway
- Partial Horizontal Removal with Nature-like Fishway
- Full Dam Height Nature-like Fishway
- Full Dam Removal

In order to evaluate these options, data was collected from numerous sources and reviewed to identify data required for the development of the fish passage alternatives. Accessible data included Geographic Information Systems (GIS) data layers, plus information about dam construction, location and design of bridges, current river access points, locations of utilities and stormwater outfalls, threatened and endangered species, and historical resources. Data collection also included a river geomorphic assessment, physical habitat assessment, and a canal and infrastructure assessment.

A detailed base map was developed to represent the portions of the Lehigh River that could potentially be impacted by the selection of any of the fish passage options listed above. The area covered by the base map includes the length of the Lehigh River from the confluence of the Lehigh and Delaware Rivers to upstream of the State Route 33 bridge crossing; this area includes the impoundment areas associated with both the Easton and Chain Dams. A base map and plan set suitable for modeling of the various fish passage options was developed using conventional survey, river bathymetry and historic mapping methods, supplemented with data collected using sophisticated sonar (i.e., Light Detection and Ranging (LIDAR)) as well as historical dam construction plans. Sediment testing was also conducted at various points within the impoundment areas to gather gross impoundment sediment thickness and to characterize the particle sizes of the impounded material. We also used hydrologic and hydraulic data for the project area to model predictions for each of the fish passage options being evaluated. Existing FEMA flood study data along with the collected base mapping data was also utilized provide preliminary evaluation and scour analysis of bridge pier infrastructure.

Because of the importance of maintaining a stable source of water to the historic navigation canal systems, we considered the evaluation of the Delaware and Lehigh canal source water systems a critical component of this project. The dam owners have indicated that if canal source water could not be provided by the dams as a result of a change in height of the dam crest, other means for watering the canals would need to be identified. Our analysis indicates that any change to the height of the individual dam, or to the impoundment depth behind a given dam, would have a significant impact on water supply to the associated canal. As such, alternative means of watering the canal(s) – such as a gravity flow system or via a pump system - would be required for any selected alternative other than “no action” (i.e., maintain the dam(s) at the current height/configuration).

Review of Findings – Below we provide a brief overview of each of the fish passage options evaluated for the Easton and Chain Dams, highlighting specific challenges and concerns for each approach. Detailed descriptions of options assessments can be found within the body of the report. Full dam removal is the preferred option for both the Easton Dam and the Chain Dam despite the specific challenges associated with that option. Our analysis indicates that full dam removal is the only option that is both feasible from an engineering and permitting standpoint, and is guaranteed to allow the

unrestricted passage necessary to restore the migratory fishery and establish a self-sustaining population of American shad.

Easton Dam:

Partial Vertical Removal with Nature-like Fishway - We evaluated two possible partial vertical removal scenarios. In one, we evaluated the possibility of lowering the crest height of the dam significantly (from approximate elevation 170.5 ft down to elevation 150.50 ft) and constructing a rock ramp just downstream of the current dam. The length and configuration of the nature-like fishway is limited by the dam's proximity to the Delaware River (i.e., the confluence is only 300 feet downstream). This approach would require a concrete cap on the dam, supplemental water supply for the Delaware Canal, sewer lines located upstream of the dam would need to be lowered or relocated, and several bridge piers would need to be reinforced. This approach would require significant rock infill (i.e., rock placed within the river channel), which would be costly and challenging to permit. This is not a preferred option.

In the second partial vertical removal scenario, we evaluated the possibility of removing nearly the entire vertical height of the dam (from approximate elevation 170.5 ft down to elevation 150 ft) and constructing a ramp upstream of the current dam location to an elevation of approximately 160.50 ft. This configuration would require nearly three times the amount of rock infill as the other partial vertical removal option (described immediately above) and would also require that sheet pile be placed within the river to maintain water within the structure (i.e., to ensure river depth). This approach would require a concrete cap on the dam, supplemental water supply for the Delaware Canal, and further investigation would be needed to determine whether sewer lines located upstream of the dam would need to be lowered or relocated and whether bridge piers would need to be reinforced. This approach would also require significant rock infill, which would be costly and challenging to permit. *This is not a preferred option.*

Partial Horizontal Removal with Nature-like Fishway - We evaluated a partial horizontal removal of Easton Dam with a 375 foot nature-like fishway. This option was evaluated because we believed it would provide a structure which would be the full height of the existing dam (i.e., elevation 170.5 ft), maintain water source for the canal, and would not require the relocation of the force main sewer lines or scour protection of the bridge abutments. Upon detailed examination, we determined that such a fishway would necessarily be either too long or too steep for shad passage. *This is not a preferred option.*

Full Dam Height Nature-like Fishway

A 750 foot Nature like fishway was examined for Easton Dam. The goal of this structure was to provide a structure which would be a full dam height (elevation 170.5) structure that would maintain water source for the canal however this option would require the relocation of the forcemain sewer lines, but may not require or bridge abutment scour protection. When examined in detail it was realized that the longer fishway would meet criteria for fish passage, however may not meet the passage requirements PFBC is trying to achieve due to its length. It would take the shad a long duration to navigate the structure as such the passage percentage results would not archived, thus this type of structure is not recommended. Significant sheet pile or other hydraulic barrier would also be required to be placed within the river in order to maintain water on the surface of the fishway and a significant amount of rock and boulders would be required to fill the ramp. Also as in the previous, the timber crib dam structure

would need to be significantly compromised and reestablished in order to maintain the remaining portion of the dam. The end result of this is that the Fishway does not meet fish passage criteria.

Full Dam Removal The preferred alternative for Easton Dam is full removal of the structure. The full removal option provides unimpeded fish passage without any long-term operation and maintenance costs associated with the dam and any associated structures. Full dam removal shares several of the challenges presented by the other options yet it is the only feasible option that will ensure successful fish passage. Numerous infrastructure upgrades would be required if full dam removal were the selected option. These include relocation of the two force main sewer lines, construction of pumping facilities to maintain water in the Delaware Canal, reinforcement of bridge piers, and extension of several stormwater outfalls.

Chain Dam:

Partial Vertical Removal with Nature-like Fishway

We evaluated a single partial vertical removal scenario at Chain Dam. Based on the configuration of the river at the location of the Chain Dam, 500 feet of the 700 foot total width of the dam would need to be lowered to an approximate elevation of 185 feet to allow for construction of a fishway of the maximum recommended height (i.e., 10 feet). Based on the proposed conditions, water levels upstream of the reduced-height dam would be high enough during the months of March and April to fill the Lehigh Canal without assistance; however, during dry summer months pumping would likely be required to maintain watered conditions. This approach would require significant rock infill, which would be costly and challenging to permit; it would also require a several hundred foot length of sheet pile to ensure that water stays within the fishway. This is not a preferred option.

Partial Horizontal Removal with Nature-like Fishway

We examined the option of removing a portion of the width of the dam, and extending a nature-like fishway upstream of the existing structure. Based on the maximum recommended structure height of 10 feet, the fishway would be 375 feet long and extend just beyond the downstream end of Hugh Moore Island. Under this scenario, a 60 foot wide section of dam would be removed and, in order to adhere to sound engineering practices, the dam elevation would need to be reduced to an approximate elevation of 185 feet (i.e., the same as under the partial vertical removal scenario) As with the Partial Vertical Removal scenario above, the Lehigh Canal could foreseeably be watered during wet months (e.g., March and April) without assistance, but pumping would be required during dry summer months. This approach would require significant rock infill, which would be costly and challenging to permit; it would also require sheet pile along a portion of the fishway. This is not a preferred option.

Full Dam Height Nature-like Fishway

We also examined a full dam height rock structure at Chain Dam. This option is not recommended or viewed as a feasible option. A 20 foot high structure would significantly exceed all design and professional recommendations and would not be stable during high flows, resulting in a greater potential for structural failure. It would also be either too long or too steep for shad passage. This is not a feasible option.

Full Dam Removal

The preferred alternative for fish passage at the location of the Chain Dam is full removal of the structure. Dam removal would relieve the City of Easton of all liability and legal requirements of owning

and maintaining a dam. Our assessment did not identify any transportation infrastructure or utility conflicts associated with the removal of the Chain Dam. Under the full removal scenario, water depths upstream of the current dam location would not be suitable to sufficiently water the Lehigh Canal without pumping assistance.

A consolidated summary sheet of the evaluated options is presented within the full report; however the following table provides the costs associated with each presented option.

Passage Options and Gross Order of Magnitude Costs	Range of Costs (in \$Millions)	
EASTON DAM		
Partial Vertical Removal with Nature- Like Fishway Option 1 (Not a preferred option)	3.4	4.7
Partial Vertical Removal with Nature- Like Fishway Option 2 (Does not meet fish passage)	9.8	13.8
Partial Horizontal Removal with Nature-Like Fishway (Not Feasible)	4.8	6.7
Full Height Dam with a Nature- Like Fishway (Does not meet fish passage requirements)	7.3	10.3
No Action	*	*
Full Dam Removal	4.5	6.4
CHAIN DAM		
Partial Vertical Removal Nature-like Fishway (Not a preferred option)	4.5	6.3
Partial Vertical and Horizontal Removal with Nature-Like Fishway (Not a preferred option)	8	11.2
No Action	*	*
Full Dam Removal	3.4	4.8

Two historic towpath canals would be potentially impacted by full or partial removal of the Easton and Chain Dams: the Delaware Canal and the Lehigh Canal. Due to their historic importance, the provision of water maintenance to these canals has been requested as part of any proposed change to the dams. The inlets of these canals are located immediately upstream of the Easton and Chain Dams, respectively, and are kept full by the backwater provided by the dams. Any alteration to the dams resulting in a reduction of the spillway elevation will require water to be supplied to these canals in some other way, e.g. via pumping or a gravity flow pipe system.

The following conceptual order-of-magnitude opinions of cost have been developed for Alternatives 1, 2, and 3. The costs shown herein are based on a limited investigation and are provided for general information only. They should not be considered an engineer's estimate, as construction costs may be less or considerably more than indicated. The opinions of cost do not include operation and maintenance costs; such costs would be determined based on a more detailed design of a selected alternative, including pump selection.

Source Water Alternative	Order of Magnitude Range of Construction Cost (in \$Millions)
Alternative 1: 1 small pumping station + 1 large pumping station	1.2 to 2.6
Alternative 2: 11 small pumping stations	2.5 to 5.4
Alternative 3: 1 large pumping station, 1 0.9-mile RCP conduit	3.0 to 6.4

Operation and maintenance (O&M) costs for supplemental source water supply pumping stations at the Lehigh Canal and Delaware Canal that would be employed in the event of removal of the Easton Dam and Chain Dam have been estimated for informational purposes. No design of pumping stations has been completed at this time, so these numbers are not based on detailed information about specific pumps, final design flows, or operational procedures.

<i>Pump O&M Costs</i>		
Design Flow (gpm)	O&M Cost for 6-Month Operation	O&M Cost for Year-Round Operation
1,200	\$18,000 - \$38,000	\$35,000 - \$76,000
1,800	\$22,000 - \$47,000	\$44,000 - \$93,000
12,000	\$91,000 - \$195,000	\$182,000 - \$389,000
13,800	\$103,000 - \$221,000	\$206,000 - \$442,000

<i>Collective O&M Costs</i>		
Conceptual Alternative	O&M Cost for 6-Month Operation	O&M Cost for Year-Round Operation
Alt 1	\$110,000 - \$240,000	\$230,000 - \$480,000
Alt 2	\$200,000 - \$430,000	\$400,000 - \$850,000
Alt 3	\$100,000 - \$220,000	\$210,000 - \$440,000

Finally, there are numerous sizes of pipes associated with each impoundment. There are large box culverts at 60 inches down to small 10 inch discharge pipes. As a matter of estimating a size of 36 inches was used as a mean size to calculate an estimated cost for extending discharge pipes to the water's edge. Specifically a cost to provide excavation, geotextile placement within the rock lined ditch and the rock placement was estimated based upon required dimensioning required for a 36 inch diameter pipe.

Relative Gross order of Magnitude costs for each outfall was estimated at between \$12,500 and \$20,000 per outfall structure.

Dam Impoundment	Total Outfalls	Upper Cost Limit	Lower Cost Limit
Easton Dam	42	\$840,000	\$525,000
Chain Dam	12	\$150,000	\$240,000

1.0 Introduction

For almost 30 years, the Pennsylvania Fish & Boat Commission (PFBC), Wildlands Conservancy, Inc. (Wildlands), and other partners have been working to restore American Shad (*Alosa sapidissima*) and other Alosines, including hickory shad (*Alosa mediocris*), blueback herring (*Alosa aestivalis*), and alewife (*Alosa pseudoharengus*) to the Lehigh River. While there has been some success in establishing a shad population imprinted to the Lehigh River, fish passage via the current constructed fish ladders at both the Easton and Chain Dams has been inconsistent and generally poor. Even after years of restoration efforts, data that the Pennsylvania Fish and Boat Commission has collected indicates that Lehigh River fish passage (measured at Chain Dam) is currently estimated at 30 percent or less. This success rate is considered insufficient to support a self-sustaining American shad population in the river. The PFBC has set a minimum target of 80% passage, with a desire to obtain 100% fish passage through both the Easton and Chain Dams. Achieving these results will require considerable, focused cooperation between dam owners, user groups and stakeholders, as well as utility owners in the vicinity of the structures. This dialogue has been initiated as part of this project.

The Lehigh River is the largest tributary to the Delaware River, dropping approximately 1,000 feet in elevation from its origin in the Pocono Mountains to the confluence with the Delaware River in Easton, Pennsylvania. Historically, the Lehigh River was used to transport anthracite coal from the upper reaches of the watershed to markets in Philadelphia via the Lehigh and Delaware Canals. These canals shaped a community and a generation, and served their intended purpose prior to the introduction of railroads along this corridor. The Lehigh River was so significant that, during the colonial period, it was referred to as the West Branch of the Delaware River. The construction of dams on the Lehigh River to facilitate more efficient coal transport effectively separated historically significant migratory alosines populations from their spawning areas along the upper sections of the Lehigh River.

In 2003, Wildlands completed the Lehigh River Watershed Conservation Plan that gave targeted recommendations to help reduce thermal pollution, improve water quality and habitat, and restore fish passage. A specific recommendation included the removal of ‘run- of-the-river’ dams on the Lehigh from the town of Bowmanstown, Pennsylvania downstream to the confluence with the Delaware River. Further, the Lehigh River Fisheries Management Plan, prepared by the PFBC in 2007, identified that the best fish passage option for Easton and Chain Dams was the removal of these structures. In accordance with these studies, full or partial removal of the Easton and Chain Dams on the Lehigh River would address a major hurdle for fish passage in this area and would likely chart a course for implementation of other fish passage projects upstream, thereby furthering the PFBC’s mission to provide passage on the Lehigh. In addition to the benefit provided to Alosines, improved passage will also enhance the inter- and intra-river movements and exchange of native and naturalized fish species in the Lehigh and Delaware Rivers.

1.1 Project Description

KCI Technologies, Inc. (KCI) was retained by Wildlands and its project partners to complete an investigation into potential fish passage options for both the Easton Dam (PADEP Dam I.D. No. D48-012) and Chain Dam, or Glendon Dam as it also known, (PADEP Dam I.D. No D48-013). The goal of this project, is to identify the potential means for successful passage of target anadromous fish species at a rate concurrent with the numbers of fish observed at the dams each year, while still maintaining current water needs in both the Delaware and Lehigh canal systems. The Pennsylvania Fish and Boat Commission has indicated that the passage rate needs to exceed 80% with a goal of 100% passage.

Alternative means of passage being evaluated include full removal, modified partial vertical and / or horizontal removal with a rock ramp fishway, and full-height inverted rock ramp design for the Easton (River Mile 0.0) and Chain (RM 3.0) Dams on the Lehigh River.

Any modifications to the dams including removal or partial removal, will have a direct affect on the source water to the Delaware and Lehigh Canal systems. The Easton Dam provides source water for the Delaware Canal, while the Chain Dam provides source water for the Lehigh Canal system for the section flowing through Hugh Moore Park in Easton, Pennsylvania. Recognizing the importance of maintaining water in the canals this study evaluated alternative source water options for the canal systems under both the full or partial removal scenarios. If the owners elect to remove the dams, engineering design and permitting and construction phases will be complete at a later date when funding becomes available.

2.0 Summary of Collected Data

Readily available information was reviewed and analyzed to gain a more detailed understanding of the river system and its potential response to various fish passage projects. KCI investigated both historic and contemporary watershed and river conditions to better understand the myriad of controls and potential responses from the standpoint of geologic, geomorphic, anthropogenic and hydrologic/hydraulic regimes. A wide variety of data sources were examined and the results are summarized here.

2.1 Dam Construction and Rehabilitation

A file review for the Easton and Chain Dams was completed at the Pennsylvania Department of Environmental Protection (PADEP) Dam Safety Office in Harrisburg, Pennsylvania in December 2011. Pertinent dam information reviewed included various rehabilitation plans implemented over the tenure of the Easton Dam as well as detailed specific construction plans for the current Chain Dam configuration on the Lehigh River.

2.1.1 Easton Dam

The plans available for Easton Dam were comprised of blueprints depicting dam rehabilitations and dam reconfigurations designed in 1943 and 1964, respectively. Original plans for the Easton dam were not available as the dam was constructed circa 1830; however, the available plans revealed critical structural design elements.

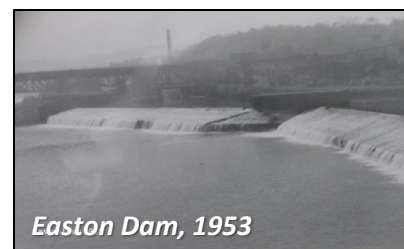


Easton Dam Repair, 1943

Reconfiguration plans from 1964 exposed decisive design elements of the dam, most notably that the core of the structure has remained a timber crib structure. A concrete cap was installed over the timber crib structure to preclude erosive structural forces. The original dam cap configuration was a wooden plank board cap composition, which was prone to breach. Both

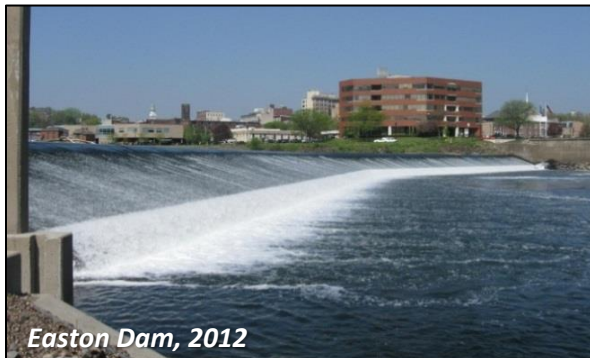


Easton Dam Repair, 1943



Easton Dam, 1953

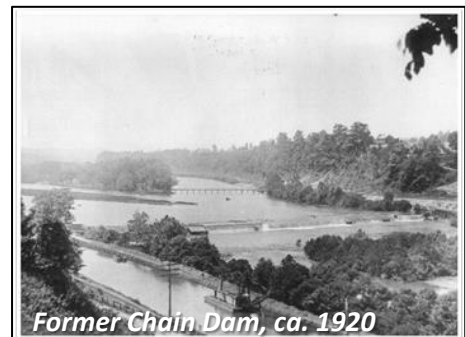
The configuration today is as completed in 1968. The addition of the fish ladder was completed in 1994 and is the only significant structural augmentation to the dam since the plans depicted in 1964 and completed in 1968. The Easton Dam is approximately 590 feet wide with a total height of 30 feet. The dam, when measured upstream to downstream, elicits a footprint of 56 feet in width and has a crest elevation of 170.5 feet. Drainage area is reported as 1,373 square miles and has a maximum storage of 1,033 acre feet. The dam is currently owned and operated by the Department of Conservation & Natural Resources (DCNR).



Plans were also found depicting a temporary crossing constructed across the Delaware Canal in the vicinity of the dam. The crossing was used for equipment and construction vehicle access in conjunction with the fish ladder construction.

2.1.2 Chain Dam

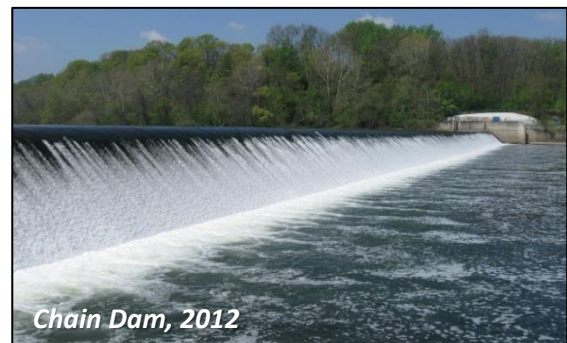
The Chain Dam, also known as the Glendon Dam, is owned and operated by the City of Easton. The original Chain Dam was constructed in concert with the Easton Dam since it provided the source water for the section of the Lehigh Canal from Guard Lock 8 downstream to its confluence with the Lehigh River. The original Chain Dam was significantly breached in 1965 during an ice flow on the Lehigh River. After several years of speculation, design plans were generated, and the current structure was completed in 1974. A full set of construction drawings was reviewed which depict the construction of the Chain Dam, completed in 1974.



The Chain Dam, with a crest height of 192 feet, impounds water from a drainage area of 1,356 square miles with maximum reservoir storage of 1,197 acre feet. Chain Dam, an Ogee-type dam construction, is 20 feet in height, and is 700 feet wide. Extending downstream of the dam are a 30-foot spillway and 45-foot-long derrick stone energy dissipater. In total, Chain Dam is 70 feet wide when measured from upstream to downstream.

A closer examination of the Chain Dam construction plans also revealed significant detail in that the former Chain Dam was not totally removed from the river bed. Chain Dam depicted on the design plan sheets, and incorporated on this project's base mapping (Appendix A), was constructed downstream of the previous Chain Dam. The previous dam is located 160 feet upstream of the current location, and 10 feet in height remains situated across the full river width at its location for a total width of 695 feet. Furthermore, the river bottom between the two structures was in-filled with a rolled embankment pervious material to a height of 186 feet, the same height as the partially removed former Chain Dam. When viewed as a whole, there is structure encompassing the remaining portion of the former Chain Dam, the rolled embankment pervious material, and the current Chain Dam that is in place at an approximate channel width of approximately 695 feet and runs a total distance upstream to downstream for a distance of approximately 275 feet.

Plans depicting the fish ladder installed in 1994 on the were also obtained. These plans also show the access used previously to construct the fish ladder. This access was made via the right-of-way that runs along the Delaware and Lehigh trail accessed via Riverside Park, at the intersection of 25th Street and Lehigh Drive. This information could be used in a construction sequence to provide access to the dam left abutment area where the fish ladder is located.



2.2 Bridge Plans & River Access

2.2.1. Bridge Plans

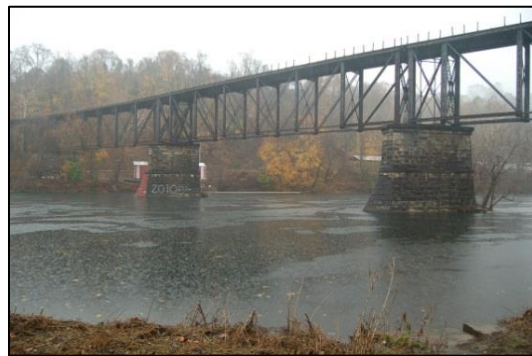
The study reach, which extends from the confluence of the Lehigh and Delaware Rivers to just upstream of the State Route (S.R.) 33 Bridge, contains six bridges (in order from downstream to upstream):



Black River and Western Railroad Bridge No. 77 (Easton Viaduct over 3rd Street)
(Metal Truss Structure)



**Dr. George S. Smith Bridge (3rd Street / S.R. 611)
(Concrete Arch Bridge)**



Eastern and Northern EA - 77A Bridge (near 9th Street)



Glendon Hill Road Bridge



Glendon-Wilson Bridge (25th Street / S.R. 2012)



Gene Hartzell Memorial Bridge (S.R. 33)

Plans depicting construction were requested from each of the owners. Bridge plans were reviewed for many of the structures. The railroad bridges located within the Easton Dam impoundment are no longer owned or operated by their former owner, Norfolk Southern Railroad. Bridge No. 77 (Easton Viaduct over 3rd Street) is now owned and operated by the Black River & Western Railroad (BRWRR). Approximately 270 drawing plans depicting the bridge's original construction from 1926 were provided by Norfolk Southern. The Eastern and Northern Railroad Bridge EA 77A Railroad Bridge, constructed in 1897, does not have detailed construction plans available from either Norfolk Southern or its current owner, Palmer Township. Information with regards to its approximate dimensions was provided by Palmer Township.

A summary of ownership for the bridge structures in the study area is provided below:

<u>Bridge</u>	<u>Owner Information</u>
3 rd Street Bridge / S.R. 611	Pennsylvania Department of Transportation - District 5 1002 Hamilton Street Allentown, Pennsylvania 18101 Contact: David Rostron, P.E., Asst. District Bridge Engineer
Eastern and Northern EA - 77 Bridge	Black River and Western Railroad Historical Trust Post Office Box 200 Ringo, New Jersey 08551 Contact: Kean Burenga, General Manager

Eastern and Northern EA - 77A	Palmer Township 3 Weller Place, P.O. Box 3039 Palmer, Pennsylvania 18043 Contact: Tom Adams, Township Engineer
Glendon Hill Road Bridge	Pennsylvania Department of Transportation - District 5 1002 Hamilton Street Allentown, Pennsylvania 18101 Contact: David Rostron, P.E., Asst. District Bridge Engineer
25 th Street Bridge	Pennsylvania Department of Transportation - District 5 1002 Hamilton Street Allentown, Pennsylvania 18101 Contact: David Rostron, P.E., Asst. District Bridge Engineer
Route 33 Bridge (Gene Hartzell Memorial)	Pennsylvania Department of Transportation - District 5 1002 Hamilton Street Allentown, Pennsylvania 18101 Contact: David Rostron, P.E., Asst. District Bridge Engineer

General information on the Chain Bridge Pier, located upstream of the Chain Dam, was also located. The bridge was constructed sometime between 1856 and 1857. The bridge pier is approximately 30 feet in height above the normal impoundment elevation. The upstream leading edge of the pier has significantly deteriorated as was noted during the field reconnaissance portion of this project. Based upon a review of available documentation including the National Register of historic Places inventory form completed in November of 1972, the owner of this structure appears to be the City of Easton, administered as a part of the Hugh Moore Parkway.



Information with regards to the effect of impoundment lowering on the bridge pier for each structure as a result of select fish passage options being evaluated as part of this report are reported in under Section 11 of this report.

2.2.2 River Access

Easton Dam

A total of five in-stream river access structures were identified within the project area. (See Appendix E, Figure 2 for the measured changes in water surfaces for each of the alternatives being modeled as part of this report). Four of the five would be impacted by lowering of the current impoundment upstream of the Easton and Chain Dams. Right and left banks of the river are in reference to “River Right” and

“River Left,” which are oriented facing downstream. The first structure on the Lehigh River, starting from the confluence with the Delaware and moving upstream, is the boat launch within the city of Easton - a concrete ramp located within the Easton Dam impoundment on river left, just upstream from the Easton Dam near Larry Holmes Drive. The next in-stream structure is a floating boat dock located under the Eastern and Northern EA - 77A just off Lehigh Drive, on river left that is owned / operated by the Lafayette College Crew Club. These two structures would be impacted by an impoundment lowering behind the Easton Dam. The third access moving upstream is located on river right just downstream of the Glendon Hill Road Bridge within the parking lot adjacent to the Delaware and Lehigh Trail Canal Towpath. This access is not within the Easton Dam impoundment; it is not expected to be directly impacted by either a partial or full removal of the Easton Dam.

Chain Dam

Within the Chain Dam Impoundment, access to the river is provided by a ramp operated by the Pennsylvania Fish & Boat Commission on river left downstream of the S.R. 33 Bridge. The other access is provided via a private dock system operated by the Bethlehem Boating Club also located on river left just upstream of the S.R. 33 Bridge. Both of these access points could potentially be impacted as a result of a removal of the dam. This was noted as observed in aerial mapping reviewed from 1971, that was taken during the breach of the original Chain Dam and prior to the current Chain Dam Structure (See Figure 6 in section 3.0 for location map.). This was also confirmed through conversations with members of the Bethlehem Boat Club.

2.3 Utilities & Stormwater Outfalls

Utilities were identified utilizing the Pennsylvania One-Call System for the full length of the project corridor. The corridor is relatively large and located within a mix of land uses; therefore many utilities were identified within the surrounding area. However as additional information was reviewed from responding utility companies and authorities, the utilities with the most concern are the ones which lie in the Lehigh River proper or in close proximities to potential work areas. Under a partial or full dam removal scenario, the channel is expected to down cut, and it is extremely important to identify utilities which may become exposed during the channel defining process.

The utilities that could be impacted as a result of full or partial are described in detail below. Approximate locations of these utilities are shown in Appendix A.

2.3.1 Easton Dam Force Main Sewer Lines

Two force main sewer lines are located within the Easton Dam impoundment. They are a 16-inch and a 24-inch force main located approximately 340 feet and 471 feet upstream respectively of the Easton Dam. The older of the two lines is a 16-inch, cast-iron force main sewer line which was constructed in approximately 1926. Historical plans, which were not provided but were reviewed by the Easton Suburban Sewer Authority, called for the line to be placed with three feet of cover and indicated that the material which was to be excavated consisted of mud with gravel and rock at lower elevations. Elevation information with regards to the vertical height of the line was limited; therefore, an exact elevation relative to the project base mapping is unavailable. Without the construction drawings depicting the proposed installation it is challenging to infer the depth relative to the current conditions. Future exploration into the relative depth would be required to identify the depth of the crossing in the riverbed. This could be achieved by sophisticated sounding equipment or utilizing a subaquatic antenna used to gather data regarding the approximate vertical height the pipe in the river bed. GIS layers provided by the City of Easton provided the approximate positioning of the line horizontally, which was consistent with the Larry Holmes Drive Sewer Pump House located during base mapping data collection.

The more recently constructed line is a ductile iron 24-inch line installed in 1978. The design drawing was provided by the Easton Suburban Sewer Authority, which provided construction location of the proposed line as well as the vertical alignment of the pipe. The benchmark elevation information for this construction design plan was correlated to the project base mapping for this project. As such, the lines horizontal information and vertical alignment are based upon construction drawings provided by the Easton Suburban Sewer Authority and not by as-built plans as they were not available.

Project drawings show that the pipe, as it crosses the project base mapping prepared for the fish passage feasibility study, has a top-of-pipe elevation at 152.45. Design plans called for the pipe to have three feet of cover placed over the pipe; however, the base mapping prepared for this project reveals that pipe to only have 2.25 feet of cover over the line, based upon the approximate location and current river bathymetry.

Both of these lines service a large portion of the region. Specifically the lines service most of the City of Easton, West Easton Borough, Wilson Borough, Palmer Township, Forks Township, Borough of Tatamy, small portions of Bethlehem Township, and Williams Township.

Owner Information

Easton Area Joint Sewer Authority
50-A South Delaware Drive
Easton, PA 18042
Attn: Daniel Shoemaker

2.3.2 Easton Dam Water Line

One 12-inch waterline crossing, located within the Lehigh River channel bottom, was identified. Horizontal location information was provided by the Easton Suburban Water Authority. This line crosses the river upstream of the Glendon Hill Road Bridge at approximate project base mapping Station 129+90 or 2.3 miles upstream of the Easton Dam. Vertical location of the line was not available from the owner. The owner indicated that vertical position of the line could be achieved by their field crews, however that information would be provided when the project was in a design phase. As vertical position of the waterline was not provided, it is uncertain whether lowering of the height of the Easton Dam would have an effect on cover over the line in this location; however, the line does not exist in what is considered the Easton Dam impoundment, as such the impact as far as a river bed lowering at this location is unlikely.

Owner Information

Easton Suburban Water Authority
3700 Hartley Avenue
Easton, PA 18045
Attn: Craig Swinsburg

2.3.3 Easton Dam Gas Line

One natural gas line was identified upstream of the Glendon Hill Road Bridge. Vertical location of the line was not provided, however the size of the pipe crossing is a 12-inch steel line. The owner indicated that vertical position of the line could be achieved by their field crews, however that information would be provided when the project was in a design phase. As vertical position of the waterline was not provided, it is uncertain as to whether augmentation to the height of the Easton Dam would have an

effect on cover over the line in this location; however, the line does not exist in what is considered the Easton Dam impoundment, as such the impact as far as a river bed lowering at this location is unlikely.

Owner Information

UGI Utilities, Inc.
2121 City Line Road
Bethlehem, PA 18017
Attn: Taylor Betts

2.3.4 Chain Dam Petroleum Line

One petroleum line was identified upstream of the S.R. 33 Bridge. The transmission pipe is an 18-inch line (material not provided) placed perpendicular to the river width and is located approximately 3.2 miles upstream of the Chain Dam. Current information regarding depth of the line was collected in September 2011 and showed a depth of the top of the pipe at elevation of 173.5 feet when correlated to the project base mapping and displayed a total of nearly 9.5 feet of cover over the line at the time of the survey. Topographic contours on the plan were also provided from 1999, 2001, and 2006 and showed little variation in the sediment thickness over the line in the 12-year period including the 2011 results. Additionally, the mapping provided shows that the pipe is placed under a layer of rock and sand within the channel bottom. Regardless of any modification to the Chain Dam to promote improved passage, the owner requested they be notified of any future decisions to move forward; however due to the considerable distance upstream of the dam, it is not foreseen that the line would be significantly impacted as a result of dam height modification.

Owner Information

PPL Interstate Energy Company
214 Shoemaker Road
Pottstown, PA 19464
Attn: Aaron Bass

2.3.5 Easton and Chain Dam Stormwater Outfalls

Numerous stormwater outfalls, both pipes and box culverts, are located within both the Easton and Chain Dam impoundments, which would be impacted as a result of lowering of the dam height. Additional length of energy dissipation or the addition of energy dissipaters at the outfalls would likely be required by the regulators to provide adequate river bank protection during the outfall functioning period. Within the Easton Dam impoundment area, a total of 42 locations were identified during the field survey and are identified on the project base mapping. A total of 12 stormwater outfall pipes were located within the Chain Dam impoundment. When the final proposed water surface is estimated at the completion of a design and mean river water course is displayed, there may be a need for the NPDES permit holder for each of these outfalls to extend and dissipate the outfall appropriately to meet the permit requirements with regards to the discharge point. It may also be possible that the construction costs associated with these extensions would be incurred by the removal project budget.

There are numerous sizes of pipes associated with each impoundment. There are large box culverts at 60 inches down to small 10 inch discharge pipes. As a matter of estimating a size of 36 inches was used as a mean size to calculate an estimated cost for extending discharge pipes to the water's edge. Specifically a cost to provide excavation, geotextile placement within the rock lined ditch and the rock placement was estimated based upon required dimensioning required for a 36 inch diameter pipe. Relative Gross order of Magnitude costs for each outfall was estimated at between \$12,500 and \$20,000

per outfall structure. As such for Easton Dam impoundment with 42 outfalls located, of varying sizes, the estimated Order of Magnitude cost would range from \$525,000 to \$840,000 for outfall upgrades. Additionally within the Chain Dam impoundment there are 12 outfalls, of varying sizes, and the estimated Order of Magnitude cost for outfall upgrades would range from \$150,000 to \$240,000.

2.4 Endangered Species

The Pennsylvania Natural Diversity Index (PNDI) System is a way to identify presence or absence of endangered species within a given project area. The system was utilized for the two project areas to identify any species of concern. Below is a description of the findings.

2.4.1 Easton Dam – PNDI Conflicts

The search for species of concern resulted in conflicts under the jurisdiction of both the DCNR and the PFBC. The DCNR conflicts were for the *Carex eburnea* (Ebony sedge), *Cuscuta campestris* (Dodder), *Cyperus schweinitzii* (Schweinitz flatsedge). Additional information regarding the project was submitted to the agency for further review and, as a result of the review, all conflicts have been resolved.

The PFBC conflicts were for the *Anodonata imPLICATE* (Alewife Floater) and the *Lampsilis cariosa* (Yellow Lampmussel) both protected freshwater mussel species under their jurisdiction, and the presence of an invasive crayfish. PFBC representatives conducted a site survey on August 9, 2012, for the species of concern. A total of three sites were surveyed within the project area and, as a result of findings, all concerns were resolved. It was recommended that if the dams are removed a rapid-response plan should be in place to salvage stranded mussels if observed. This response plan should be coordinated with local volunteers and consist of collecting mussels and returning them to the flowing waters of the Lehigh River. Further sampling may also be required depending on timing of the implementation of the selected alternative.

2.4.2 Chain Dam – PNDI Conflicts

The search for species of concern resulted in a single under the jurisdiction of the DCNR for the *Cystopteris tennesseensis* (Bladder Fern). Additional information regarding the project was submitted to the agencies for further review and as a result of the review the conflict has been resolved.

2.5 Historical Resources Information

The project area includes three resources listed in the National Register of Historic Places (NRHP) that may be impacted by the proposed project. The Delaware Division of the Pennsylvania Canal, determined a National Historic Landmark in December 1976, is located at the northern end of the project area near the Easton Dam. The Lehigh Canal: Easton Section, listed in the NRHP in October 1978, extends from Hopeville to the confluence of the Lehigh and Delaware Rivers. The Chain Bridge, listed in the NRHP in February 1974, is located south of the Chain Dam. The Chain Bridge (built in 1856 - 1857), Chain Dam (Dam #8, replaced in 1974), and the Easton Dam (Dam #9, rebuilt in 1966) are located within the National Register boundaries of the Lehigh Canal: Easton Section.

Since dam removal or modification will likely require a federal permit, federal approval, or possible use of federal funding. As such, consideration of the effect of the project on the National Register historic properties would be required under Section 106 of the National Historic Preservation Act of 1966, as amended. Coordination among the federal agency, the State Historic Preservation Officer, and the project sponsor would be required to confirm the National Register status and integrity of the historic properties and their contributing elements, as well as to determine whether the project would have an

adverse effect on the historic properties. Consultation with interested parties also would be undertaken as part of this process.

2.6 Geographic Information Systems (GIS) Data

GIS data was provided by both the City of Easton and Wildlands Conservancy in an effort to complete mapping for the project area. Data provided for the project site mapping and for the entire project area is displayed on accompanying project base mapping in Appendix A. The list provided below presents the relevant GIS data layers that have been provided in order to facilitate appropriate coverage of the full project extent. Supplemental data was also secured from both Pennsylvania Spatial Data Access (PASDA) and the Lehigh Valley Planning Commission (LVPC).

2.6.1 GIS Data Layers

The following data layers were reviewed and utilized in the project base map and report:

- Topographic Contours (one and five-foot intervals)
- PA and NJ Streets PA Bridges
- Flood (flood hazard areas, FEMA flood elevations)
- Flood (cross section locations)
- Geology
- Land Use
- Historic Canals Locations
- Natural Water Areas (rivers and ponds)
- Municipal Boundaries
- Tax Parcels
- Parks
- Railroads (active and inactive)
- Soils Mapping
- Utility (sewer / water)
- Watersheds
- Woodlands / Wetlands

3.0 Detailed Geomorphic Assessment

KCI conducted a field investigation for the purposes of understanding the active channel processes, supporting the sediment analyses, and evaluating potential impacts of bed degradation and channel migration in order to determine appropriate management approaches under the various alternatives. The field investigation, conducted on January 16-17, 2012, included a river geomorphological assessment, physical habitat assessment, and canal and infrastructure assessment. In addition to these specific assessments, the river was continuously observed from a kayak from the Route 33 Bridge crossing to the Lehigh River confluence with the Delaware River. Additionally, the Lehigh River was continuously observed along the Delaware and Lehigh Canal bike path from Easton Dam to 8.85 miles upstream to Freemansburg. This allowed for a connected view of the river as it moves from points upstream of the Chain Dam impoundment, and allowed KCI to gain insight and understanding into not only the project area but also to free-flowing sections not influenced by the dams.

According to United States Geological Survey (USGS), stream flow gaging data on the Lehigh River at Glendon, Pennsylvania (Station 01454700), gage height ranged between 8.76' to 9.10' during the days the field investigation was conducted. During that time period, the gage on the Lehigh River indicates that the flow was a part of the falling limb on the hydrograph.

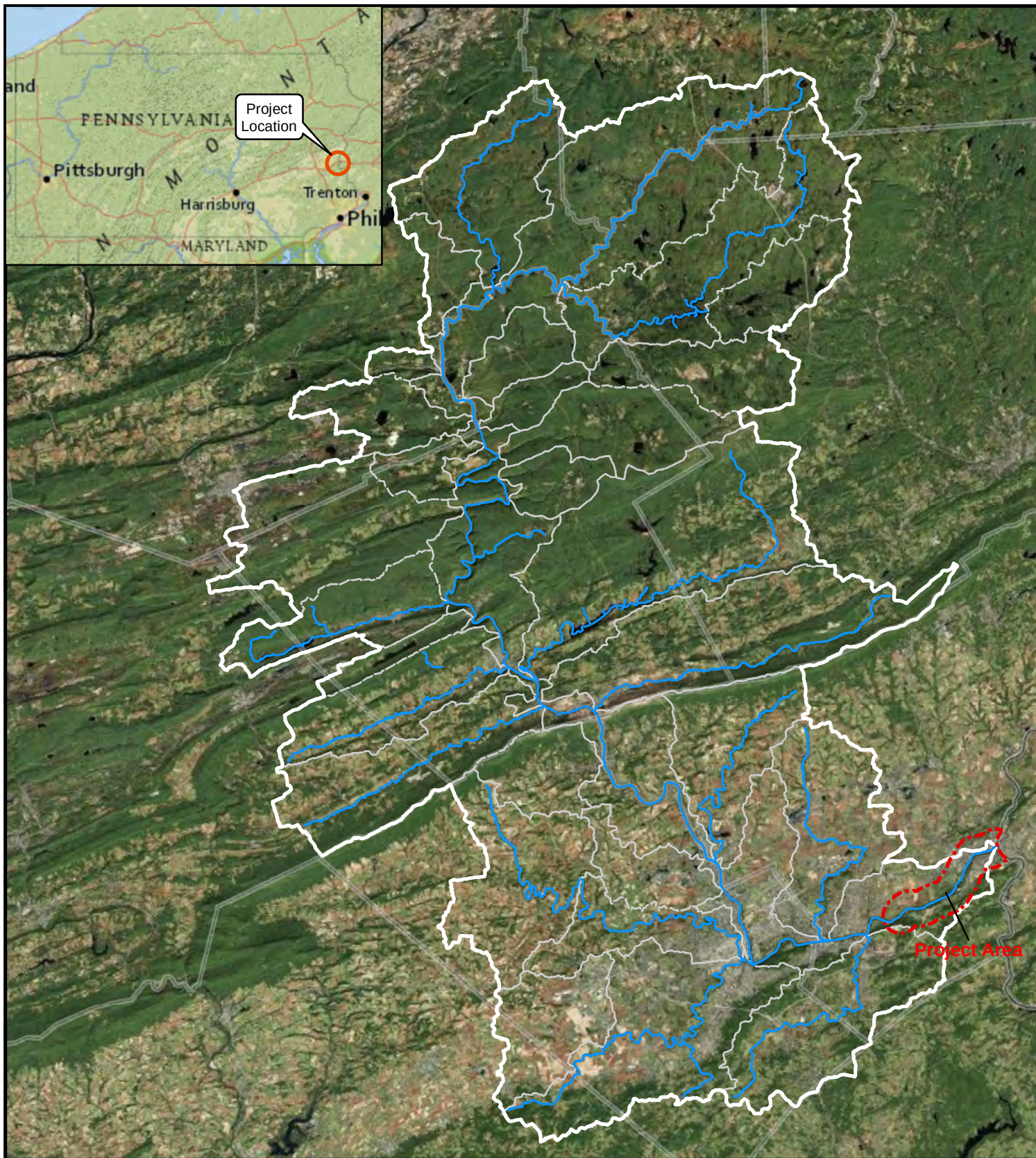
3.1 River Geomorphic Assessment

A qualitative geomorphic assessment of the channel was performed to determine dominant channel processes throughout the project area. KCI assessed bedform and profile, cross-sectional shape and approximate dimensions, bank characteristics, bed composition, planform characteristics, constraints,

and preliminary channel classification using Rosgen and Channel Evolution Model (CEM) methodologies (Rosgen 1994, Montgomery and Buffington 1997). The Easton and Chain Dams were investigated along with the river reaches upstream and downstream of each dam to determine the extent of the dams' influence on channel morphology. The river segments characterized by the hydraulic influence of the Easton and Chain Dams are called the Easton Reach and Chain Reach, respectively. For comparison, a reference reach upstream of the influence of both dams was also assessed. Figure 2 and 3 show the reach locations. Right and left banks of the river are in reference to "River Right" and "River Left," which are oriented facing downstream. These reaches are compared in Table 1 below. Once reach limits were identified during the field investigation, measurements were approximated using Google Earth (2012).

Table 1. Approximate Planform Measurements

	Easton Reach	Chain Reach	Reference Reach
River Width at Dam	590 ft	700 ft	N / A
Reach Length	1.5 mi	4.0 mi	3.5 mi
Average Channel Width (W)	250 - 300 ft	250 - 300 ft	250 ft
Average Radius of Curvature on Bends (R_c)	1,649 ft	3,119 ft	3,641 ft
R_c / W	6.0	11.3	14.5
Sinuosity (S)	1.0	1.0	1.0

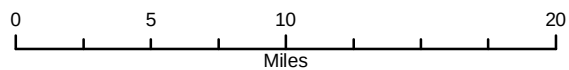
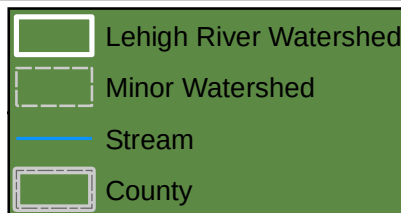


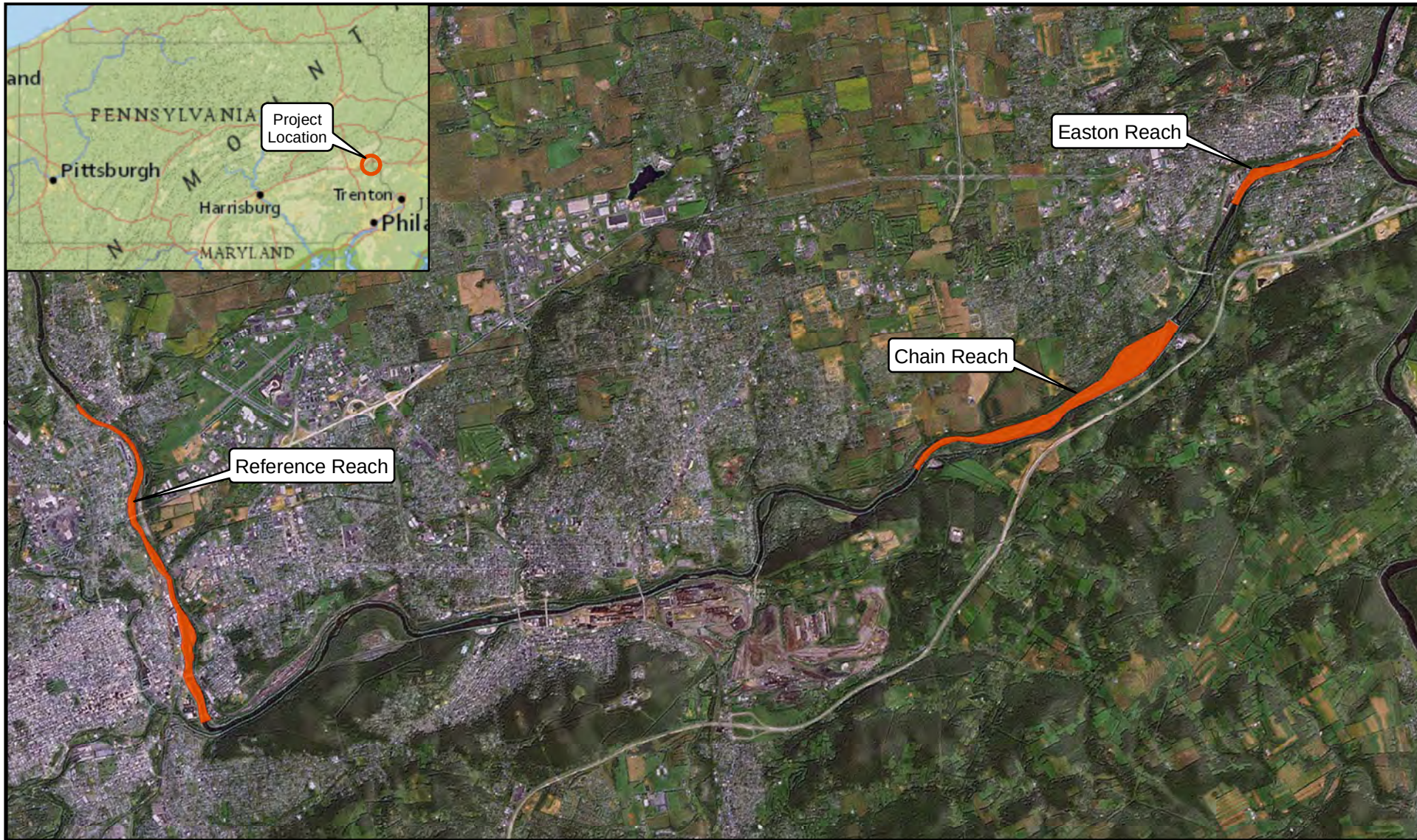
Lehigh River Watershed

Figure 1

Lehigh River Fish Passage Improvement
Feasibility Study
KCI Job No. 16111094

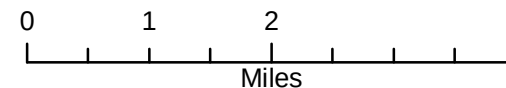
Bing Maps Aerial Imagery
Web Mapping Service
(c) 2009 Microsoft Corporation





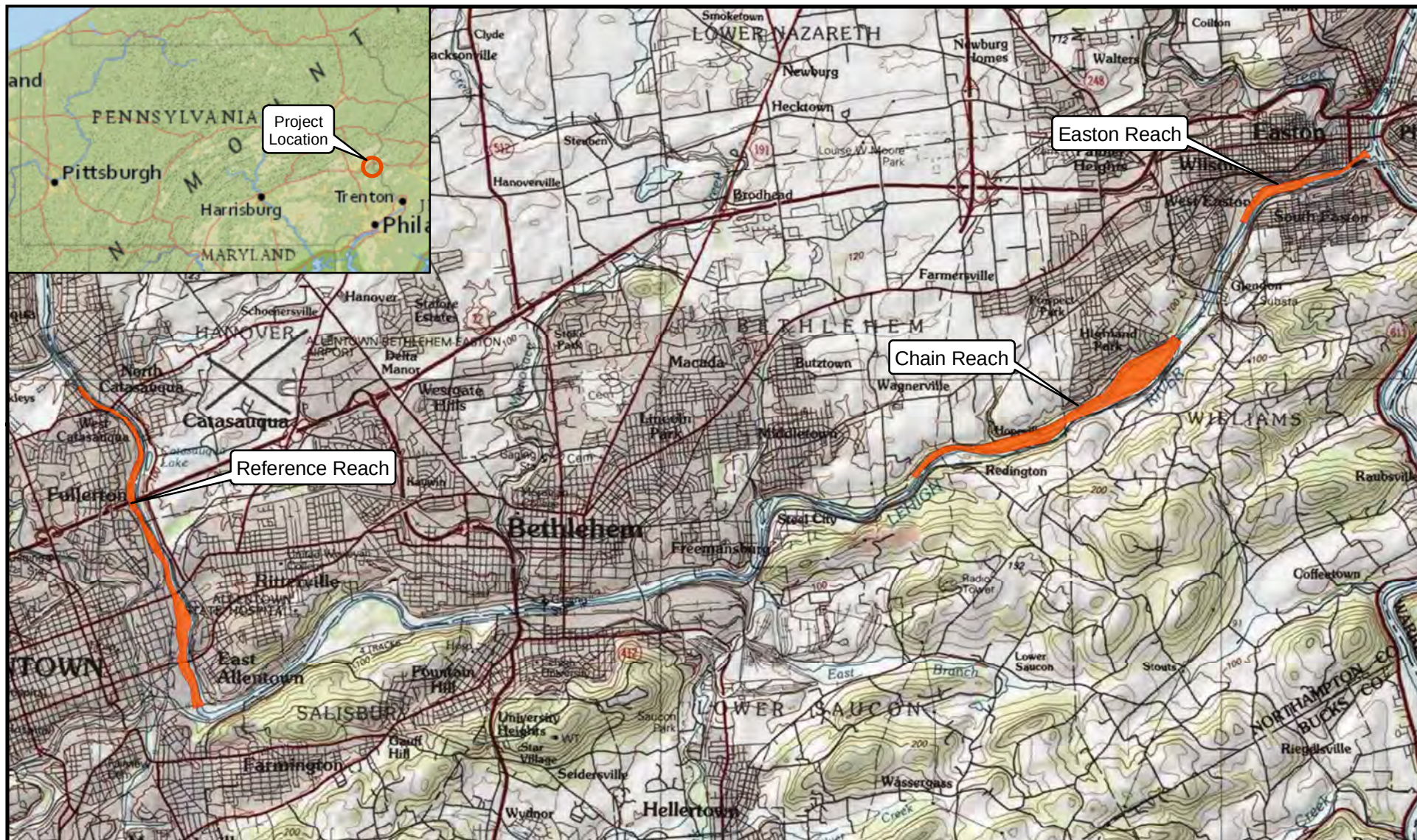
Lehigh River Watershed Figure 2

Lehigh River Fish Passage Improvement
Feasibility Study
KCI Job No. 16111094



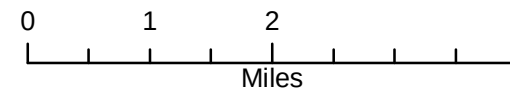
Pennsylvania Spatial Data Access
USGS High Resolution Orthoimage
Lehigh / Northampton County, PA, 2010
<http://www.pasda.psu.edu>





Project Location Map Figure 3

Lehigh River Fish Passage Improvement
Feasibility Study
KCI Job No. 16111094



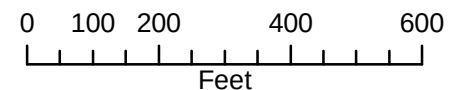
Pennsylvania Spatial Data Access
Topographic Maps for Pennsylvania
U.S. Geological Survey, 1996
<http://www.pasda.psu.edu>





Lehigh River Easton Dam Figure 4

Lehigh River Fish Passage Improvement
Feasibility Study
KCI Job No. 16111094



Pennsylvania Spatial Data Access
USGS High Resolution Orthoimage
Lehigh / Northampton County, PA, 2010
<http://www.pasda.psu.edu>





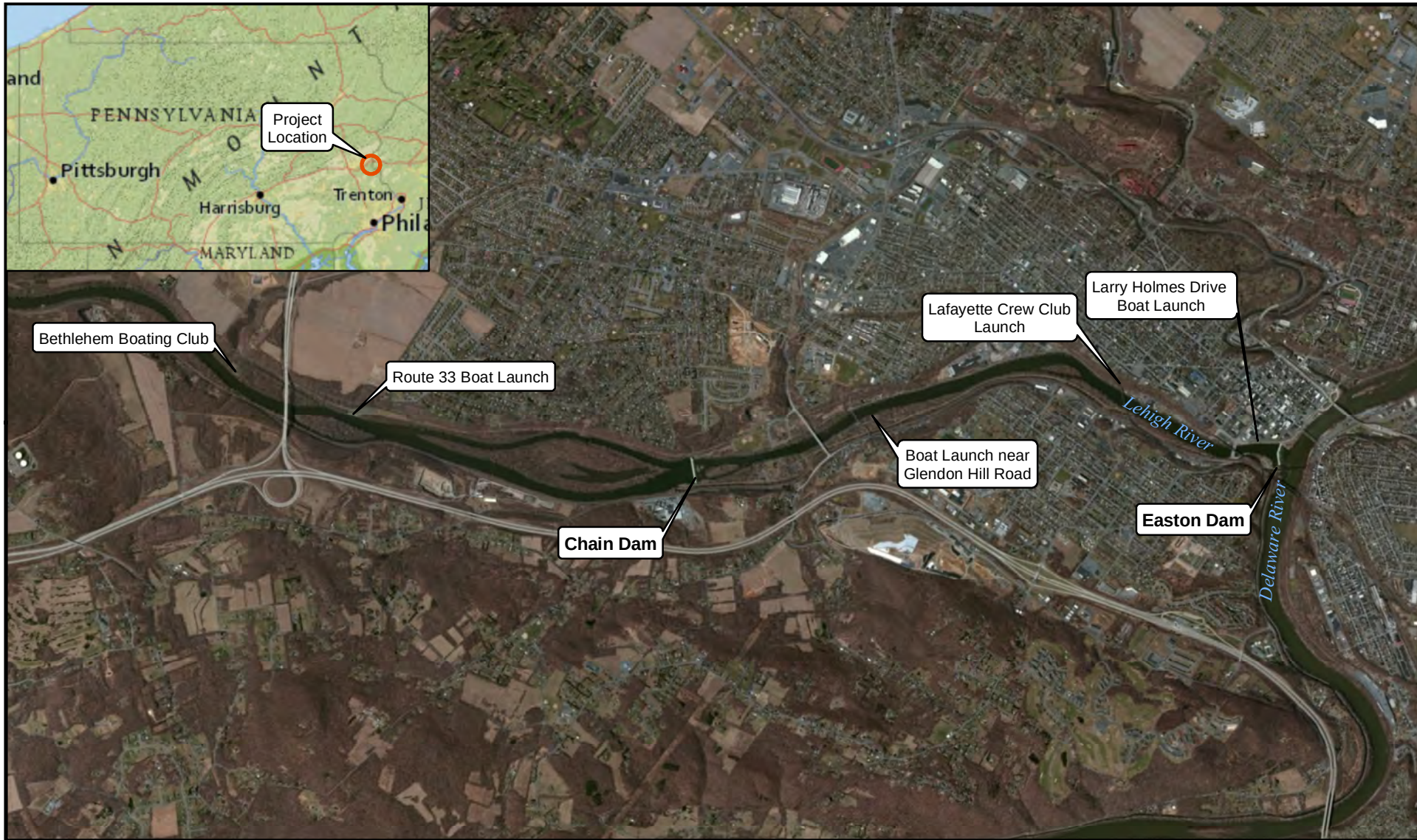
Lehigh River Chain Dam Figure 5

Lehigh River Fish Passage Improvement
Feasibility Study
KCI Job No. 16111094

0 162.5 325 650 975
Feet

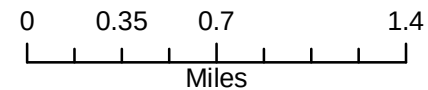
Pennsylvania Spatial Data Access
USGS High Resolution Orthoimage
Lehigh / Northampton County, PA, 2010
<http://www.pasda.psu.edu>





Lehigh River - River Access Figure 6

Lehigh River Fish Passage Improvement
Feasibility Study
KCI Job No. 16111094



Pennsylvania Spatial Data Access
USGS High Resolution Orthoimage
Lehigh / Northampton County, PA, 2010
<http://www.pasda.psu.edu>



The area of influence of the dams varied greatly, with hydrologic influence from the Easton Dam continuing approximately 1.5 miles upstream from the dam and hydrologic influence from the Chain Dam continuing approximately 2.5 miles upstream from the dam. This is due to the height of the dam relative to the slope of the valley. The first upstream head of riffle above Easton Dam occurs nearly 2.0 miles upstream, while the first head of riffle above the Chain Dam impoundment occurs 4.5 miles upstream from the Chain Dam.

The average channel widths of the Easton and Chain impoundment reaches (~250 - 300 ft) are wider and more variable than the Reference Reach (~250 ft). Much of the range in widths is due to the impoundment and canal systems, as the channel widths include the wetted widths through the river and any canals at each cross section.

Using measurements estimated from Google Earth (2012), the average radius of curvature on the meander bends was calculated with the following formula (1):

$$R_c = \frac{C^2}{8M} + \frac{M}{2} \quad (1)$$

Chord length (C) is measured as the distance between the inflection point coming in and going out of the curve, and M is the greatest distance from the chord to the arc of the bend, when measured perpendicular to the chord. In order to compare the radius of curvature among reaches, a proportion of the average radius of curvature per average channel width (R_c / W) was calculated. The R_c / W is lowest in the Easton Reach (6.0), indicating a tighter bend, and highest in the Reference Reach (14.5).

The sinuosity (S) is similar among reaches. Sinuosity was calculated using formula 2 below:

$$S = \frac{\text{channel length}}{\text{straight-line valley length}} \quad (2)$$

During the geomorphological assessment, the banks were visually estimated to be approximately six to eight feet above the water surface with visible bank slopes ranging from near vertical to approximately 1.5:1. In the area of influence of the Easton Dam, the banks were near vertical on the right bank and approximately 1.5:1 on the left bank. Much of the Easton Reach is along a meander bend towards River Right. Although the left bank should be the steeper “cut-bank,” many of the banks were significantly altered by industrial and commercial development as well as railway and transportation infrastructure. Several hundred feet upstream of the dam were also protected with riprap and concrete. In areas where banks had more native material cover, they were composed of sand with a thin layer of coal dust from effluent of local refineries. In the area of influence of the Chain Dam, banks were much less altered and more natural in appearance; however, there were some areas of alteration. Stormwater or stream confluences were present, but there was minimal bank protection and development throughout the reach. Bank slopes ranged from 1:1 to 1.5:1 and were composed of mostly sand with a stretch of orange clay approximately 200 feet in length upstream of the dam visible just above the water surface.

According to the NRCS, the surrounding soils are predominantly silt loams, sand loams, and outcrops of the Ryder-Rock Outcrop Complex, linear shaley limestone outcrops with associated silt loam due to weathering. All predominant soil mapped units from NRCS indicate that lithic bedrock is within 100 inches (8.3 feet) of the surface. The lithic bedrock in these areas is limestone and calcium-rich siltstones (NRCS 2011). The proximity of bedrock may be a primary factor influencing the placement of the dams,

especially that of Chain Dam and the potential resistance to down cutting in a full removal scenario.

A Wolman Pebble Count was conducted on the exposed portion of a riffle several hundred feet downstream of the Chain Dam in order to determine the particle size distribution for the bed (Wolman 1954). The composition of the bed material is primarily gravels (59%) and cobbles (41%). The median grain size (D_{50}) is 55 mm, classified as very coarse gravel. Particle data is provided in Appendix D. With little range in the particle size, the data suggests that during flow events with velocities sufficient to mobilize the bed sediment, 100% of the surface bed particles could be mobilized. The particles were also observed in a shingled orientation, indicative of full bed movement.

3.2 Physical Habitat Assessment

A physical habitat assessment was performed within each dam impoundment and at the reference location upstream of any dam influence to document existing in-stream and riparian habitat conditions. Using the EPA's Rapid Bioassessment Protocol (RBP) (Barbour et al. 1999) for in-stream habitat of low gradient channels, our team of stream specialists evaluated the quality of habitats within each reach. Such factors as vegetation, hydrology, and geomorphology were rated on a scale of 0 to 20, and the sum of scores was calculated for an overall value to compare among reaches. The results of this assessment are shown in Table 2 below. Higher values indicate higher habitat quality.

Table 2. Physical Habitat Assessment Results

	Easton Reach	Chain Reach	Reference Reach
Available Cover	13	10	16
Pool Substrate	*	*	*
Pool Variability	13	15	16
Sediment Deposition	17	10	13
Channel Flow	19	19	19
Channel Alteration	13	15	13
Sinuosity	11	11	12
Bank Stability	10	14	14
Vegetative Protection on Banks	4	10	8
Riparian Zone Width	8	11	12
TOTAL	108	115	123

* Pool substrate was not visible in the impounded reaches and therefore could not be assessed.
 For equal weighting this parameter was also not evaluated in the reference reach.

According to this assessment, the highest quality habitat is within the reference reach located upstream of the hydraulic influence of the Chain Dam, and the lowest quality habitat is within the Easton Reach. Available cover and pool variability have greatest potential for recovery after the dams are removed, while vegetative protection on banks will likely increase with a decrease in water surface elevation especially at Chain Dam. Because the dams are currently moderating the flow regime, the Easton and Chain Reaches are not subjected to the high variability of flows that typically create a high variability in habitat within the channel. Once a more variable flow regime is restored, a geomorphic shift towards greater habitat diversity will occur in pool and bank morphology as well as by the presence of snags and logs.

Island Park, the island upstream of Chain Dam adds significant habitat and diversity to this reach, though it is not represented in the RBP due to its focus on the main active channel. The pond-like area located in the middle of this island can serve as a nursery for juvenile fish and habitat for hundreds of different aquatic plants and animals. The connectivity of this pond to the river will likely be lost if the Chain Dam is removed. This loss of connectivity could potentially impact the diversity and value of island, though it may still serve as habitat for several species.

4.0 Base Mapping

KCI's sub consultant, Thew Associates, completed a field survey of each dam impoundment, including both structural and topographic contouring. The survey is referenced to North American Datum of 1983 (NAD83), horizontally projected on the Pennsylvania State Plane Coordinate System (North Zone) and vertically on the North American Vertical Datum of 1988 (NAV88). This survey and datum correlation is consistent with the datum utilized in the existing survey FEMA mapping for the project area. Datum was established using static GPS surveying techniques.

A bathymetry survey was conducted by means of a vessel-mounted dual-frequency single beam echo sounder (SBES) coupled to an RTK GPS recorder to record continuous river bottom profiles along selected transects of the project area. Bathymetry for the shallow shoreline areas (and landward topography) was collected via conventional survey techniques. In addition, spot elevations were collected along each transects at 5 foot intervals and at significant breaks identified in the river bottom.

4.1 Existing Conditions Plan

The existing conditions plan prepared for the project is attached in Appendix A. These plans include existing structural components, dams, fish ladders, river access points, bridges, bathymetry, topography, edge of water, stormwater outfalls, utilities within the water, locks, and canal sections. The deed and property ownership information for all adjacent lands, as provided by PASDA and the City of Easton, is also represented on the plan set. Profiles of the dam impoundments have been prepared to display pertinent information with regards to the dams, utilities and bridge infrastructure. Cross sections were prepared for incorporation into the HEC-RAS model (as described in Section 6.0). Cross Section depictions were completed by incorporating the collected field survey data and then supplementing the landward topography with LiDAR data provided by the Pennsylvania Spatial Data Access (PASDA). LiDAR is an acronym for "Light Detection and Ranging", and is utilized in developing various data products including point-based digital terrain models (DTM); grid-based digital elevation models (DEM), and contours.

5.0 Sediment Analysis

5.1 Existing Sediments

Sediment data were collected throughout the impoundments and further upstream of the dams to characterize existing sediments for volume and composition. "Depth to Refusal" surveys were conducted within the impoundments, and samples were collected using vibracore or ponar dredge apparatus at select locations (as shown on the base mapping plans) to accurately depict the existing conditions of the Lehigh River throughout the project area. A total of 20 sampling locations were established. As established in the Scope of Work nine (9) of these locations were identified for laboratory analysis of particle size. The selected locations were based on their proximity to the dam to identify stratification and spatial distance to represent the length of impoundment and possible mobile

sediments. The results of the bathymetry aided the selections. The 9 sample point locations had a total of 12 sample analyses due to stratification at Sample Point 12 and 20. The photo log in Appendix D shows the different 3 strata for Point 12 and 2 strata for Point 20. Each stratum was then analyzed separately. Bathymetry surveys revealed that the majority of impounded sediment throughout the project area was located behind Chain Dam (uppermost dam in the project area), rather than Easton Dam. As a result, KCI placed 7 samples upstream of Chain Dam to provide for a more accurate analysis of the project area and 4 from behind Easton Dam.

5.1.1 Limit of Refusal

A summary table of each sampling point and their depth to refusal are shown in Appendix D. The greatest limit of refusal within the Easton impoundment is at Sample Point 18, approximately 1,500 feet upstream of the Easton dam. Sediment depth at this location is approximately 5 feet. The existing bed elevation is approximately 156 feet at this sample point. A 5 feet reduction in bed elevation would equate to 151 feet, which is just 0.5 feet greater than the base elevation of Easton Dam. This could indicate it is the original bed sediments prior to the Dam installation. This location is also near a scour hole formed from the 3rd Street Bridge. This sample location did not have a full particle analysis conducted. It is located upstream of the 3rd Street Bridge and not within impounded sediments but is within the backwater area under normal flow conditions.

The greatest limit of refusal at Chain Dam occurs at Sample Points 12 and 13, both extending 10 feet below the existing bed surface. Sample Point 13 is outside the main flow path of the river and more aligned with the side channel flow around Hugh Moore Island. Point 12 is within the main flow of the river and represents the highest area of sediment buildup due to the dam. At a 10ft bed reduction the elevation is approximately 176 feet. This is 1 foot higher than the downstream base elevation of Chain Dam. This indicates the refusal depth could be the original bed surface of the Lehigh River. The remaining sample points had significantly less depth to refusal, but also less sediment accumulation. Depending on the location of the sample the depth to refusal could be larger sediments that could have been transported into the impoundment after dam installation or could mean the original bed has been located. In both instances there is indication of large particles within the impoundment that could produce an armor layer if the dam were to be removed. This armor layer is made up of the larger particles and is too heavy to transport during storm events. It therefore protects the bed below from eroding.

5.1.2 Particle Size

The majority of samples analyzed were composed of a mix of silt, sand and clay (making a loam) and small gravel. The majority of samples analyzed were taken near the two dams on their upstream side. A few samples were taken from further upstream to support the sediment mobility analysis presented in Section 5.2. The results of the analysis are presented in Appendix D and summarized below in Table 3.

Table 3. Sediment Size Particle Analysis for Chain & Easton Dams

Sample Point Location	ATL sample Identifier	D ₈₅ (mm)	D ₆₀ (mm)	D ₅₀ (mm)	D ₃₀ (mm)	D ₁₅ (mm)	D ₁₀ (mm)
Chain Dam Samples							
1	CT3234S11	48.7	45.4	44.1	41.6	39.8	39.3
4	CT3234S12	4.2	1.5	1.2	0.8	0.6	0.5
5	CT3234S1	6.2	1.6	1.2	0.7	0.6	0.5
7	CT3234S2	18.9	8.1	5.6	2.5	1.0	0.8
11	CT3234S3	5.2	0.9	0.8	0.6	0.5	0.5
12	CT3234S4	1.1	0.7	0.7	0.5	0.4	0.3
12	CT3234S5	3.4	0.5	0.3	0.1	-	-
12	CT3234S6	0.2	-	-	-	-	-
Easton Dam Samples							
17	CT3234S7	9.0	1.4	0.9	0.5	0.2	0.2
19	CT3234S8	8.8	1.9	1.1	0.7	0.5	0.4
20	CT3234S9	63.4	14.7	3.8	0.7	0.4	0.3
20	CT3234S10	0.8	0.6	0.5	0.4	0.3	0.3

Three of the analyses from Easton have a majority of sand while one analysis shows a significant amount of coarse gravel. In all other samples nothing larger than fine gravel was noted and, when found, gravel was minimal in samples. The coarsest sample was associated with the lower strata of Sample Point 20, while the upper strata at 20 showed results consistent with little to no gravel and mostly sand. Point 20 is nearest to Easton Dam and may reflect the diversity of material that is accumulated against the dam.

Samples from the Chain Dam impoundment range from coarse gravel upstream of RT 33 to full mixes of gravel, sand and fines and to samples with a majority of fines. The sample with the majority of fines is found at the lowest strata of Sample Point 12, where the greatest amount of sedimentation occurs. The middle and top strata increase in coarseness, respectively to height, with a broader mix of sediments and fewer fines. No chemical testing was done on any samples. Should dam removal prove to be a viable option, sediment testing in the vicinity of Sample Point 12 is recommended.

A single pebble count was taken of an exposed side channel bar within a riffle section. The bar was just upstream of the 25th Street Bridge. Pebble count data for this location is provided in Appendix D and summarized in Table 4 below. This sample location was in the free flowing area between Chain and Easton Dams.

Table 4. Pebble Count Data Summary

Percent Greater Than	Size (mm)
D ₁₆	27
D ₃₅	42
D ₅₀	55
D ₆₅	71
D ₈₄	110
D ₉₅	160

5.1.3 Sediment Chemical Characterization

Sediment Chemical testing or Chemical Characterization was not part of the scope of this project. It is recognized that some characterization of sediment has been undertaken in conjunction with the Palmerton Zinc Superfund Site. This information regarding the Superfund site can be located at <http://www.fws.gov/contaminants/restorationplans/Palmerton/Palmerton.cfm> while additional information has been provided in Appendix I and is provided as part of this feasibility study as a reference for future discovery in Phase II of the project.

Chemical testing of the sediment will be required by the regulatory agencies as these dams are located downstream of known contaminant sources. These factors will have to be evaluated in moving any of the presented options to a design and should be part of discussions in the future. Costs for removing potentially contaminated sediments have not been made part of this study.

6.0 Hydrology & Hydraulics

Fuss & O'Neill assisted KCI Technologies in developing hydraulic modeling to investigate fish passage feasibility at the Easton Dam and Chain Dam on the lower Lehigh River. This section summarizes these efforts in data development, hydraulic analysis, and scour assessment.

6.1 Data Collection

Fuss & O'Neill and KCI collected a variety of information to be used in an engineering evaluation of the potential project. A description of these data follows.

6.1.1 FEMA Data & Mapping

The Federal Emergency Management Agency (FEMA) has published a Flood Insurance Study (FIS) for Northampton County, Pennsylvania with an effective date of April 6, 2001. The FIS includes flood elevation profiles and calculated peak discharges for the Lehigh River for floods having a return frequency of 10, 2.0, 1.0, and 0.2 percent annual chance of exceedence (commonly and erroneously referred to as floods having a probable frequency of 10, 50, 100, and 500 years). FEMA-designated flood zones, including areas inundated by the base (1.0 percent annual chance) flood, are shown on Flood Insurance Rate Maps (FIRMs) with the same effective date as the FIS.

The information included in the 2001 FIS was developed based on a detailed hydrologic study and a hydraulic model of the Lehigh River. The 1985 hydrologic study was completed by the U.S. Army Corps of Engineers (USACE) to serve as a basis for the design of modifications to the Francis E. Walter Dam, which was originally constructed in 1961. It includes exceedence frequency curves at various control points on the Lehigh River, both with and without the flood control dam. The original report summarizing the hydrologic study (an appendix to a 1985 general design memorandum) is not available

in electronic format; however, the study information is summarized in a 1994 revision of the dam's water control manual. Gage data does not appear to have been directly utilized in the development of the frequency curves for the lower Lehigh River, but Gage #01454700 (Lehigh River at Glendon) is listed as one of the control points for which frequency flows are provided as a function of drainage area size. This gage has a period of record extending back to October 1966.

Fuss & O'Neill requested that FEMA provide a copy of its hydraulic model, which was developed using the USACE's Hydrologic Engineering Center's River Analysis System (HEC RAS) software. The digital copy of the HEC-RAS model formed the basis of our new hydraulic model; however, it was updated considerably using surveyed river cross-sections developed for this project, and available topographic mapping for overbank areas. The model was also updated to better reflect the type of flow occurring at the two dams. We used frequency flows from the FEMA study in the hydraulic analysis to evaluate the effect of proposed fish passage alternatives on large floods.

6.1.2 USGS Hydraulic Analysis

The U.S. Geologic Survey (USGS) published a Scientific Investigations Report in 2008 providing regression equations for estimating frequency flood flows in Pennsylvania. The report also provides frequency flood flows for gages substantially impacted by upstream regulation, including Gage #01454700 (Lehigh River at Glendon). The period of record used for this gage in the report is 1967 to 2006. Peak flows having a probable return frequency of 2, 5, 10, 50, and 100 years are included, and are 16 to 20 percent higher than the corresponding values used in the FEMA study previously cited.

The feasibility-level hydraulic analysis made use of the FEMA Flood Insurance Study flows, since these flows form the basis for floodplain regulations and permitting for activities within the regulatory floodplain and floodway. The flood flows provided by the USGS were obtained for comparison and may be considered for use in future design of a selected alternative, if appropriate and allowed by permitting authorities. The USGS flows were included in the hydraulic model; however, only the FEMA flows were used for tabulating results and determining most hydraulic impacts. Based on a cursory check it appears the relative impacts to flood elevations, velocity and scour potential would increase for the USGS flows, commensurate with the relative increase in flow. The relative impacts, however, are expected to be minimal as explained below. Final design will necessitate modification to the hydraulic model to reflect the details of design at which time a determination as to the appropriate flows to utilize will have been made.

The choice of which flows are assumed in an analysis can potentially affect three types of results: scour potential, sediment mobility, and flood elevations. Because bridge scour potential is considered to be one of the most critical aspects of this project, the more conservative USGS flows were used for that assessment. The rate of sediment movement to downstream areas may be affected by a change in assumed flows, but ultimately the channel is expected to reach a state of equilibrium after any structural change. The relatively small difference in flood depths, velocity and scour potential translates into a relatively small increase in the rate of sediment movement. A full or partial dam breach is expected to result in a substantial net decrease of flood elevations in upstream areas regardless of which flood flows are assumed. This will necessitate a change to FEMA Flood Insurance Study mapping as part of the permitting process. At that time it can be determined if FEMA would allow the hydrology to be adjusted given the more recent USGS gauge data for the river. Similarly any alternative, such as a rock ramp within the floodway, that causes a rise in water surface elevation, which is otherwise prohibited by FEMA regulations, would necessitate requesting a legal flood mapping revision from FEMA at which time the specific proposed flows and hydraulic models would have to be approved by FEMA.

For the reasons outlined above, the use of the FEMA flows versus the USGS flows would not change the conclusions of this feasibility study.

FEMA and USGS flows are summarized in the following table.

Table 5. Frequency Flood Flows: FEMA vs. USGS

Flood Flow Frequency	FEMA Flow (cfs)	USGS Flow (cfs)	Increase (%)
2-Year	-	25,800	-
5-Year	-	38,900	-
10-Year	40,000	48,100	20.3%
50-Year	60,000	69,900	16.5%
100-Year	69,000	79,800	15.7%

It should be noted that water management at FE Walter Dam may need to be taken into account if future hydraulic calculations and modeling are conducted. Flows from the reservoir are controlled for a variety of reasons, and changes in the management of these flows may have an impact on flow calculations in the lower portion of the Lehigh River. Appropriate periods of record would need to be selected to match the flow conditions likely to be encountered into the future.

6.1.3 Geometry Information

In addition to FEMA modeling, a variety of information was used to develop and update channel sections, dams, bridges, and other geometrical information in the hydraulic model. Field survey, available bridge plans and reports, and visual observations in the field were all used to develop channel sections, inline structures, and bridge geometry. High-resolution (1/9 arc second) elevation data developed by the USGS was used for overbank areas. These data sources are described in detail elsewhere in this report.

6.2 Field Visit for Hydraulic Assessment

Fuss & O'Neill staff toured the river on November 15, 2011. Major observations made at that time are presented below, ordered from upstream to downstream:

Upstream of Chain Dam

1. The Route 33 Bridge is founded on piers that are well outside of the river channel.
2. The PA Fish and Boat launch facility is located downstream from the Route 33 Bridge that provides trailered and car top boat access to the river on river left (facing downstream).
3. The Lehigh canal was dewatered.

Upstream of Easton Dam

1. A fishing pier is located at river left within Palmer Riverview Park.
2. Stone masonry training walls and storm sewer endwall observed on river right at Hugh Moore Park upstream from the Glendon Hill Road truss bridge.
3. Glendon Hill Road truss bridge provides access to the Hugh Moore Park and has bridge piers located within the river. River bottom appeared cobbly at this location with cobbles in the 6 to 12 inch diameter range.

4. Stone masonry training wall on river right downstream from truss bridge with endwall for large conduit.
5. Lower portions of the Lehigh canal where a lock is located just upstream of the upper railroad bridge prior to discharge to the Lehigh River.
6. Stone masonry training walls along river left upstream from the lower (3rd Street) railroad bridge.
7. Concrete training wall and cantilevered walkway along river right upstream from 3rd Street Bridge. Walkway extended beneath the 3rd Street Bridge as well.
8. Inlet to the Delaware Canal. Substantial scour and material loss due to recent flooding. Evidence of high water that overtopped fishway structure at right side of Easton dam.

6.3 Hydraulic Analysis

In order to assess potential impacts of proposed alternatives on fish passage, infrastructure, flooding, and canal source water, a hydraulic analysis was completed for the lower Lehigh River, extending from the confluence of the Lehigh and Delaware Rivers up to just above the Route 33 Bridge. This 5.7-mile study reach was modeled using the U.S. Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS) hydraulic modeling software, version 4.1.0.

Existing Conditions

The digital model obtained from FEMA was updated with survey data, available bridge data, and elevation data in overbank areas to create an “existing conditions” model reflecting the present configuration where backwater is created by the Easton Dam and Chain Dam. The study reach was assessed for the range of flood events provided in FEMA’s FIS (i.e. 10-, 50-, 100-, and 500-year flows), as well as fish passage flows or low flows typical of normal conditions or drought conditions. Tailwater effects from the Delaware River were conservatively assumed to be negligible (i.e. it was assumed that the Delaware River was not in flood). This existing conditions model constituted a baseline reference for comparison of proposed fish passage alternatives. The locations of cross sections used in the model are shown in Appendix E.

The geometry of the model was updated to reflect several proposed configurations, using a subset of the cross-sections in the existing conditions model. These configurations included full and partial vertical and horizontal configurations removal of both dams.

Full Removal

For full removal, it was assumed that the entire dam structures were removed and impounded sediment was dredged or mobilized, restoring a natural flow system to the reach. In this scenario no special structures are required for fish passage.

Partial Vertical Removal

Two detailed hydraulic conditions were modeled including the full removal and partial vertical removal were selected. For partial vertical removal, it was assumed that the dams were lowered and rock ramps were installed on the downstream side to accommodate fish passage. Ramp slopes of two percent and three percent were evaluated.

Results

For each modeled condition, information such as flow depth, velocity, and shear force was calculated at points of interest for the full range of project flows. This information was then used to assess sediment

mobility and scour potential for proposed alternatives. Flow profiles of the study reach for existing conditions, full removal, and partial removal with rock ramps (2 variations) are included in Appendix E.

In general, lowering or removing either dam will decrease flood elevations and increase flow velocity in upstream areas. These effects are most pronounced immediately upstream of the dams and in the flow condition where backwater from the Delaware River is not significant.

Immediately upstream of the Easton Dam, the model indicates that the 100-year flood profile could be lowered by up to 16.1 feet for partial removal and 16.9 feet for full removal of the dam. It also indicates that the flow velocity could increase by 10.2 feet per second for partial removal and 15.3 feet per second for full removal of the dam. These high flow velocities appear to be due in part to the fact that the channel is constricted through this area by local topography associated with native bedrock formations.

Upstream of the Chain Dam, the 100-year flood profile could be lowered by about 2.0 feet for partial removal and 5.7 feet for full removal of the dam. The associated flow velocity at this location could increase by 1.0 foot per second for partial removal and 1.2 feet per second for full removal of the dam.

6.4 Fish Passage Flow Determination

The amount of flow through a nature-like fishway at the migration period of the selected target species is extremely important to determine. The amount of flow can be made to move faster or slower and deeper or shallower based on the needs of the fish by manipulating the design of the fishway. Since there is a range of flows for every migration period over numerous years the data must be organized to give the best estimate of flow conditions the migrating fish may face. The fishway must provide the appropriate velocity and depth for the fish throughout the migration period. To most accurately determine this range of flow a procedure called baseflow separation is performed on the USGS gage data for the Lehigh River. The baseflow separation allows the determination of a flow range that is likely during the migration period and is denoted as a non-exceedence value. A non-exceedence value means that of all the data processed only that amount does not exceed the corresponding value. For example a 50% non-exceedence value of 400 cfs means half the flow values evaluated are greater than 400 cfs and half are less.

KCI conducted a baseflow separation analysis for the Lehigh River fish passage assessment using US Geological Survey (USGS) gage data from the Lehigh River at Glendon, PA (USGS Stream Gage # 01454700). This USGS gage is located between Easton and Chain Dams. Daily mean discharge data was imported from the USGS database for the time period of April 20 through June 30 each year from 1980 through 2005. This time frame corresponds to the known migration period of American Shad at the Lehigh River.

The baseflow separation analysis was performed using the fixed interval method, developed by Pettyjohn and Henning (1979). In this method, the data was maintained in chronological order, but separated by intervals. The minimum daily mean discharge within each interval is pulled aside so that the minimum discharge from within each interval can be sorted by discharge, and then ranked.

The interval is a direct relationship to the duration of surface runoff which is calculated using the empirical relationship:

$$N=A^{0.2} \quad (1)$$

N represents the number of days to the cessation of runoff; A represents the watershed area (square miles) draining the site. The fixed interval is determined by $2N^*$, where the N calculated in equation 1 is multiplied by 2. The * indicates that the nearest odd integer to the product should be used.

The watershed area (A) for this gage site is approximately 1,359 square miles. Using the equations above, the fixed interval used for this analysis is 9. Therefore, the imported data was grouped in intervals of 9 days, and the minimum daily mean discharge from each group was pulled together for sorting and ranking. Each year started the interval anew. No carryover was done between years.

After ranking from least to greatest the non-exceedence probability for the occurrence of each discharge is found using the Weibull equation:

$$P_i = i/(n+1), \quad (2)$$

where n is the number of discharge values ranked and i is the rank of an individual discharge value. Non-exceedence probabilities were determined at 10%, 50%, and 90% for the Lehigh River to capture the greatest range of flows. Discharge values at each non-exceedence value are the baseflows and represent the fish passage flows at the USGS gage location. These flows are shown below in Table 6.

Table 6. Baseflow Results for USGS Gage on the Lehigh River at Glendon, PA

Probability	Discharge - Q (cfs)
10 % Non-exceedence	1,010
50 % Non-exceedence	1,765
90 % Non-exceedence	3,625

The discharge values of Table 6 are used to derive the baseflow discharges (i.e. fish passage flows) at the Easton and Chain Dams. To estimate the fish passage flows at each Dam a simple watershed area scaling ratio is done to estimate discharge (Q):

$$Q_a/A_a = Q_b/A_b, \quad (3)$$

and solving for Q_b :

$$Q_b = (Q_a * A_b)/A_a. \quad (4)$$

The discharge at the USGS gage is represented by Q_a and the watershed area at the gage (1359 mi²) is represented by A_a ; the discharge at the dam location is represented by Q_b . The known watershed area at the dam locations is 1356 mi² at Chain dam and 1373 mi² at Easton Dam and is represented by A_b in equations (3) and (4). The 10%, 50%, and 90% fish passage flows scaled for the Easton Dam are presented in Table 7 below and Chain Dam's are presented in Table 7.

Table 7. Extrapolated Baseflow Data at Easton Dam

Probability	Discharge - Q (cfs)
10 % Fish Passage	1,020
50 % Fish Passage	1,783
90 % Fish Passage	3,662

Table 8. Extrapolated Baseflow Data at Chain Dam

Probability	Discharge - Q (cfs)
10 % Fish Passage	1,008
50 % Fish Passage	1,761
90 % Fish Passage	3,617

Since the fish passage flows at each dam location are very similar to each other (within 2%) and that the gage is located between the two dam sites the fish passage flows of the gage station (see Table 6) were selected to represent both locations for the fish passage analysis. If greater variance between the two sites were derived through the scaling method the values for each dam location would have been utilized.

7.0 Fish Passage

7.1 Target Species and Design Criteria

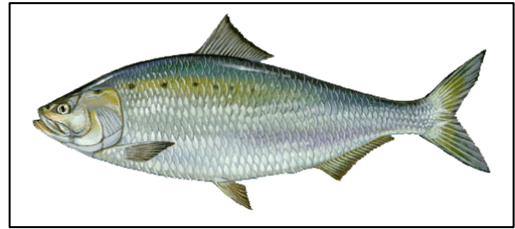
The purpose of the Lehigh River Fish Passage Improvement Feasibility Study is to determine ways to improve fish passage at Easton and Chain Dams. Any instance where the full dam height is not removed to the active width of the channel requires the assistance of a fish passage structure. All fish passage structures are designed based established design criteria. The design criteria establish the minimum depth of flow and maximum velocity requirements based on a one or several fishes (called target species) swimming capabilities. Additional considerations include a fishes leaping ability and its burst and prolonged swimming speeds. For this feasibility assessment the American Shad is the target species. This fish has limited leaping ability and is considered a “poor” swimmer. Data collected by Bell (1991) and presented in the Fishing Swim speed table (USFS 2006) are summarized below.

Table 9. American Shad Swim Capabilities

Common Name	Swim Category	Swim Speed (ft/s)	Min Length (in)	Max Length (in)	Default Time To Exhaust (s)
American shad	Burst	10.75	12	14	10
American shad	Burst	2.15	1	3	10
American shad	Prolonged	5.00	12	14	1800
American shad	Prolonged	1.50	1	3	1800

The range in fish length indicates both juvenile in adult shad were tested. The adult fish would be the ones migrating through the Lehigh River so will set the velocity requirement. Since these swim speeds are median values and based on KCI’s work with fish experts from NOAA and US Fish and Wildlife Service on American Shad fish passage a maximum velocity of 4 ft/sec is established for fish passage.

Most spawning Shad range in length from 20-25 inches with a corresponding body depth of 25-30%. At this percent and large end of the length range the average shad is 6.25-7.5 inches in body depth. The Maine DOT suggests a fish passage water depth of 1.5 x total depth. The total depth accounts for the fin heights and is greater than the body depth size. Temporarily ignoring the fin height and using the depth calculation with the body depth and water depth of 11.25 inches is calculated. Using this slight under calculation and again KCI's experience with American Shad fish passage projects and NOAA and USFWS a minimum water depth of 12 inches is established for the Lehigh River fish passage feasibility study.



7.2 Fish Passage Structures

All fish passage structures discussed as options in the document are considered nature-like fishways (NLF). There are several different types of NLF each with its own limitations and applications. Three types of structures are discussed below and their application to Easton and Chain Dams.

7.2.1 Rock Ramps

Rock ramps are basic rock structures that gradually increase in elevation to the desired final elevation, literally a ramp. They can be placed up or downstream of obstructions to allow a passible river condition for upstream or downstream fish migration. General professional guidelines for these structures are for 8 feet of hydraulic head or less. It is also the recommended design practice of fish passage professionals to limit rock ramp slope to 2-3%. This type of structure has minimal control on depth and velocity and would not likely be sufficient alone at either the Chain or Easton Dam to ensure fish passage.

7.2.2 Weir Rock Structure

Flow Constrictor / Step Pools (FC/SPs) are NLF designed to concentrate flow to provide necessary water depth and velocity for traversing blockages. In their basic form, FC/SPs are linear structures with multiple rock weirs set at different elevations to provide fish passage for varying flows and stages. Multiple weir openings also provide redundancy to account for debris and the range of design flows. Multiple steps are installed in series with the gaps in these steps horizontally offset to force lateral flow through the intermediate pools. These weirs can also be placed in an in arch formation pointing upstream with gradual increase in elevation to the outside of the weir. This is commonly known as the arch rock rapid and was pioneered by Luther Aadland (2010). Both weir formations allow for fish passage a various flow conditions and are built with the weirs embedded in a rock ramp.



The confining nature and drop over a weir increases the need for a pool between each successive weir. In basic terms these pools serve several purposes. The first is to dissipate energy as the water falls over

the weir, without this fish could become disoriented in turbulent flow; second is to create a resting area for fish during navigation through the structure, often a very long structure will not be navigated in a continuous fashion but traversed in segments; and third is to allow the fish to swim in an upward projection in order to pass over the flow falling over the upstream weir, shad do not have much leaping ability so swimming within the fast moving flow is necessary.

The pool length, energy dissipation and step height combine together to control the slope and length of the step pools. KCI has designed these structures at slopes up to 5%; however, this was for better swimming and leaping anadromous fish such as Salmonids and was less than 10 feet high. Design guidelines for the arch rock rapids also recommend a slope of 2-5%, with caution at 5%. Due to the size of structures required for Chain and Easton Dam a maximum of 10 feet hydraulic head is recommended at slopes of 2-3%. As a surrogate to hydraulic head, dam height of 10 feet will be used for future discussions.

7.3 Fish Passage Structure Summary

The maximum height of the NLF is 8-10 ft. depending on the structure. Due to the size of river and less control of a rock ramp the weir rock structure should be used if a NLF is required. This establishes a 10 feet maximum height and a slope preference range of 2-3%. Using the maximum recommendation of a 10 feet high structure corresponds to a proposed maximum dam height of 10 feet. At the recommended 2-3% slope a structure with 0.8 foot weir drops (typical maximum drop for NLF) and 30 feet long pools (typical for constructability and energy dissipation) requires 13 weirs and is 375 feet long at 2.7% slope.

Additional considerations must be made with any NLF, especially at the height and length calculated above. Flow into the interstitial spaces (gaps between rocks) can have detrimental effect on a NLF's stability and performance. Flow into these spaces can potentially move rocks, especially during storm flows destabilizing an entire structure. At low flow conditions, water that enters the spaces is reduced from the required flow for passage, which may result in low depths in the structure and preventing passage. To mitigate some of these potential issues water barriers should be placed at least every change in 5 vertical feet to prevent water from flowing through the length of a structure. A barrier is often made with sheet piles placed within the structure at the required interval (approximately 185 feet at 2.7% slope). A final concern is fish fatigue. A Shad may tire while swimming the 375 feet length requiring resting places and slower water. Pools can serve as resting places but may not provide enough space during the peak migration period.

8.0 Dam Removal Options with Fish Passage

8.1 Partial Vertical Removal

A partial dam removal involves numerous options to leaving a portion of the dam in place while removing another portion for the promotion of flow and fish passage. A partial vertical removal would be a height reduction in the total dam elevation. By only removing a portion of the total height the remaining dam would not be declassified and fish passage would still remain an issue. A NLF would be required downstream of the structure to allow fish passage over the dam. The maximum recommended height for any NLF structure is 10 feet. At just 10 feet high both Easton and Chain Dams would need to be reduced by approximately 10 feet. On very wide rivers like the Lehigh a NLF could either span the entire channel width with a design to accommodate the previously derived fish passage flows or it could be just a portion of the channel width.

8.2 Partial Horizontal Removal

A partial horizontal removal involves removing the full vertical height of the dam over a portion of the dam width. If only a portion of the dam were breached all or nearly all of the water would rush to this lowered elevation and place tremendous force through a small opening. This would cause both structural deficiencies during storms to the portion left in place and be too strong of flow for fish passage. To avoid diverting all the flow into breached segment a NLF would rise from the riverbed at or just downstream of the dam up to the dam height. The sides must be vertically maintained to a height equal the dam elevation to prevent seepage from the edges. To draw just a portion of the flow into the NLF a flow entrance of 1-2 feet lower than the dam would be required. In addition since a NLF is limited in height to 10 ft. the remainder of the dam should also be reduced in height to 10 ft. The result is a NLF set just below the elevation of the reduced dam height spanning a portion of the channel width.

8.3 Partial Width Nature-like Fishway

When a NLF is just a portion of the channel width only a portion of the flow should traverse the structure. A weir analysis was conducted for both Easton and Chain Dams to determine how much flow should be drawn into a NLF when only a portion of the river is being utilized. The dams were modeled with weir equations and notches cut into the dam heights to determine the flow within the notches. Analysis was initiated using a width of 50 feet and two different elevation notches below what would need to be the dam height (10 feet due to NLF limitations). The flow through the notches was determined at each of the fish passage flows derived in Section 6.5. The total notch width at Easton Dam was determined to be 70 feet and 60 feet wide at Chain Dam.

These widths were validated through the use of a KCI proprietary spreadsheet tool specifically designed to determine fish passage through a weir rock structure. This tool uses the submerged weir theory and iterations of water depth and velocity finally reaching a balance at the subcritical flow state at downstream most weir. The tool then works in a step backwater fashion similar to HEC-RAS to determine the next upstream weirs depth and velocity. Input values include the downstream water surface (tailwater) elevation which was taken from the HEC-RAS models, weir widths and notch elevation. Notches are prescribed widths and elevations that make up each weir. The variations in notch width and elevation allow for redundancy and passible routes at the three fish passage flows. Therefore as long as the weir has at least one notch that meets the depth and velocity criteria it is determined passable. Fish passage was assessed as acceptable through the weirs if the depth was greater than 1 foot and velocity was less than 4 ft/sec as determined in Section 7.1. Analysis of the dam notches and fish passage associated with each weir is provided in Appendix G.

8.4 Full Dam Removal

Full Dam removal involves complete dam removal both vertically and horizontally to allow the river to pass through the former dam location unimpeded. It is common for dams and their upstream impoundments to be much wider than the associated free flowing river. In this situation a portion of the dam can be left in place for historic, educational, or cost saving reasons, but is in effect a full dam removal since the river would be able to return to its free flowing condition.



9.0 Feasibility Analysis

9.1 Easton Dam

9.1.1 Site Constraints and Considerations

There are significant challenges to any type of dam modification at Easton Dam and yet there are also concerns with taking no action. Below is a summary of the major challenges at Easton Dam:

- Upstream of Easton Dam there are two sanitary sewer lines and a channel constriction due to surrounding development and natural geologic formations. These constraints may limit the length of an upstream structure.
- Easton Dam's effective height (dam crest to bed elevation just downstream) is 20 feet.
- The recommended maximum NLF height limit is 10 feet. This requires the dam height to be reduced to at least that of the NLF.
- Easton Dam is a concrete capped timber crib dam and would not likely be able to withstand the rivers power if partially breached (horizontal removal) or reduced in height (vertical removal). The portion of the dam left in place would require a new concrete cap or concrete infill to reinforce the remaining timbers plus a cap over the new face/top/side of the dam.
- Any reduction in dam height would require supplemental water supply to the Delaware Canal.
- The Delaware River is approximately 300 feet downstream of Easton Dam precluding any extension of a structure further than that distance. It is recommended that any structure end at least 100 feet prior to the Delaware River to prevent scour of the structure due to the turbulence of the two large rivers during heavy flows. In addition there is an existing rise in bed elevation between the dam and the Delaware River further reducing the downstream extent of the structure to 140 feet.
- Upstream bridge piers induce river bed scour that may be impacted with any type of removal.
- Dams left in place create a permanent fish passage blockage.
- Existing shape of the dam produces a current that draws fish to the center, called the attraction flow.
- It is estimated that sediment is scoured down to elevation 150 (also the bed elevation downstream of the dam) approximately 660 feet upstream and it gradually builds up to the full dam height.
- The Delaware Canal entrance is at elevation 164.

9.1.2 Partial Vertical Removal with Nature-like Fishway

A NLF would be required with a partial vertical removal. A partial vertical removal would require a rock structure across the entire channel width to promote fish passage. The dam 80 feet closest to the existing fish ladder is beyond the existing upstream channel width and would not need a NLF. Placing any portion of the rock structure downstream of the dam would require only a partial width dam notch for the active area of fish passage but a full width structure. Without a full width structure the water cresting the dam in the non-NLF area would potentially destabilize the NLF during storm flows.

The NLF length of 375 feet derived in Section 7.3 and maximum downstream extent of a NLF at Easton Dam create two options; the first (Option A1) is to only have 140 feet ramp, which corresponds to a dam height of 3.8 feet; the second (Option A2) is to remove the dam to 3.8 feet as noted previously and then continue the structure the rest of the distance upstream to achieve the final 10 feet height. The upstream extent would require a sheet pile edge effectively creating a new dam structure 235 feet

upstream of the current location of Easton Dam. No material removed from the dam will likely be reusable as fill material for rock structure due to the timber cribbing.

9.1.2.1 Option Recommendation

The first partial vertical removal option (Option A1) would leave a minimal amount of dam and would result in few benefits. The maintenance of the rock structure would quickly outweigh any cost savings from leaving a portion of the dam in place. The 3.8 feet dam would not help with canal water but may provide grade control for the 16" sewer crossing depending on the sewer lines elevation. This option is represented by the partial removal HECRAS data. This slope is between that of the 2% and 3% analysis.

The second partial vertical removal option (Option A2) would also leave a minimal amount of dam but also continue building the ramp upstream of the existing dam. The existing fill behind the dam consists mostly of sand and gravel and would need to be removed for the installation of the rock structure. While this material is unsuitable material to build upon it could be used to fill the void space between the larger materials used for the rock structure. The upstream extent of the structure would be into the scour zone of the upstream peers but at approximately the same elevation to the existing bed. The canal entrance would still be 4 feet higher than this structure which is likely greater than the headwater base on the partial removal and existing conditions HEC-RAS models. Each model has an increased head water of 3.5 and 1.2 feet for partial removal and existing conditions, respectively, at the March through April (Mar-Apr) flow above the structure or dam elevation. This would still have significant effect on the impoundment elevation and therefore the canal watering. Pumping or other means of getting water to the canal would be required.

9.1.3 Partial Horizontal Removal with Nature-like Fishway

A partial horizontal removal with a NLF is considered Option B. In Section 8.3 it was determined that only 70 feet would be required for any partial width structure at Easton Dam. Using the same structure height and resulting length requirements as noted in Section 7.3 there results only one real option. When only removing a portion of the dam width it is best to do so from one of the edges rather than the middle. This allows the use of an existing bank and has a smaller effect on the structural integrity of the remaining portions of the dam. As described in Section 8.2 the structure's downstream extent is at the existing bed elevation at the toe of the dam and ramped upstream of the dam. Sheet piling would be needed at the upstream extent of the rock and along the entire side along the channel for its length of 375 feet. The upstream extent would be at the 10 feet elevation but the side sheet piling would need to be equal to that of the remaining portion of the dam. This will prevent excessive amounts of water in the rock structure, compromising its stability and fish passage capabilities. A structure of this length would put the upstream extent within the general proximity of the existing 16" sanitary line. It is likely that driving sheet pile would compromise the pipes by direct contact while driving, or indirect contact through vibrations while driving the sheet piles. The weight of the structure may also crush or break the pipes due to the weight sitting above the pipes in this option.

While Option B may meet the design criteria there are several concerns. Due to the upstream peak of the existing dam, a structure may have problems competing with the attraction flow if placed on river left. If placed on river right additional sheet piling would be needed on the bank side to prevent flow from leaving the NLF and filling the current canal entrance area. Any partial removal of Easton Dam has stability concerns. Lastly, due to the reduced dam height, regardless of river side pumping or other means of getting water to the canal would be required.

9.1.4 Full Dam Height Nature-like Fishway

A full dam height rock structure is not recommended or viewed as a feasible option; however, the parameters are discussed here as Option C at the request of the Fish and Boat Commission. At 20 feet tall, a structure this high would significantly exceed all design and professional recommendations. The previously determined passable 2.7 % slope for a 20 feet high rock structure would extend 750 feet. Even if steepened to 5% the structure would be 400 feet long and would require extensive safety measures, while surpassing all design recommendations. A partial width rock structure would require sheet piling along the side and upstream extents as well as within the structure every 100 feet (or 5 feet change in elevation). Both sanitary lines would be covered with the structure and it would significantly encroach into the upstream pier scour area for the 3rd Street Bridge. This may result in increased scour at the piers and additional structural support for the rock structure. It is approximated that a structure of this height would not be stable during high flows. Due to this structure exceeding all design recommendations and provisions, its likelihood of failure or difficulty in passing fish, impediment to the scour zone and compaction over the sanitary lines this option is not considered feasible. A visual depiction of this option is provided as Option C, but should not be considered feasible.

9.1.5 Full Dam Removal

A full dam removal at Easton Dam would result in declassification by PADEP as a Dam and relieve the DCNR of all liability and legal requirements of owning and maintaining a dam. Full removal could affect the exposure of one if not both sanitary pipes within the impoundment of Easton Dam. Due to the shape of the impounded sediment wedge the expected loss of sediments would end near the 24" pipe location. More detailed mobility analysis is provided in Section 10. It should be noted due to the size of the river that a removal of all impounded sediment prior to breaching would be very challenging, however if the sediment is found to be contaminated this may be required. Future testing and communications with the regulatory community will provide insight into the preferred approach. If the sediment is left to natural evacuation it would have little to no effect on biota due to the confluence with the Delaware River just downstream of the Dam. Ample fish passage would return full Shad runs as well as other migratory fish moving up the Delaware River to the Lehigh River immediately after removal. Water surface elevations with full dam removal would not provide any direct water to the Delaware Canal requiring pumping or other means to fill the canal.

9.1.6 Easton Dam Removal and Fish Passage Summary

Sediment evacuation would depend on the final height reduction. Sediments are at elevation 160 at approximately 150 feet upstream of the dam. Any partial dam removal (vertical or horizontal) will require the dam to be reduced to approximate elevation of 160.5 feet due to the NLF height limitations and drawing the appropriate water into the fishway. A 375 feet structure will likely require maintenance over the long term as weirs become occasionally clogged with trees or boulders are dislodged. Another risk of a structure this long is a fishes ability to make it this far. A NLF structure at Easton Dam will likely increase fish passage but at the size evaluated will not likely be able to pass full fish runs due to fatigue. Leaving the dam in place will continue to incur dam maintenance and provide minimal fish passage. Full removal will provide the most optimal fish passage and remove maintenance costs and thus is the recommended option for Easton Dam.

9.2 Chain Dam

9.2.1 Site Constraints and Considerations

There are significant challenges to any type of dam modification at Easton Dam and yet there are also concerns with taking no action. Below is a summary of the major challenges at Easton Dam:

- Hugh Moore Island is approximately 300 feet upstream of Chain Dam and may affect the ability to create an upstream structure.
- Chain Dam effective height (dam crest to bed elevation just downstream) is 18 feet.
- The recommended NLF height limit is 10 feet. This requires the dam height to also be reduced.
- Just upstream of Chain Dam remains a portion of an earlier version of this dam. It was breached in 1965 and approximately 90 feet near the right side had been removed. The remainder of the dam still stands at elevation 186 feet. Any vertical removal of the existing Chain Dam below this elevation would involve significant excavation and debris removal of the former dam.
- Partial vertical removal at Chain Dam would also reduce the inflow to the Lehigh Canal and likely require pumping.
- Maximum sediment elevation is approximately 185 feet, but decreases a few feet nearest the dam.
- Dams left in place create a permanent fish passage blockage.
- The canal entrance at this location is estimated to be elevation 186 feet.

9.2.2 Partial Vertical Removal with Nature-like Fishway

At Chain Dam there is the same fish passage criteria, therefore the same 2.7% slope, 375 feet long structure will be discussed in the partial vertical removal with a NLF as Option D. Chain Dam is much wider than the required cross section width seen up and downstream of the dam, however, the upstream island splits the flow increasing the overall width. The channel comes back together approximately 300 feet upstream of the dam but this width is maintained through the dam. Due to this width increase only 500 feet of the total 700 feet of Chain Dam would need to be vertically reduced. Chain Dam would need to be reduced down to approximate elevation 185 feet to meet the maximum recommendation of 10 feet NLF height.

In Option D the 500 feet wide rock structure would stretch downstream 375 feet ending near the upstream portion of the large island on river right. The existing left bank would be utilized as part of the structure embankment however the right bank would need to be built up along the entire structure length. A sheet pile wall would be required along the right bank to keep water within the structure. Additional rock or other fill would likely be used to connect the bank into the surrounding topography. One row of sheet pile would also be required approximately halfway down the structure to prevent water from running down into and out of the structure. The vertical pile will allow water to fill the interstitial space but not flow through, causing the water to pile up and flow on top of the structure. The concrete debris from the dam removal portion can also be used as the base of the rock structure. This will add some cost savings to the job by slightly reducing the amount of stone fill material imported and for hauling and disposing of the dam debris.

It is anticipated that a foot or less of sediment will be flushed out of the impoundment with this scenario. This is a result of the structure height approximately equal to that of the existing impounded sediments. Some sediment may be flushed out just upstream of the structure will likely maximized to 1 foot. The partial removal scenarios at Chain Dam are modeled in HEC-RAS at 2% and 3% to show the range of slopes possible. At these conditions, there is a water surface elevation of 189.4 feet at the Avg Mar-Apr flow. The Lehigh Canal entrance is at approximately elevation 186 and will allow for over 3 feet of head into the canal for unassisted pumping. Based on an entrance width of 20 feet, 3 feet of headwater, and a velocity of 1.44 ft/s (taken from the upstream impounded water) during the Avg Apr-Mar flow an approximate flow rate of over 38,000 gpm is achieved. This is significantly more than the

required rate to fill the canal as described in the Canal Watering Options. During dry summer months pumping may be required to maintain the appropriate inflow.

9.2.3 Partial Horizontal Removal with Nature-like Fishway

The location of the island split flow just 300 feet upstream of the Dam makes an upstream structure more challenging (Option E in Appendix G). Using the maximum structure height of 10 feet and the corresponding 375 feet long structure the upstream extent will go slightly beyond the downstream end of Hugh Moore Island. To maintain connectivity of flow the structure should extend into both the main and secondary channel until the full structure height and length is met. The approximate width of the dam removal and installed rock structure is 60 feet as determined in Section 8.3. The Dam elevation will need to be reduced to the same elevation as the NLF. Sheet pile will be required on the upstream and right side of the structure. Sheet pile within the structure could be minimized due to the presence of the previous dam. The previous breach may be the only location where a water barrier is needed. The remaining dam remnants can act as a water barrier the remainder of the rock structure width. Concrete dam debris can also be used as fill material as presented in Option D in Appendix G.

It is anticipated that little to no sediment will be flushed out of the impoundment with this scenario. This is a result of the proposed structure height approximately equal to that of the existing impounded sediments (185 feet). Additionally the slight decrease in sediment elevation directly against the dam under current conditions may further reduce the amount of sediment released with Option E. The height of an upstream structure in a partial horizontal removal is equal to that of the partial vertical removal making the headwater elevation approximately equal as well. Under this condition it may be possible to fill the Canal without additional assistance at the spring flows.

9.2.4 Full Dam Height Nature-like Fishway

A full dam height rock structure is not recommended or viewed as a feasible option; however, the parameters are discussed here at the request of the Pennsylvania Fish and Boat Commission. At 20 feet tall, a structure this high would significantly exceed all design and professional recommendations. The previously determined passable 2.7 % slope for a 20 feet high rock structure would extend 750 feet. Even if steepened to 5% the structure would be 400 feet long and would require extensive safety measures, while surpassing all design recommendations. A partial width rock structure would require sheet piling along the side and upstream extents as well as within the structure every 100 feet (or 5 feet change in elevation). The split channel at Huge Moore Island would present difficulty in running the structure up just the main channel or also the secondary channel or truncating the secondary. It is approximated that a structure of this height would not be stable during high flows. Due to this structure exceeding all design recommendations and provisions and its likelihood of failure or difficulty in passing fish this option is not considered feasible. A visual depiction of this option is not provided.

9.2.5 Full Dam Removal

In a full removal scenario of Chain Dam would result in declassification as a Dam and relieve the City of Easton of all liability and legal requirements of owning and maintaining a dam. There would be ample fish passage opportunity and little to no maintenance of the channel required. Sediment transport would increase immediately after initial removal but is expected to decrease within a few weeks. Large transport events would only occur during storm flow conditions as the impounded sediments naturally redistribute downstream. Full transport of the impounded sediments will likely occur within a few years of normal storms. It should be noted due to the size of the river that a removal of all impounded sediment prior to breaching would be very challenging, however if the sediment is found to be contaminated this may be required. Future testing and communications with the regulatory community

will provide insight into the preferred approach. Analysis of this is provided in the Sediment Mobility section. Upstream water depths would not be suitable for power boats, or sufficient to provide any direct water to the Lehigh Canal. Fish passage for shad and other resident fish would be returned upstream of the dam following the barrier removal.

9.2.6 Chain Dam Removal and Fish Passage Summary

Minimal sediment evacuation is expected for either partial removal, but full evacuation is expected for full dam removal. Any partial dam removal (vertical or horizontal) will require the dam to be reduced to approximate elevation of 185 feet due to the NLF height limitations and drawing the appropriate water into the fishway. A 375 feet NLF structure will likely require maintenance over the long term as weirs become occasionally clogged with trees or boulders are dislodged. Another risk of a structure this long is a fish's ability to make it this far. A NLF structure at Chain Dam will likely increase fish passage but at the size evaluated will not likely be able to pass full fish runs due to fatigue. Leaving the dam in place will continue to incur dam maintenance and provide minimal fish passage. Full removal will provide the most optimal fish passage and remove maintenance costs and thus is the recommended option for Chain Dam.

10.0 Sediment Mobility

The eventual transport of impounded sediments will be dependent on several factors including the amount of dam removed. Other factors include the storms that occur within the watershed and the river dimensions and particle size. Ultimately, this mobility comes down to two factors: competency and capacity. Capacity is a measurement of amount of bedload a given stream reach can transport (Bunte and Abt 2001), while competency is the measure of the size of particle that can be moved. Determination of Armoring, or when a resistant layer is formed in the channel bed is another aspect to identifying when a mobile bed stops massive sediment transport.

KCI conducted a sediment mobility analysis for the full removal and partial removal alternatives for Easton and Chain Dam. Sediment mobility was evaluated in three parts:

1. *Competence* – does the river have the power to entrain and mobilize the bed material or impounded sediments?
2. *Capacity* – Will the new channel have the ability to route sediments from upstream or will the new condition create aggradation or degradation?
3. *Armoring* – if the sediments mobilize how much of the sediment will erode before a stable stream bed is established?

10.1 Competence

Competence is defined as the ability of the hydraulic forces within a river to mobilize the grains comprising the stream bed. The hydraulic force in the stream channel that erodes the channel bed is the shear stress (τ_0). Equation 1 is used to compute the channel shear stress at a cross-section.

$$\tau_0 = \rho_w g R S_f \quad (1)$$

Where,

$$\rho_w = 1.94 \text{ slugs/ft}^3$$

$$g = 32.2 \text{ ft/sec}^2 \text{ gravitational acceleration}$$

R = hydraulic radius (ft)
 S_f = Slope of the energy grade line (ft/ft)

The shear stress can be dimensionally analyzed related to a mobile grain size with the critical shear stress (τ_c) equation (Equation 2), which quantifies the force required to erode a grain of size D.

$$\tau_c = \tau_{ci}^* (\rho_s - \rho_w) g D \quad (2)$$

Where,

ρ_s = 5.15 slugs/ft³ (quartz sediment)
 D = threshold grain size (ft)
 τ_{ci}^* = Shields number (0.06) or dimensionless critical shear stress (a scaling factor that typically ranges from 0.6 for uniform size sediment to 0.03 for sorted interlocking sediments).

By substituting τ_0 for τ_c , we can then solve for D to determine if the impounded sediments are mobile by comparing the computed D to the grain size distributions measured at the site (Equation 3). In general sediments that are larger than the computed D are not mobile and those smaller than the computed D are mobile.

$$D = \frac{\tau_0}{\tau_{ci}^* (\rho_s - \rho_w) g} \quad (3)$$

If the bed is determined to be mobile, degradation (loss of bed sediments) is expected; however, this degradation only occurs when the upstream sediment supply is limited such that the eroded sediments are not replaced at the same rate as they erode. In the case of the Easton Dam, Chain Dam likely serves to impound some sediment but not all. This is determined based on the general lack of sediments behind Chain Dam. This could only be a potential issue if Easton Dam were to be removed but not Chain Dam.

10.2 Capacity

Capacity is defined as the river's ability to transport a given sediment load. Given that bedload was not measured within the Lehigh River, we will rely on a dimensionless assessment of the sediment load (bedload flux) based solely upon an empirical relationship. Furthermore, it should be noted that the computed bedload flux is a representation of the sediment load that a river is capable of moving and not what it is actually moving. For example, downstream of a dam a river may have a high capacity, but no load; therefore, without calibration to a measured load, these computations should only be used for comparison and discussion purposes.

KCI employed the Meyer-Peter and Müller (1948) equation (Equations 4 and 5) to compute bedload flux because it applies to gravel bed rivers and the variables are easily measured or approximated for the study reach (Equation 4 and 5). The basic Meyer-Peter and Müller equation is a function of boundary shear, grain size, and sediment and fluid densities:

$$q^* = 8(\tau^* - 0.047)^{3/2} \quad (4)$$

Where,

τ^* = Critical dimensionless shear stress defined by Equation 5

$$\tau^* = \frac{\tau_0}{(s-1)\rho g D} \quad (5)$$

Where,

s = 2.65 specific weight of silicate sediments

D = Grain size (ft)

By comparing the bedload flux to that of an upstream supply reach, we can determine if the study reach is likely to degrade or aggrade or if the reach is in a state of dynamic equilibrium. If the bedload flux of the supply reach is greater than that of the study reach, sediments are expected to accumulate and the channel will aggrade. If it is less than the study reach we would expect supplied sediment to route through the study reach and degradation to occur. The bedload flux in the supply reach is similar to that of the study reach we would expect quasi-equilibrium.

10.3 Armoring

Armoring is defined as the coarsening of a stream bed as the result of the finer particles eroding from the bed matrix. Armoring typically occurs in stream beds that are poorly sorted such that the larger grains (non-mobile) are supported in a matrix of finer grains and not by each other. This is often the case with sediments behind dams, where an abrupt change in stream power as a result of the backwater condition causes the channel to drop its entire sediment load rather than sorting the materials.

KCI used the Borah (1989) equation (Equations 6 and 7) presented in the NEH 654.TS14 (NRCS 2007) to compute a depth to armoring (z_t). This relationship is based on armoring that occurred downstream of a dam, but the principles are applicable to this discussion.

$$z_t = \frac{D_x}{(1-e)P_x} - D_x \quad (6)$$

Where,

D_x = Armor grain size in feet (smallest non-mobile grain) determined by equation 3

e = porosity of bed material determined by Equation 6

P_x = Fraction of bed material coarser than D_x

$$e = 0.245 + \frac{0.0864}{(0.1D_{50})^{0.21}} \quad (7)$$

Where,

D_{50} = Median grain size of bed material in mm

Comparing the depth to armoring to the stream profile can show degree or risk of degradation if the sediment supply from upstream is insufficient in amount or size. If the depth to armoring is excessively large, the gradation of the existing materials is too fine for an armor layer to develop and will erode

downstream until a new local base level is reached. In the case of dam impoundments this is often a buried pre-dam stream bed or geologic control.

If the above assessments indicate that degradation is expected, the extent of degradation can then be predicted. Since Equations 1 through 6 rely on the same relationship between the shear stress (τ_0) and a grain size (D), we can substitute Equation 1 into the above equations to express them in terms of depth (R) and slope (S_f). This gives us the ability to solve for the depth required or slope required to maintain an immobile bed or balance sediment supply. By comparing these values to the site data we can predict the limits of degradation, identify boundary conditions, and discuss mitigation as necessary.

10.4 Analysis & Results

10.4.1 Easton Dam – Full Removal

For the initial evaluation at Easton Dam, the supply reach was considered to be within HEC-RAS stations 66-73 for average values of slope and depth for the 2-year event however the D_{50} used is from the Chain Dam lower impoundment particle data. This was done since the only particle data taken for Easton Dam was within a few hundred feet of the structure. Therefore the material from the lower impoundment from Chain Dam will be used as the Supply Reach's measured grain size. The study reaches for Easton are all downstream sections. The sections were broken into two reaches; the bridge transport reach is RAS stations 74-81, impoundment are RAS stations 82-87. It is expected that the bridge transport section will have a very large ability and capacity to move sediment since it is a very confined stretch of river. After the impoundment is the Downstream Reach which is represented by RAS stations 88-89. There was no particle data measured at the downstream area so depth to armoring will not be evaluated, but a threshold grain size can still be determined.

Table 10. Easton Dam - Full Removal Threshold & Mobility Determination

Reach	River Stations	Field Measured Grain Size (D_{50}) (mm)	Shear Stress (τ_0)	Threshold Grain Size (D) (mm)	Bedload Flux (q^*)	Depth to Armoring (z_t) (ft)
Upstream (Supply)	66-73	0.76	0.56	37	25.03	1.11
Bridge Transport	74-81	0.9	3.4	223	383.47	23.24
Impoundment	82-87	1.8*	1.82	119	149.80	12.22
Downstream	88-89	NA	1.95	128	165.84	NA

* Value is an average D_{50} of the results from Sample Points 19 and 20.

The threshold grain sizes for Supply and Study Reaches are greater than their D_{50} indicating the channel is competent to mobilize its own sediments. Bedload flux for all study reaches is greater than the supply reach. This indicates that all reaches are able to pass the sediment of the supply reach. It also indicates there is a chance of degradation. There is some existing armor made of Derrick Stone at the toe of the existing dam which will likely be needed to abate the calculations in depth to armoring. If this material is larger than the threshold size predicted no additional material would be required. If it is not at threshold size or greater, a grade control may be helpful in preventing large bed degradation immediately after dam removal. The scour estimates for the 3rd street Bridge are discussed in section 6.5 Scour Analysis,

but bed degradation could be limited by the armor layer that may have been detected through the depth to refusal at Sample Point 18. The countermeasures suggested could also control the depth to armoring calculations.

Based on the information determined in the sediment mobility analysis, existing thalweg and the depth to refusal data collected an estimate total quantity of sediment movement under full dam removal can be derived. Assuming an average channel width of 275 feet the estimate for sediment movement is 132,000 to 156,000 cubic yards. This amount will flush out over a series of storms and will likely take a few years to complete.

Table 11. Easton Dam - Partial Removal Threshold & Mobility Determination

Reach	River Stations	Field Measured Grain Size (D_{50}) (mm)	Shear Stress (τ_0)	Threshold Grain Size (D) (mm)	Bedload Flux (q^*)	Depth to Armoring (z_t) (ft)
Upstream (Supply)	66-73	0.76	0.67	44	32.78	1.33
Bridge Transport	74-81	0.9	2.63	172	260.36	17.96
Impoundment	82-87	1.8*	3.86	253	463.47	25.94
Downstream	88-89	NA	7.04	461	1144.22	NA

* Value is an average D_{50} of the results from sample points 19 and 20.

10.4.2 Easton Dam – Partial Removal

Sediment mobility under partial removal was evaluated for the 3% Rock Ramp HEC RAS results. The structure height for this partial removal is at elevation 152.5 feet and this is less than the 10 foot structure that will be discussed later. A higher structure will have slight differences to the bed mobility. All values of shear stress and bedload flux have increased in this scenario. However, it is only estimating the potential capacity and is not based on an actual load. The ability to degrade based on a large bedload flux in the transport reaches over the supply reaches will be buffered by the slight backwater effect of a ramp structure. However, the depth to armoring calculations indicate there is significant potential to downcut after removal if an armor layer is not uncovered within the impounded sediments. The threshold size at the downstream reach indicates a much larger stone than exists will be needed on a rock ramp structure. This size will likely also help in reducing the depth of armoring.

Overall, the full dam removal scenario will cause the most sediment movement due to a lack of backwater until the Delaware River. Minimal aggradation will be seen at any time downstream of Easton Dam due to the greater Delaware River. There is an existing sediment build up downstream of Easton Dam prior to the Delaware. Some sedimentation will likely occur in this vicinity but is not expected to last beyond a single flood event. Both the full and partial removal options may require added bed stability with large stones.

10.4.3 Chain Dam – Full Removal

For the initial evaluation at Chain Dam the supply reach was considered within HEC-RAS stations 1-9 for average values of slope and depth for the 2-year event. Sample Point 1 data was used for D_{50} particle data and the study reach was all downstream sections. The impoundment was broken into two reaches; the upper impoundment was RAS stations 10-27, lower impoundment RAS stations 28-38. The Downstream Reach which is represented by RAS stations 39-52. A comparison of the existing to

threshold sediments for the expected shear stress within each of these reaches indicates there is no mobilization in the expected Supply Reach. The threshold grain size is smaller than the existing D_{50} indicating the lack of competency to mobilize the bed. Without competency to mobilize the bed the capacity (bedload flux) cannot be evaluated.

Table 12. Chain Dam - Full Removal Threshold Determination

Reach	River Stations	Field Measured Grain Size (D_{50}) (mm)	Shear Stress (τ_0)	Threshold Grain Size (D) (mm)
Upstream (Supply)	1-9	44	0.43	28
Upper Impoundment	10-27	1.16	0.39	26
Lower Impoundment	28-38	0.76	0.77	51
Downstream	39-52	55	0.77	51

The threshold grain size for both the upper and lower impoundments are greater than their D_{50} indicating the channel is competent to mobilize its own sediments. An evaluation of the upper impoundment as the Supply Reach is computed for capacity of sediment transport. A study reaches bedload flux will be greater than the supply when it can fully transport all material brought into the reach. This can also indicate potential channel degradation if there is no armor layer or other grade control.

Table 13. Chain Dam - Full Removal Sediment Mobility Results

Reach	River Stations	Field Measured Grain Size (D_{50}) (mm)	Shear Stress (τ_0)	Threshold Grain Size (D) (mm)	Bedload Flux (q^*)	Depth to Armoring (z_t) (ft)
Upper Impoundment (Supply)	10-27	1.16	0.39	26	7.261	2.63
Lower Impoundment	28-38	0.76	0.77	51	21.420	5.28
Downstream	39-52	55	0.77	51	21.409	0.2

There is significant capacity in both the lower impoundment and the downstream reach at full dam removal. Since the D_{50} of the lower impoundment is less than the D_{50} at the upper impoundment the Downstream Reach will also have the capacity to transport material supplied from the Lower Impoundment. The depth to armoring is maximized in the lower impoundment where there is the greatest buildup of sediments. The previously discussed limit of refusal is at the approximate base elevation of the dam and could indicate a source of material similar to that of the downstream reach. That material is larger than the threshold size so is likely to reduce the depth to armoring to less than indicated from the calculations.

Based on the information determined in the sediment mobility analysis, existing thalweg, and the depth to refusal data collected an estimate total quantity of sediment movement under full dam removal can be derived. Assuming an average channel width of 250 feet the estimate for sediment movement is

395,000 to 565,000 cubic yards. This amount will flush out over a series of storms and will likely take numerous years to complete.

10.4.4 Chain Dam – Partial Removal

Partial removal for Chain Dam was also evaluated using the HEC-RAS results for the 3% rock ramp. At a partial removal there are several similarities but also a few differences to the Full Removal. The upstream reach once again was invalid for partial mobilization so the upper impoundment was used for the mobility assessment. Threshold grain size exceeds the field measured grain size within the impoundments but not that of the downstream reach.

Table 14. Chain Dam - Partial Removal 3% Rock Ramp Sediment Mobility Results

Reach	River Stations	Field Measured Grain Size (D_{50}) (mm)	Shear Stress (τ_0)	Threshold Grain Size (D) (mm)	Bedload Flux (q^*)	Depth to Armoring (z_t) (ft)
Upper Impoundment (Supply)	10-27	1.16	0.29	19	4.59	1.94
Lower Impoundment	28-38	0.76	0.6	39	14.47	4.1
Downstream	39-52	55	0.43	28	8.57	0.07

The partial removal analysis indicates the potential to transport material based on an assumed mobile bed. Actual transport will depend on the actual load from upstream. The bathymetry survey indicated that most of the sediments behind Chain Dam are at or lower than the Dam height under partial removal conditions. The presence of the dam equal or greater than the sediment height will have an effect on the overall evacuation of sediment. The depth to armoring calculations indicates minimal bed degradation will occur in a partial removal scenario.

The full removal scenario is anticipated to expose the most sediment to erosion. The release of these sediments to the downstream reach at Chain Dam is expected to cause temporary aggradation until the sediments from the impoundment are fully eroded. Once the impoundment is no longer a source of sediment, the bedload flux of the downstream reach will equalize to that of the supply reaches and sediments will be routed through the system.

11.0 Screening Level Scour Assessment

A screening level scour assessment was performed for the following seven structures crossing the Lehigh River upstream of the Easton Dam:

- (3rd Street) - Dr. George S. Smith Bridge - BMS ID: 48 0611 0180 0046
- (Eastern and Northern No. 77) Norfolk Southern Railroad Bridge Lehigh Valley Railroad
- Glendon Hill Road – BMS ID: 48 7302 0000 0001
- (25th Street) Glendon-Wilson Bridge – BMS ID: 48 2012 0160 0089
- Historic Bridge Pier at Chain Bridge
- (S.R. 33) Gene Hartzell Memorial Bridge – BMS ID: 48 0033 0004 0312

The intent of these assessments was to determine if an increase in scour potential in each location is likely in the event of removal of the Easton Dam and Chain Dam. As these scour assessments are only screening level, detailed calculations of scour depths have not been performed. The approach to the assessments was selected based upon the information and data available for each of the bridge crossings; this includes bridge inspection reports, bridge plans, and the results of hydraulic modeling of the subject reaches of the Lehigh River performed by Fuss & O'Neill.

The scour assessments were performed based on a 100-year flood of 78,900 cubic feet per second (cfs), which was obtained from USGS SIR 2008-5102, "Regression Equations for Estimating Flood Flows at Selected Recurrence Intervals for Ungaged Streams in Pennsylvania." This document is more recent than the flows provided by FEMA. Changes anticipated in the hydraulics of the Lehigh River, such as flow depths and velocities, were obtained from hydraulic modeling of the existing and alternative conditions, as described previously.

11.1 Analysis & Results

Dr. George S. Smith Bridge

The Dr. George S. Smith Bridge crosses the Lehigh River in approximately the northwest-southeast direction. It consists of three spans of reinforced concrete arches. The piers supporting two of the arches are located in the main channel of the River. Results of the HEC-RAS analyses indicate that both abutments are also located inside of the 100-year flood limits. Plans for the bridge (S-17759), provided by the Pennsylvania Department of Transportation (PennDOT), indicate that the abutments are supported on erodible rock and the piers are partially supported on both soil and erodible rock.

Norfolk Southern Railroad Bridge (over Dr. George S. Smith Bridge)

The Norfolk Southern Railroad Bridge is positioned such that it crosses over the Dr. George S. Smith Bridge and the Lehigh River in the east-west direction. The entire bridge is roughly 975 feet long with eleven steel truss spans supported on two abutments and ten piers. Only the three easternmost bridge spans, however, crosses the Lehigh River and the Dr. George S. Smith Bridge. The remaining eight spans are located west of the River and carry the railroad over Lehigh Drive and a paved parking lot.

Two of the reinforced concrete piers that support the eastern three spans are in the channel of the River on either side of the Dr. George S. Smith Bridge. Although the piers of both bridges are roughly oriented with the direction of flow in the River, they are not parallel with each other. Relative to the piers on the Dr. George S. Smith Bridge, the piers on the railroad bridge are skewed slightly in the northeast-southwest direction.

Plans were requested from the owner of the bridge, but were not available for review as part of this scour assessment. It is not known if the piers are pile supported.

Lehigh Valley Railroad Bridge

Similar to the Norfolk Southern Bridge, the Lehigh Valley Railroad Bridge consists of multiple spans of steel trusses, but only three of these cross the Lehigh River. The three spans are supported on four piers, two of which are located in the main channel of the River, with the remaining two located in the left and right channel overbanks. All four of the piers are located within the 100-year flood limits. Plans of the bridge were not available for review as part of this scour assessment. It is not known if the piers are pile supported.

Glendon Hill Road Bridge:

The Glendon Hill Road Bridge is a three span steel truss bridge supported on two abutments and two piers. Each pier is constructed from stone masonry and is located in the main channel of the River. The right and left abutments are also located within the 100-year flood limits. Plans for this bridge could not be obtained from PennDOT. It is not known if the abutments or the piers are pile supported.

Glendon-Wilson Bridge

The Glendon-Wilson Bridge consists of eight spans of steel girders supported on two abutments and seven piers. Each of the piers consists of two concrete columns. The results of the HEC-RAS analyses indicate that six of the piers are located within the 100-year flood limits. The plans (PennDOT S-8536) indicate that both of the abutments and all of the piers are supported on steel H-piles.

Historic Bridge Pier –Chain Bridge

The Chain Bridge was historically used for pedestrian and animal crossing over the Lehigh River. Remnants of the bridge today include a stone masonry pier located in the main channel of the River. Little information is known today concerning the construction of the pier or the nature of the material that it is founded on.

Gene Hartzell Memorial Bridge

The Gene Hartzell Memorial Bridge consists of six spans of steel trusses supported on two abutments and five piers. Each of the piers consists of two concrete columns. Plans for the bridge (Penn DOT S-21421) indicate that each is pile supported. All of the piers are located outside of the main channel of the River and are not inundated during normal flow conditions, but two of the piers are located within the 100-year flood limits.

11.2 Previous Bridge Inspections

Inspection reports were obtained from the Pennsylvania Department of Transportation (PennDOT) for the Dr. George S. Smith Bridge, Glendon Hill Road Bridge, Glendon-Wilson Bridge, and the Gene Hartzell Memorial Bridge. A similar request was made from the owners of the Norfolk Southern Railroad Bridge and the Lehigh Valley Railroad Bridge, however, no information is available at this time. There is no known information for the historic pier at the former Chain Bridge.

- ***Dr. George S. Smith Bridge:*** An underwater inspection was performed by Pickering, Corts & Summerson, Inc. on June 22, 2010. The inspection focused on the piers. The south and north piers are identified in the inspection report as Pier 1 and Pier 2, respectively. The tops of the footings were reported to be partially exposed at both piers. Riprap has been reported to have been placed near the upstream noses of the piers.
- ***Glendon Hill Road Bridge:*** An underwater inspection was performed by Pickering, Corts & Summerson, Inc. on June 21, 2010. The inspection noted that the concrete footing of one of the piers (identified in the inspection report as “Pier 1”) was partially exposed around its entire perimeter and an area of undermining seven feet in length was located along the mid-point of its western edge (left edge looking in the downstream direction). The inspection report also reports that grout bags were installed at Pier 1 in 1998 along the entire eastern edge, upstream nose, and the upstream portion of the western edge. Similar scour damage and voids were reported at Pier 2. Grout bags were also installed at this location along the entire east and west edges and at the upstream nose.

- **Glendon-Wilson Bridge:** An underwater inspection report by Pickering, Corts & Summerson, Inc., dated June 21, 2010, focused on the middle pier, identified in the inspection report and in the bridge plans (S-8536) as “Pier 4”, which is inundated during normal flow conditions. The inspection reported only minor scour around the upstream noses of the columns and a minimum of 2.4 feet of material between the streambed and top of the footings.
- **Gene Hartzell Memorial Bridge:** A bridge inspection performed by AECOM on January 14, 2010 did not note scour damage at any of the piers. All of the piers are located outside of the main channel of the River; therefore, an underwater inspection was not necessary.

11.3 Comparison of Existing & Alternative Conditions

Output from the hydraulic model was used to compare existing conditions with full dam removal conditions. As noted previously, the proposed condition HEC-RAS model conservatively assumed the 100-year flood on the Lehigh River occurs coincident with normal (i.e. non-flood) conditions in the Delaware River.

Comparison of the results of the existing and alternative conditions HEC-RAS models indicate that the flow velocities upstream and downstream of all of the structures, except the Dr. George S. Smith Bridge and the historic Chain Bridge pier, will increase between 0.5 – 1.3 feet per second for alternative conditions. The corresponding flow velocities at the Chain Bridge Pier increase by as much as 3.8 feet per second and at the Dr. S. Smith Bridge by as much as 5.3 feet per second.

The depths of flow are reduced at all of the bridge crossings. The greatest change occurs at the Dr. George S. Smith/Norfolk Southern Railroad Bridge, where the flow depth is reduced by 7.0 feet and 8.5 feet upstream and downstream of the structures, respectively. The flow depths at the Lehigh Valley Railroad Bridge are reduced by 4.6 feet upstream and 5.0 feet downstream. At the Chain Bridge pier, the depths are reduced by 3.0 feet upstream and 5.0 feet downstream. At the remainder of the bridge crossings the flow depths are reduced by 1.0 – 1.5 feet.

11.4 Assessment of Scour Potential

A screening level assessment of scour potential was performed for each the bridge crossings. This included limited computations (as discussed below) and detailed scour calculations were not performed. Scour mechanisms at bridges are defined in two categories: local scour at abutments and piers and general scour due to the contraction of flow through the bridge opening. Local scour at piers and contraction scour through the bridge openings can occur at any of the structures; therefore, these were the focus of the scour assessments. The results of the HEC-RAS model indicate the abutments at the Dr. George S. Smith Bridge and the Glendon Hill Road Bridge are located in the 100-year flood boundaries. As such, there is a potential for increased local scour to occur at the abutments of these structures as well as the piers if the dam height is lowered.

11.4.1 Contraction Scour

An important parameter for the computations for contraction scour is the gradation of the streambed material. Although some general information on the composition of the bed material is provided in the underwater inspection reports, the data is not detailed enough for use in calculating the potential contraction scour at the bridge crossings.

In lieu of contraction scour computations, a comparison was made of the ability of the River to transport streambed material from the existing to alternative conditions. The following equation by Laursen was used:

$$V_c = K_u y_1^{1/6} D_{50}^{1/3}$$

or

$$D_{50} = \left[\frac{V_c}{K_u y_1^{1/6}} \right]^3$$

Where:

V_c = Critical velocity above which the mean bed material size will be transported (ft/sec)

y_1 = Average depth of flow in the approach section (ft)

D_{50} = Mean bed material size

K_u = 11.17 (English Units)

The mean bed material size (D_{50}) that can be transported at each location was calculated in the existing and proposed conditions using the flow depths and velocities from the results of the corresponding HEC-RAS models. The results are summarized in the following table:

Table 15. Mean Bed Material Mobilization

Location	Existing Transportable D_{50} (feet)	Alternative Transportable D_{50} (feet)	ΔD_{50} (feet)	ΔD_{50} (inches)	% Increase in D_{50}
Dr. George S. Smith / Norfolk Southern Railroad Bridge	0.3	1.0	0.7	8.4	233
Lehigh Valley Railroad Bridge	0.03	0.2	0.17	2.0	567
Glendon Hill Road Bridge	0.18	0.24	0.06	0.7	33
Glendon-Wilson Bridge	0.06	0.09	0.03	0.4	50
Chain Bridge - Historic Pier	0.02	0.10	0.08	1.0	400
Gene Hartzell Memorial Bridge	0.03	0.04	0.01	0.1	33

With the exception of the Dr. George S. Smith/Norfolk Southern Railroad Bridge, the increases in the transportable mean bed material size from the existing to alternative conditions are small. However, the impact this will have on the potential increase in contraction scour is dependent on the existing gradation of the bed material. It is notable that the ability of the River to transport material is increased in the alternative condition at all locations. A detailed analysis of contraction scour would be required to estimate the degree of additional scour and whether an increase would be problematic.

11.4.2 Local Pier Scour

Detailed calculations for pier scour cannot be performed without data on the gradation of the streambed material or the condition of the streambed, but for the purposes of these assessments the Colorado State University (CSU) Equation was used to qualitatively assess the likelihood of increased scour potential at the piers from the existing to alternative conditions. The CSU pier scour equation is:

$$y_s = 2.0 K_1 K_2 K_3 K_4 a^{0.65} y_1^{0.35} Fr_1^{0.43}$$

Where:

y_s = Depth of scour (ft)
 K_1 = Correction factor for pier nose shape
 K_2 = Correction factor for angle of attack of flow
 K_3 = Correction factor for bed condition
 K_4 = Correction factor for armoring of bed material
 a = pier width (ft)
 y_1 = Flow depth directly upstream of pier (ft)
 Fr_1 = Froude number directly upstream of pier

All of the variables in the right side of the equation will not change from the existing to alternative conditions except for y_1 and Fr_1 and can be treated as a single constant. The y_1 and Fr_1 variables can be obtained for both scenarios from the results of the HEC-RAS models. An increase in the multiple of the two variables from the existing to the alternative conditions would also indicate an increase in the scour potential, but will not provide scour depths. As this is the best available information, this approach was applied to each of the bridge crossings. The results are summarized in the table below:

Table 16. Predicted Increase in Scour

Location	Existing $y_1^{0.35} \times Fr_1^{0.43}$	Alternative $y_1^{0.35} \times Fr_1^{0.43}$	$\Delta y_1^{0.35} \times Fr_1^{0.43}$	% Increase
Dr. George S. Smith / Norfolk Southern Railroad Bridge	2.1	2.3	0.2	10
Lehigh Valley Railroad Bridge	1.65	1.74	0.1	5
Glendon Hill Road Bridge	2.0	2.1	0.1	5
Glendon-Wilson Bridge	2.0	2.03	0.03	1
Chain Bridge - Historic Pier	1.6	1.9	0.3	19
Gene Hartzell Memorial Bridge	1.4	1.4	0.0	0

Note that this analysis was not performed for each individual pier at the bridges as would be the case in a detailed scour assessment. As this is a screening level assessment, the average upstream flow depth and Froude number was applied to all of the piers at each bridge, giving an average result. While the actual computed scour depths will depend on the values applied to the remaining variables in the equation, the above results do indicate that the potential pier scour is increased at all locations but the Gene Hartzell Memorial Bridge.

11.4.3 Alternatives for Scour Protection

The scour assessment performed was qualitative in nature. It provides a general assessment of whether removal of Easton Dam and Chain Dam would increase scour potential at bridges in the study reach, but does not quantify this increase or provide detailed calculation of how scour potential might differ at individual piers or abutments. A detailed analysis would be required to understand the full effect of alternative changes on existing infrastructure, and should be completed as part of final project design.

As such it should be understood that the alternatives for scour protection provided below are conceptual in nature and not based on detailed analysis.

Traditional scour countermeasures can be categorized into the following groups:

- Armoring Countermeasures
- Structural Countermeasures
- Biological Countermeasures

Armoring countermeasures can include a variety of materials and installation methods. They are categorized as either flexible or rigid. Flexible countermeasures include, but are not limited to, riprap blankets, articulated concrete block mats, and gabion mattresses. Rigid countermeasures include reinforced concrete, grouted riprap, or grout filled bags. Structural countermeasures include modification of pier geometry and strengthening of the foundations by the use of piles, micropiles, or extending the footings further below the streambed.

Biological countermeasures, such as biotechnical/bioengineering stabilization, have been specifically addressed in this assessment as an alternative to armoring or structural countermeasures because they are generally only recommended for channel banks and are not recommended where a failure of the countermeasure could lead to a failure of the bridge.

11.5 Conclusions

The existing scour damage, if any, or the potential for scour damage, increases for the potential scour in the alternative condition, and alternatives for scour protection for each of the bridges are summarized below. While this screening level assessment is useful in the preliminary identification of potential scour problems at the bridges, detailed scour analyses should ultimately be performed at the final design stage for any bridge crossing or other structure that could be impacted in the event of removal of Easton Dam and Chain Dam.

Dr. George S. Smith Bridge

An underwater inspection report for the bridge noted existing scour damage at both of the bridge piers, but not at the abutments. The removal of Easton Dam, if that option is ultimately pursued, will result in decreased backwater at the bridge and will increase flow velocities in the River. The results of the screening level assessment indicate that the potential for local scour at the piers will be increased. They also show that the mean size of the transportable streambed material will increase from 0.3 feet to 1.0 feet, which could lead to increased contraction scour through the bridge opening.

In consideration of the existing scour problems at this bridge and the increased scour potential in the alternative condition, installation of scour countermeasures will very likely be required. Plans for the bridge (PennDOT S-17759) indicate that the abutments are supported on erodible rock and the piers are partially supported on both soil and erodible rock. Because the substructure elements are not currently pile supported consideration should be given to the use of micropiles as an alternative to armoring countermeasures.

Norfolk Southern Railroad Bridge (over Dr. George S. Smith Bridge)

Underwater inspection reports and plans for this bridge were not available for review as part of this assessment. Therefore, it is not known if there is currently scour damage at either of the piers. Additionally, there is no information regarding the nature of the material that the piers are founded on, or if they are supported by piles. As with the results of the screening level assessment of the Dr. George

S. Smith Bridge, the potential for contraction scour and local pier scour is indicated to increase in the alternative condition.

Hydraulic modeling predicts an increase of approximately 8 feet per second in flow velocities for the alternative condition. As such, installation of scour countermeasures will likely be required. Alternatives for countermeasures include micropiles and armoring of the bed using materials such as riprap/grouted riprap.

Lehigh Valley Railroad Bridge

Similar to the Norfolk Southern Bridge, underwater inspection reports and plans for this bridge were not available for review as part of this assessment. Therefore, it is not known if there is currently scour damage at the piers. Additionally, there is no information regarding the nature of the material that the piers are founded on, or if they are supported by piles.

The results of this screening level assessment indicate an increase in scour potential from the existing to alternative conditions. Therefore, installation of scour countermeasures may be required. If necessary, alternatives for countermeasures include micropiles and armoring of the bed using materials such as riprap/grouted riprap.

Glendon Hill Road Bridge

The most recent underwater inspection report for this bridge indicated scour damage at both piers. It was also noted in the report that grout bags were previously installed at the piers in an effort to address the scour damage. The results of this assessment indicate that the scour potential at the bridge will be increased in the alternative conditions. As such, the installation of additional scour countermeasures may be required. Countermeasures could include increasing the extent of the existing grout bags, placement of riprap, or installation of micropiles.

Glendon-Wilson Bridge

Minor scour at two of the piers has been noted in recent inspections reports, but the footings were not exposed and the damage was indicated to be minimal. Plans for the bridge (PennDOT S-8536) indicate that both of the abutments and all of the piers are supported on steel H-piles. Since the results of this assessment indicate that the scour potential at the bridge will be increased in the alternative conditions, scour armoring countermeasures, such as riprap, may be required. In general, exposure of H-piles to scour is not permitted.

Historic Bridge Pier –Chain Bridge

Underwater inspection reports and plans for this bridge were not available for review as part of this assessment. Therefore, it is not known if there is currently scour damage at the pier. Additionally, there is no information regarding the nature of the material that the pier is founded on.

The results of this assessment indicate that the scour potential at the pier will be increased in the alternative conditions. As such, the installation of additional scour countermeasures may be required. In consideration of the age of the stone masonry structure, installation of micropiles could be difficult; however, armoring with riprap or grouted riprap could be utilized. Further evaluation of the structure may determine that micropiles or other approaches are viable.

Gene Hartzell Memorial Bridge

Plans for the bridge (Penn DOT S-21421) indicate that each pier is pile supported. Only two of the piers are located within the 100-year flood limits. Scour damage at the piers was not indicated in the recent bridge inspection reports. The results of this screening level assessment indicate that the increase in potential scour will be minimal. Based on this information, it is likely that additional bridge scour countermeasures will not be required.

12.0 Canal Watering Options

Two historic towpath canals would be potentially impacted by full or partial removal of the Easton and Chain Dams: the Delaware Canal and the Lehigh Canal. Due to their historic importance, the provision of water maintenance to these canals has been requested as part of any proposed change to the dams. The inlets of these canals are located immediately upstream of the Easton and Chain Dams, respectively, and are kept full by the backwater provided by the dams. Any alteration to the dams resulting in a reduction of the spillway elevation will require water to be supplied to these canals in some other way, e.g. via pumping or a gravity flow pipe system.

12.1 Delaware Canal

According to DCNR literature, the 60-mile Delaware Canal is the only remaining continuously intact canal of the great towpath canal building era of the early and mid-19th century. It was originally completed in 1832 and is currently maintained by DCNR staff as part of the Delaware Canal State Park. Source water for approximately half of the length of the canal is supplied by the Easton Dam. The remaining canal length is supplied from a separate inlet.

Fuss & O'Neill contacted Mr. Richard Dalton of the Delaware Canal State Park, to discuss canal operational procedures. Mr. Dalton described repeated setbacks in recent years due to flood damage in 2004, 2005, 2006, and 2011. Much of the canal is currently drained pending repairs, although a cofferdam and pump were installed to maintain enough water in a 3-mile section to operate the mule drawn canal boat rides. Under normal operations, the knife gate at the entrance to the canal is kept open to feed the 30-mile length of canal from the Easton Dam downstream to New Hope. Besides loss due to seepage and evaporation, water is lost from the canal through imperfectly sealed waste gates. A past effort by the Friends of the Delaware Canal to pump water into the canal at the intersection of Routes 212 and 611 in Durham was halted because it did not provide water sufficient to conduct mule drawn boat rides for the public.

12.2 Lehigh Canal

The Lehigh Canal was completed in 1829 with a total length of 46 miles, and was the last fully functioning towpath canal in North America. The Easton section of the canal is maintained by the National Canal Museum. Source water for a 2.5-mile section of the canal is supplied by the Chain Dam.

12.3 Source Water Requirements

Detailed information regarding typical inflow rates, seepage rates, evaporation rates, and pumping rates for the canals was not available for this analysis. However, methods were used to estimate how much water is required to keep the canals supplied and operational. It was assumed that water supply would need to replace water lost to seepage, evaporation, and leakage at waste gates. Because the downstream end of each canal typically remains closed off, water for "flow-through" was assumed to be negligible.

Using guidance provided in “Estimating Seepage Losses from Canal Systems” (R.V. Worstell, Journal of the Irrigation and Drainage Division, March 1976), a seepage loss rate of 0.5 feet per day was assumed for the clay-lined channels. Assuming an average width of 25 feet and a length of 30 miles, a loss rate of 10,300 gallons per minute (gpm) was calculated for the Delaware Canal. Based on an assumed average width of 50 feet and a canal length of 2.3 miles, a loss rate of 1,600 gpm was calculated for the Lehigh Canal.

Evaporation losses were found to be relatively negligible. Assuming an evaporation rate of 0.2 in/day and a surface area based on the width and lengths described above, the loss rate was estimated to be 340 gpm and 50 gpm for the Delaware and Lehigh Canals, respectively. Leakage through the waste gates was likewise found to be small in comparison to seepage losses, and was estimated to be approximately 580 gpm and 45 gpm, respectively.

Total required water supply was rounded up to 12,000 gpm for the Delaware Canal and 1,800 gpm for the Lehigh Canal to provide additional capacity for initial filling. These are the rates which were assumed to be required by pumping or gravity systems replacing the water supplied by the two dams.

12.4 Source Water Alternatives

The two canals are owned and operated by separate entities. Each of these will ultimately choose what watering option(s) they are willing to pursue. Nevertheless, some of the potential alternatives would require coordination between the two canals. For this reason, at this conceptual stage alternative scenarios were evaluated holistically, treating the watering of both canals as part of a joint project.

Five alternatives for canal source water were considered. These alternatives were conceptual in nature and did not include detailed design.

12.4.1 Alternatives Considered

The considered alternatives listed here are shown in Appendix F.

1. One small pumping station, one large pumping station – This alternative assumes that a smaller pumping station will be required to supply the Lehigh Canal and a large pumping station to supply the Delaware Canal. These two stations would be located near the upstream end of each canal.
2. Eleven small pumping stations – This alternative assumes a distributed approach wherein one small pumping station is provided for the Lehigh Canal, and ten more pumping stations are distributed along the 30-mile length of the Delaware Canal.
3. One large pumping station, one 0.9-mile 42” conduit – For this alternative a large pumping station would be provided near the inlet of the Lehigh Canal. A large pipe, on the order of 42 inches in diameter, would convey flows by gravity from the downstream end of the Lehigh Canal to the upstream end of the Delaware Canal.
4. One 3.1-mile 48” conduit, one 20-mile 24” conduit – Under this alternative both canals would be fed by gravity via individual conduits, which would be extended far enough upstream to intercept the flow. Pipe sizes would be on the order of 48 inches in diameter for the Delaware Canal and 24 inches for the Lehigh Canal.
5. One 8.7-mile 48” conduit, one 0.9-mile 42” conduit – This is a combination of the conduits in alternatives 3 and 4. Under this alternative flow sufficient for both canals would be fed into the Lehigh Canal by gravity via a conduit, which would be extended far enough upstream to intercept the flow. This pipe would be on the order of 48 inches in diameter. A second pipe, on

the order of 42 inches in diameter, would then convey flows by gravity from the downstream end of the Lehigh Canal to the upstream end of the Delaware Canal.

12.5 Discussion of Alternatives

For alternatives 1 through 3 where a pump option is used, pumping stations need to provide for the screening of debris, the construction of an adequate sump area, and armoring or energy dissipation in the discharge area. The type and size of the pumps and housing structure are to be determined in future design. Power would need to be provided, and ongoing maintenance is required.

For alternatives 3 through 5 where a gravity option is used, water must be diverted from the river far enough upstream to be at an elevation higher than the canal invert, in addition to compensating for the effects of friction loss in the conduit or channel. If a conduit is used, flow must have a velocity sufficient to prevent sedimentation inside the pipe. Because the lower Lehigh River is a relatively flat reach, achieving this elevation gain is a challenge and conduits must be extended quite far upstream. In addition, the high level of development along the river means that the cost of resolving conflicts with utilities, roadways, bridges, and railroad alignments is expected to be very high. In addition it appears that bedrock outcroppings may be prevalent in some areas, most notably in the area near the 3rd Street Bridge.

12.6 Opinion of Costs

The following conceptual order-of-magnitude opinions of cost have been developed for Alternatives 1, 2, and 3 as described above. The costs shown herein are based on a limited investigation and are provided for general information only. They should not be considered an engineer's estimate, as construction costs may be less or considerably more than indicated. Opinions of cost were not developed for Alternatives 4 and 5, as these alternatives were developed for information only and are considered less feasible than the others. The opinions of cost do not include operation and maintenance costs; such costs would be determined based on a more detailed design of a selected alternative, including pump selection.

Table 17. Canal Watering Costs

Source Water Alternative	Order of Magnitude Range of Construction Cost
Alternative 1: 1 small pumping station + 1 large pumping station	\$1,200,000 to \$2,600,000
Alternative 2: 11 small pumping stations	\$2,500,000 to \$5,400,000
Alternative 3: 1 large pumping station, 1 0.9-mile RCP conduit	\$3,000,000 to \$6,400,000

12.7 Opinion of Operation and Maintenance Costs

We have approximated ongoing operation and maintenance (O&M) costs for supplemental source water supply pumping stations at the Lehigh Canal and Delaware Canal that would be employed in the event of removal of the Easton Dam and Chain Dam. No design of pumping stations has been completed at this time, so these numbers are not based on detailed information about specific pumps, final design flows, or operational procedures.

We previously estimated that inflows of approximately 1,800 gallons per minute (gpm) and 12,000 gpm would be required to keep the Lehigh and Delaware Canals watered, respectively. Order-of-magnitude construction costs were developed for several conceptual alternatives for canal water supply, including:

- Alternative 1: One 1,800 gpm pumping station for Lehigh Canal + one 12,000 gpm pumping station for Delaware Canal
- Alternative 2: One 1,800 gpm pumping station for Lehigh Canal + ten 1,200 gpm pumping stations for Delaware Canal
- Alternative 3: One 13,800 gpm pumping station for both canals, with a large gravity pipe between the canals.

In order to estimate annual O&M costs for pumping stations of these sizes, we utilized equations presented in a report entitled “Assessing Opportunities for Municipal Wastewater Reuse in the Metropolitan Chicago Area,” written in November 2011 by Paul R. Anderson and Yi Meng of the Illinois Institute of Technology Department of Chemical and Environmental Engineering. These equations are based on pumping station design flow and were originally developed to estimate O&M costs for low lift sewage pumping stations with an assumed service life of 15 years. Operation costs include labor, preventive maintenance, and minor repairs; materials costs include replacement parts, major repair work, and electrical power costs. The equations were adapted to account for an assumed total dynamic head (TDH) of 30 feet, and converted to 2013 dollars.

The results of this estimation are presented in the table below for the various pumping stations, for both year-round operation and operation for only 6 months of the year. As a simplifying assumption, 6-month costs are assumed to be half of year-round costs. An Order of Magnitude Opinion of Probable Cost range of minus 30 percent to plus 50 percent of the calculated results is provided.

Table 18. Pump O&M Costs

Design Flow (gpm)	O&M Cost for 6-Month Operation	O&M Cost for Year-Round Operation
1,200	\$18,000 - \$38,000	\$35,000 - \$76,000
1,800	\$22,000 - \$47,000	\$44,000 - \$93,000
12,000	\$91,000 - \$195,000	\$182,000 - \$389,000
13,800	\$103,000 - \$221,000	\$206,000 - \$442,000

Using these values and summing the component stations for each of the three conceptual alternatives, we obtain the following. Note that the costs for Alternative 3 do not include any ongoing O&M costs associated with the large conduit between canals.

Table 19. Collective O&M Costs

Conceptual Alternative	O&M Cost for 6-Month Operation	O&M Cost for Year-Round Operation
Alt 1	\$110,000 - \$240,000	\$230,000 - \$480,000
Alt 2	\$200,000 - \$430,000	\$400,000 - \$850,000
Alt 3	\$100,000 - \$220,000	\$210,000 - \$440,000

As noted above, these costs are not based on an engineering design and are for planning purposes only.

13.0 Summary

A consolidated summary sheet of the evaluated options is presented below. Each of the options is presented with several evaluation criteria, merits, and potential impacts to associated resources and infrastructure, as well preliminary order of magnitude cost of implementation of that option (presented in millions of dollars). The costs developed for these options take in to account the need for each of the criteria presented, however KCI has not factored in to these costs the supplemental canal watering options presented previously. The costs shown herein are based on a limited investigation and are provided for general information only. They should not be considered an engineer's estimate, as construction costs may be less or considerably more than indicated.

The selection of a specific option as the "best" option is not provided, however a recommended options is offered in section 14.0 of this report. Each option does have to be fairly evaluated for its merits and associated challenges. Successful fish passage at either Easton or Chain Dam is one of a considerable cost would be incurred; however the benefits to the species and the Lehigh River as a premier fishery for future generations to come is immeasurable. A list of the fish passage options and the associated infrastructure impacts is included below (with the table Legend following):

Table 20. Options Summary

	Provides Passage	Rock Structure Required	Bed Protection Required	Scour Protection Required	Canal Water Impacts	Sewer Line Impacts	Permits	Range of Costs (in \$Millions)	
EASTON DAM									
Partial Vertical Removal with Nature- Like Fishway Option 1 (Not Feasible)	✓	✓	X	✓	✓**	O	A	3.4	4.7
Partial Vertical Removal with Nature- Like Fishway Option 2	✓	✓	X	✓	✓**	O	A	9.8	13.8
Partial Horizontal Removal with Nature-Like Fishway	✓	✓	X	✓	O	O	A	4.8	6.7
Full Height Dam with a Nature- Like Fishway	X	✓	X	O	X	✓	A	7.3	10.3
No Action	X	X	X	O	X	X	*	*	*
Full Dam Removal	✓	X	O	✓	✓**	✓	B	4.5	6.4
CHAIN DAM									
Partial Vertical Removal Nature-like Fishway	✓	✓	X	X	✓**	N/A	A	4.5	6.3
Partial Vertical and Horizontal Removal with Nature-Like Fishway	✓	✓	X	X	✓**	N/A	A	8	11.2
No Action	X	X	X	X	X	N/A	*	*	*
Full Dam Removal	✓	X	X	X	✓**	N/A	B	3.4	4.8

*** "No Action" has no cost listed however the cost for dam maintenance, canal entry dredging, fish ladder maintenance as well as all liability concerns, continue.**

**** Canal Watering is necessary as such the canal watering selected option also must be added to the range of costs presented once one of those selected options is selected.**

Legend	
✓	Yes
O	Partial (More Study Needed)
N/A	Not Applicable to Location
X	No

Each of the options presented will involve impacts to regulated and jurisdictional resources under the purview of several local, state and federal regulatory agencies. In an effort to capture the major

components of a permitting scenario for each project, KCI has developed the table below. This is referenced as Scenario A or Scenario B in the Table 19 above.

Table 21. Permitting

Scenario A	Scenario B
Joint Permit Application USACE Clean Water Section 404 Permits to Discharge Dredged or Fill Material Act 14 Notification Cultural Resources Notice (PHMC Review Letter) Pennsylvania Natural Diversity Inventory Clearance Site Plans (Cross Sections/profiles/details) Project Narrative Environmental Assessment Hydrologic and Hydraulic Analysis Stormwater Management Consistency letter Floodplain Management Analysis Erosion and Sedimentation Control Plan Risk Assessment PE Seal of Certification Alternative Analysis Mitigation Plan PA Fish and Boat Drawdown Application Local Municipal Demolition / Construction Permits	Dam Removal Permit (25 PA Code Ch 105.12(a)(16)) Site Plans (Cross Sections/Profiles/Details) PA Fish and Boat Drawdown Application Act 14 Notification Pennsylvania Natural Diversity Inventory Clearance Project Narrative Local Municipal Demolition / Construction Permit Erosion and Sedimentation Control Plan PA Fish and Boat Drawdown Application
Section 10 Permit USACE Joint Aquatic Resources Permit Application (JARPA)	Section 10 Permit USACE Joint Aquatic Resources Permit Application (JARPA)

14.0 Recommended Option

14.1 Discussion of the Recommended Option

The recommended option which has the greatest chance of success for both Easton and Chain Dam is Full Dam Removal. Other options that were evaluated are were either not feasible, not achieving fish passage goals, or simply less desirable due to other available options. Full Dam Removal for both dams, while perhaps not the least costly option, does not continue the perpetuation of costs the other options presented and ensures the unimpeded passage of fish to a 100 percent level. It also provide guaranteed successful fish passage. If both Easton and Chain dams were removed or significantly altered to provide fish passage it would provide for nearly 17 miles of restored fishery to the base of the Hamilton Street Dam located in Allentown.

By selecting the Full Dam Removal option operation and maintenance concerns for each dam are eliminated, and it eliminates all the liability and safety concerns associated with each dam for each of the owners. It does however add in the need for supplemental water supply for the canals as the Easton and Chain Dam provide source water to the Delaware and Lehigh Canals respectively. The operation and maintenance cost associated with a gravity flow system or via pumping would be incurred, however those costs would be partially offset once pumps are installed by not having the dam maintenance costs added to canal operation and maintenance over time.

Additionally all dams have a lifespan and dams were not intended to be permanent structures. If a dam breach were to occur at some point in time it is perhaps unlikely that the dam would be permitted to be rebuilt. This may be due to the fact that the nature and purpose that the dam was constructed for has since been removed or significantly altered since the dams were installed. In these ever challenging and economic times, securing funding for reconstruction efforts could also prove to be very difficult.

15.0 References

- Aadland, L.P. 2010. Reconnecting Rivers: Natural Channel Design in Dam Removals and Fish Passage. Minnesota Department of Natural Resources, Division of Ecological Resources Stream Habitat Program. 191 pp
- Barbour, M.T., Gerritsen, J., Snyder, B.D. and Stribling, J.B. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. Second edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington.
- Buffington, J.M., and D.R. Montgomery. 1997. A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers, *Water Resources Research*, 33:1993-2029.
- Bunte, K. and S.R. Abt. 2001 Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel and Cobble-Bed Streams for Analysis in Sediment Transport, Hydraulics, and Streambed Monitoring. United States Department of Agriculture, Forest Service Rocky Mountain Research Station. GTR RMRS-GTR-74, pp 380.
- Federal Emergency Management Agency, April 6, 2001, Flood Insurance Study, Northampton County, Pennsylvania (All Jurisdictions).
- Google. 2012. "Google Earth (Version 6)." Available at www.google.com/earth/download/ge/agree.html. Accessed February 2012.
- Meyer-Peter, E. and Müller, R. 1948. Formulas for Bedload Transport. In: *Proceedings of the 2nd Congress IAHR*, Stockholm, Sweden, pp. 39-64.
- Natural Resources Conservation Service (NRCS). "Web Soil Survey Release 2.3 Revision." December 6, 2011. United States Department of Agriculture. Available at: www.websoilsurvey.nrcs.usda.gov. Accessed February 15, 2012.
- Natural Resource Conservation Service. 2007. Part 654 National Engineering Handbook. Stream Restoration Design. 210-VI-NEH.
- Pennsylvania Department of Conservation and Natural Resources, Delaware Canal State Park website. Available at: <http://www.dcnr.state.pa.us/stateparks/findapark/delawarecanal/index.htm>. Accessed February 16, 2012.
- Pettyjohn, W.A., and Henning, Roger, 1979, Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio: Ohio State University Water Resources Center Project Completion Report Number 552, pp 323.
- Roland, M.A., and Stuckey, M.H., 2008, Regression equations for estimating flood flows at selected recurrence intervals for ungaged streams in Pennsylvania: U.S. Geological Survey Scientific Investigations Report 2008-5102.
- Rosgen, D.L. 1994. A classification of natural rivers. *Catena*, 22: 169-199.

Simon, A., Hupp, C.R., 1986. Channel evolution in modified Tennessee channels. Proceedings, Fourth Federal Interagency Sedimentation Conference, Las Vegas, March 24-27, 1986, vol. 2, pp. 5-71-5-82.

Simon, A. and M. Rinaldi. 2006. Disturbance, stream incision, and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response. *Geomorphology*, 79: 361-383

U.S. Army Corps of Engineers, Philadelphia District, October 1961 (Revised October 1994), Water Control Manual (Revised) - F.E. Walter Dam and Reservoir, Lehigh River Basin, Lehigh River, Pennsylvania.

U.S. Department of Transportation, Federal Highway Administration, National Highway Institute, May 2001, Evaluating Scour at Bridges, Fourth Edition (Hydraulic Engineering Circular No. 18, Publication No. FHWA-NHI-01-001).

United States Geological Survey (USGS). "USGS Real-time Water Data." February 26, 2012. United States Department of the Interior. Available at: www.waterdata.usgs.gov. Accessed February 26, 2012.

Wolman, M.G. 1954. A method of sampling coarse river-bed material: Transactions of the American Geophysical Union, v. 35, p. 951-956.

Worstell, R.V., Journal of the Irrigation and Drainage Division, March 1976, Estimating seepage losses from canal systems.

16.0 Responses to Public Comment

16.1 Response to Public Comments, September 2013

Background and Intent of the Feasibility Study

The Lehigh River Basin is the second largest drainage of the Delaware River basin. The basin drains 1,368 square miles within Pennsylvania, originating from glacial bogs in the Pocono Plateau, eventually discharging into the Delaware River. Prior to the era of dam building, the Lehigh River hosted tremendous runs of American Shad. Shad fishing by Native Americans and later, the Moravians is well documented. The Lehigh River was first dammed in 1829 by the Lehigh Coal and Navigation Company to provide for barge traffic to deliver anthracite coal from the headwaters to markets in Philadelphia. This dam, at Easton, cut off access to Shad spawning grounds and ended the Shad fishery in the Lehigh. Construction of more dams soon followed. Five dams are currently in place on the Lehigh River: Easton Dam (river mile (RM 0.0), Chain Dam (RM 3.0), Hamilton St. Dam (RM 17.0), Northampton Dam (RM 24.0), and Francis E. Walter Dam, (RM 77.6).

Shad restoration efforts began in the Lehigh drainage in the early 1980's and continue today. Vertical slot fishways were completed at Hamilton Street Dam in 1983 and at Easton and Chain Dams in 1994 to open passage for Shad to the lower 24 miles of the Lehigh River. Various alterations were made to the Easton and Chain Dam fishways in an attempt to improve passage efficiencies and meet Pennsylvania Fish and Boat Commission (PFBC) American Shad restoration goals. PFBC established the restoration goals of 165,000 to 465,000 adult American Shad entering the Lehigh River annually and 80% passage efficiency at each dam. Passage at Chain Dam averages about 25% and the highest passage numbers at Easton Dam was 4,740 American Shad in 2001. It is apparent that additional fish passage measures are necessary for sufficient numbers of American Shad to enter the Lehigh River to establish a self-sustaining population and signify the restoration of American Shad to the river.

It was acknowledged that restoration goals were not being met with alterations to the concrete technical fishways (vertical slot) that are currently in place at the dams. Additional modifications to these fishways and further exploration of concrete technical fishways are not warranted at this time due to the lack of confidence in restoring Shad runs utilizing this type of fishway. It was PFBC's intent to explore full and partial dam removal options with natural fishway designs (i.e. rock ramps) at both the Easton and Chain Dams on the lower Lehigh River to provide sufficient fish passage to meet restoration goals.

The PFBC utilized funding from the Palmerton Natural Resource Damage Settlement and the American Rivers-NOAA Community Based Restoration Partnership to explore the feasibility of providing fish passage at Easton and Chain Dams. The PFBC provided funding to Wildlands Conservancy (WC) via cooperative agreement to oversee and administer the project. Project partners wanted to explore alternatives from an engineering and fish passage perspective and what those options would cost. The PFBC and Wildlands Conservancy (WC), in cooperation with the dam owners and other partners, initiated the Lehigh River Fish Passage Improvement Feasibility Study (feasibility study). The goals of the study were to:

- Assess primary and secondary water supply needs currently provided by Easton and Chain dams and the maintenance of flows to the Delaware Canal and Lehigh Navigation Canal

- Identify alternative methods and associated construction costs of providing water supply assuming full or partial removal of each dam
- Estimate cost of operation and maintenance for alternative water supply methods
- Identify potential impacts to existing infrastructure and recreation that will need further evaluation should a formal engineering design for dam removal/partial removal be advanced
- Evaluate impacts to localized flood flows assuming full or partial dam removal
- Provide conceptual designs for dam removal and/or partial dam removal with rock ramp fishway, and associated infrastructure for alternative water supply for each dam
- Provide a written summary (including alternative analysis) and plan(s) to disseminate project information

Wildlands Conservancy contracted KCI Technologies, Inc. (KCI) through a competitive bid process to conduct the feasibility study that was finalized in March 2013. This study led to KCI's conclusion that from an engineering and cost perspective the only two viable alternatives are to fully remove Easton and Chain Dams or proceed with no action. The long term goal is to achieve adequate fish passage to restore a self-sustaining Shad population in the Lehigh River. To achieve adequate fish passage full dam removal is the only option. In addition to benefitting the American Shad population, dam removal would benefit all resident and migratory fishes that presently utilize, or have historically utilized the Lehigh River, and would restore natural form to the river, which in turn would restore the natural physical and ecological functions of the river system. Benefits provided by a self-sustained Shad run and restored Lehigh River would be wide-ranging to the local communities along the Lehigh River.

KCI's recommendation comes from a strict engineering and fish passage standpoint and does not take into consideration the various cultural, societal, economic or recreational impacts and benefits. Given the funding and resources available, project partners wanted to first identify if there was a way to improve fish passage. Since one option to improve fish passage at each dam was identified, the next step would be to continue discussions with the broad range of stakeholder groups to identify all benefits and impacts of the identified option, including those relating to cultural, societal, economic and recreational values. Should consideration of the dam removal option move forward, the stakeholder groups involved should identify all impacts and benefits in a way that they can be quantified and accounted.

The decision to advance any of the options or recommendations in the feasibility study lies with the dam owners (DCNR and City of Easton). It appears to project partners that public support may not be sufficient to pursue removal of the Easton and Chain Dams at this point in time. This will ultimately affect the goals of restoring American Shad to the Lehigh River and may ultimately affect how PFBC manages the Lehigh River fishery. Project partners believe that if adequate funding could be acquired, improving fish passage into the Lehigh by removing the Easton and Chain Dams can be accomplished while meeting a majority of the goals of the surrounding communities, but broader collaboration and public support is needed to see the reality of a restored Lehigh River.

Summary of Meetings and Stakeholders Involved

Four Steering Committee and Partners Committee meetings were held throughout the course of the feasibility study. These meetings were held in an effort to help guide the study and engage the community, landowners and stakeholder organizations throughout the project process. The committees

were comprised of representatives from a wide range of stakeholder groups including the dam owners, resource agencies, nonprofit groups and different users of the Lehigh River and canals. The groups' representatives would then be able to keep their respective organizations informed on progress of the project. At least 70 groups were invited to participate in the Steering Committee and Partners Committee meetings and are listed in Attachment A. These meetings were held in November 2011, March and August 2012, and May 2013.

On April 17, 2013, the project partners met with Easton City Mayor Panto to discuss the results of the feasibility study. At the Mayor's request, on July 10, 2013, PFBC, WC and KCI Technologies presented the findings of the feasibility study at the Easton City Council meeting. The purpose of the meeting was to inform the Council of the findings of the feasibility study and to entertain questions from the Council about the project.

Summary of Comments

The Lehigh River Fish Passage Improvement Feasibility Study (study) was made available to the public via press release on the PFBC and WC websites in May, 2013. Public comments were solicited and requested by July 17, 2013. Eight public comments were received by July 17th and 2 were received after this date for a total of 10 public comments. Additionally, the US Fish and Wildlife Service Fish Passage Engineering Division reviewed the study and provided comments that can be seen in Attachment B. Rather than address each public comment individually, the comments were summarized into the following list of general themes:

1. Has there been any support expressed for the project?
2. Why was the scope of the feasibility study so narrowly focused on fish passage and watering of the Delaware and Lehigh Canals?
3. Are there other options for fish passage that were not explored?
4. What are the impacts to recreational uses?
5. How will the protection of sewer lines and other infrastructure be addressed and who will be responsible for the cost?
6. Who would be responsible for the overall cost of the project?
7. What are the environmental benefits?
8. How were the flow calculations figured to water the canals and what assurance is there that these will be sufficient?
9. Given the historical significance of the area and the canals, why was there little emphasis on the historical and cultural aspects of the area that may be affected by such a project?
10. How much flooding relief can actually be expected given the location of the dams relative to the Delaware River?
11. How can the benefits of this project be compared to other potential uses of the sites such as the development of the sites to produce hydropower?

Response to Comments

1. Has there been any support expressed for the project?

Of the ten public comments received, two expressed positive support as the study was presented or with additional clarity provided on some of the project details. Furthermore, Wildlands Conservancy and partners received numerous letters that were received outside of the public comment period that expressed positive support for the study.

2. Why was the scope of the feasibility study so narrowly focused on fish passage and watering of the Delaware and Lehigh Canals?

The specific focus of the study was to identify what options are feasible from an engineering perspective to improve American Shad passage. Since the purpose of the dams is to maintain water to the canals, evaluating alternatives for watering the canals were included in the study. Identifying options for improved passage at the first two dams on the Lehigh River follows a logical prioritization of addressing passage at the downstream most dams first. However, the long term goal to restore American Shad to the Lehigh River would be to improve passage where feasible at all dams downstream of FE Walter Reservoir.

Project partners believe that the objectives of the study were met. The next step (outside of the scope of this study) would be to fully assess and identify all socioeconomic, cultural, recreational and environmental benefits and impacts associated with the identified options.

3. Are there other options for fish passage that were not explored?

The intent of the feasibility study was to explore all options for fish passage. It is the collective opinion of the PFBC that any modifications that could be made to the existing **vertical slot fishways** at Easton and Chain dams will be unsuccessful at passing sufficient numbers of American Shad to sustain a natural population. Further, it was determined to not consider technical fishways or the modification of existing fishways in this study because there is no evidence of a model on the East coast that would return sufficient numbers of American Shad to sustain a Lehigh River population. **Rock ramps** were considered as alternatives and discussed in the feasibility study, but were determined not to be feasible for various reasons. **Fish elevators** were not considered in this study and would likely meet or exceed the costs of any of the options considered in the feasibility study. Drastic alterations to the dams would also be needed to make the sites suitable for an elevator. In 2005, upgrades to an existing fish elevator alone cost \$4 million dollars on Holyoke Dam, MA (http://www.hged.com/html/hadley_falls_fish_lift.html). While it is acknowledged that there are dam sites with various fish passage options that successfully pass some fish species, each situation and location is unique. The study authors and project partners believe that all feasible fish passage options were explored for the Easton and Chain Dam sites that would have the potential to successfully restore American Shad to the Lehigh River.

4. What are the impacts to recreational uses?

One of the objectives of this project is to:

“Identify potential impacts to existing infrastructure and recreation that will need further evaluation should a formal engineering design for dam removal/partial removal be advanced”

The study met this objective by identifying potential impacts to the infrastructure associated with recreational use that would need to be further evaluated should any of the options be advanced to the design stage. The authors of the study expanded the scope of work by developing approximate costs associated with impacts to recreational accesses and infrastructure and can be seen in the overall opinion of costs.

Project partners also acknowledge that a project of this magnitude would affect the recreational usage of the river. Although there may be a loss of use to large recreational boats and rowing activities, there would be an increase in use by shallow draft fishing boats, canoes, kayaks and other small vessels. There would be a shift in how the river can be utilized by boaters due to the natural flow regime being restored to the Lehigh River, but it is entirely plausible that there would be a net increase in the number of boaters using the river. Unpowered boating (canoeing/kayaking) is currently one of the fastest growing activities associated with outdoor recreation. In comparing nationwide surveys conducted from 1982-83 and from 2005-2009, the number of canoe and kayak users increased by 106%. Bird watching (287%), backpacking (161%), off-road vehicle use (142%) and walking outdoors (111%) were the only outdoor activities that had faster growth rates. For comparison, the increase in number of participants for other popular outdoor activities include: motorboating (63%), fishing (32%) and hunting (28%) (<http://www.srs.fs.usda.gov/trends/pdf-iris/IRISRec12rptfs.pdf>).

5. How will the protection of sewer lines and other infrastructure be addressed and who will be responsible for the cost?

One of the objectives of this project is to:

“Identify potential impacts to existing infrastructure and recreation that will need further evaluation should a formal engineering design for dam removal/partial removal be advanced”

Project partners believe that the study met the objective of identifying impacts to existing infrastructure that would need further evaluation at design stage. The study went beyond the original scope of work and estimated costs associated with addressing the various infrastructure impacts. These costs were included in the overall opinion of costs.

It should also be noted that project partners would insure that if the removal option was advanced at either location that it would be done so in a responsible manner. Impacted infrastructure would be addressed in a way that would maintain or improve the current functionality of that infrastructure. Addressing these infrastructure impacts would not be advanced without insuring that the appropriate stakeholders are confident in the modification to the affected infrastructure.

6. Who would be responsible for the overall cost of the project?

The Lehigh River Fish Passage Feasibility Study was funded with Palmerton Natural Resource Damage Settlement funds and an American Rivers-NOAA grant. The identification of additional funding sources to cover the overall cost of the project is not warranted at this point due to the perception that there is insufficient public support for the recommended option. Project

partners and stakeholders cannot advance any of the options identified in the feasibility study to the design stage without consent of the dam owners.

It should be noted that if public support was sufficient for the dam owners to agree to advance the removal option to the design stage at either Easton or Chain Dam that there would be a need to identify additional funding sources. The intent would be to eliminate the financial burden to the dam owners and the owners of affected infrastructure. Potential funding sources could include a variety of grant sources, damage settlements and mitigation funds. It would be the intent of the project partners and stakeholders to identify funding sources to fund all components of the project. This would include the construction associated with removal, infrastructure protection, river access upgrades, installation of watering options for the canals, and identifying creative solutions to fund the operation and maintenance of the canal watering options.

7. What are the environmental benefits?

The main objective of this study was to identify options to provide sufficient fish passage to restore American Shad to the Lehigh River. American Shad populations were eliminated from the Lehigh River due to the historical use of the river by humans. Restoring a historically important species that once displayed prolific runs to the Lehigh River is the main environmental benefit associated with addressing fish passage at the Easton and Chain Dams. However, there are other significant environmental and ecological benefits to restoring natural riverine function to the river through the recommended alternative, removing Easton and Chain Dams. The environmental benefits associated with the dam removal option at Easton and Chain Dams can be viewed in the context of improvements to the function of a flowing river system and improved fish passage.

The main function of a flowing system is to transport water and materials from the surrounding watershed. This transport function affects the physical distribution of materials within the channel to create aquatic habitat, affects the natural water quality in that system, and ultimately affects what can live there; including fish, organisms that fish rely on, and organisms that rely on fish. The construction of a dam on a flowing waterway interrupts the natural transport function of that system. The obstruction caused by a dam shifts the aquatic habitat from that typical in a flowing system to that typical in an impounded system. This affects water quality (increased temperature, decreased dissolved oxygen, affects nutrient cycling, etc.) and alters the makeup of the aquatic community inhabiting the impounded reach of the river.

The removal of dams restores the natural transport function of that river system. This translates to restored physical habitat conditions, improved water quality, and the aquatic community will return to that typical of a flowing system. This will equate to a shift in how that waterway is used by people, but the improved functioning of the system will likely appeal to a broader range of user groups and provide for a renewed connection of the surrounding communities to the aquatic resource.

Dams also block the movement of fish and other aquatic organisms. Dams have been a major contributor to diminished diadromous fish populations on the East Coast and species affected include American Shad, American Eel, Blueback Herring, Alewife, Atlantic Salmon, and Atlantic Sturgeon. Improving passage for these fish at localized scales, like the Lehigh River, will help to

supplement these populations across their range. Fish movement within a river system is not only important for migratory fishes but also those fish that are considered resident fish and spend most of their life in the same river system. Fish move to seek refuge from predators, to seek food, to seek suitable spawning habitat, to escape localized water quality conditions, and to respond to competitive pressure. Thus, dams prevent fish from finding conditions most suitable to their survival.

These environmental benefits are some of the reasons the PFBC and project partners are advocates for the removal of dams when feasible. Dam removal was identified as a feasible option at Easton and Chain Dams from an engineering and fish passage perspective. Restoring fish passage and riverine function in the lower Lehigh River would yield wide ranging environmental benefits.

8. How were the flow calculations figured to water the canals and what assurance is there that these will be sufficient?

The information provided in this study was based upon available data. Research and requests for information revealed very little data that were helpful in estimating required flow to water the canal. The project team relied on information relayed through owner interviews, identifiable literature, and estimates of seepage based on other project experience and performance data on the abilities of dams to water associated canals. Flow estimates were based upon data that were available and the experience of the engineers in estimating seepage flow. It is fully understood that if more practical data are available then the potential exists for new estimates to be made based upon these data.

The intent of this study was to produce a planning document to develop cost estimates based on a gross order of magnitude. They are not presented as costs that are exact or final. The data provided in the study are not presented as the basis for final design of construction documents. It is acknowledged that additional data may be available and that additional information gathering, constructive conversation and planning would be required if any of the options were advanced to the design stage. As such, the information provided is done so to provide the reader with an order of magnitude opinion of costs associated with conceptual watering options.

Originally, the study team planned to explore the option of installing only one large pumping station. Based on discussions with facility managers, it was decided to also include the concept of exploring the cost of 10 smaller pumping stations. This concept was explored due to the fact that the canal walls are prone to failure. If the canal were sectioned in this way the canal section with the wall failure could be isolated while maintaining water to the remainder of the canal. It may be true that there are not 10 suitable sites to install pumping stations, but this concept was explored to provide cost estimates and would have to be further explored if this concept was further advanced.

There was concern about the need for backup pumps, power and equipment to maintain water in the canals in case of equipment failure. Backup pumps and equipment could be kept on hand to handle equipment failure and the cost of the extra equipment would be minor compared to the cost to construct the pumping facility. Faulty or outdated equipment is also minor compared to the regular failures of the canal walls. The study simply proposes concepts and

provides order of magnitude cost estimates. Many of the details dealing with backup pumps and equipment would be addressed at a later stage of project development.

9. Given the historical significance of the area and the canals, why was there little emphasis on the historical and cultural aspects of the area that may be affected by such a project?

The historical and cultural importance of the Delaware and Lehigh Canals has been acknowledged throughout the study process. If any options were advanced to the permitting stage, the project would be thoroughly reviewed by the Pennsylvania Historical & Museum Commission, and if warranted, recommendations would be made to avoid or mitigate historical impacts. Stakeholder groups would have ample opportunity to provide public comment during this period.

As discussed previously, the scope of this study was to identify what is possible to improve fish passage from a strict engineering perspective. It was not within the scope of the study to identify every social, cultural and historical impact. The importance of these concerns is acknowledged and would need to be addressed if any of the identified options was advanced.

10. What are the anticipated benefits of the proposed removals as they relate to flooding?

The point was brought up that the flooding in the immediate area of Easton Dam would not be alleviated under dam removal conditions because the Delaware River is what causes the flooding in Easton due to a backwater effect. Project partners and the study authors do not dispute this fact and acknowledge that when the Delaware River is at flood stage the Easton Dam does not impact flooding, nor would removing the dam alleviate flooding. However, it is also inaccurate to state that removal of the dam would do nothing to alleviate flooding. The study points out that the hydraulic analyses were carried out under the assumption that the flooding in the Delaware was negligible (page 39 and 40 of the study). It is plausible to experience a localized storm event in the Lehigh Drainage that would not be seen in the upper Delaware drainage. We believe that the study accurately reports the results and qualifies the statements relating to flooding by stating that the results are reported when backwater from the Delaware is not significant. It is acknowledged that under certain conditions, removal of the dam would have no effect on flooding issues. The backwater effect at the confluence of the Lehigh and Delaware Rivers does not affect the flooding relief at Chain Dam. Please see comments from US Fish and Wildlife Service relative to the accuracy of the report as it relates to flooding in Attachment B.

11. How can the benefits of this project be compared to other potential uses of the sites such as the development of the sites to produce hydropower?

Project partners are not in a position to comment on the site suitability for hydropower development. It is noted that there has been an Order Issuing Preliminary Permit to explore hydropower projects at both Chain and Hamilton Street dams by Hamilton Street Hydro, LLC. These records can be found on the Federal Energy Regulatory Commission (FERC) website (<http://www.ferc.gov/for-citizens/projectsearch/SearchProjects.aspx?Region=Northeast>). A Preliminary Permit Application indicating hydroelectric development interest at Easton Dam was submitted to FERC by Siting Renewables, LLC on December 17, 2013 and the permit is pending (<http://www.ferc.gov/industries/hydropower/gen-info/licensing/pre-permits.asp>; Docket

#14573). Preliminary Permits are obtained to study the feasibility of developing hydropower projects and gives the applicant priority in continuing the permitting/licensing process. This does not mean that it will be feasible to construct hydropower projects at any of these sites. It should be noted that providing sufficient fish passage will be mandated during the FERC licensing process for hydropower development and that fish passage will remain an important discussion item in the licensing process.

Steering Committee

Representatives of the following stakeholder groups were invited to take part in the four Steering Committee meetings.

American Rivers

City of Easton (Owner: Chain Dam)

Delaware & Lehigh National Heritage Corridor

Delaware River Basin Commission

Lehigh Valley Planning Commission

National Canal Museum

National Oceanic & Atmospheric Administration

Pennsylvania Department of Conservation & Natural Resources (Owner: Easton Dam)

Pennsylvania Department of Environmental Protection

Pennsylvania Fish & Boat Commission

US Army Corps of Engineers

US Fish & Wildlife Service

Wildlands Conservancy

Partners Committee

Members of the following stakeholder groups were invited to take part in the four Partners Committee meetings.

Alburtis Rod and Gun Club
Allentown Environmental Advisory Committee
Beaver Run Rod & Gun Club
Bethlehem Boat Club
Bethlehem Environmental Advisory Committee
Blue Mountain Fish & Game Assn.
Blue Ridge Rod & Gun Club
Bushkill Stream Conservancy
City of Allentown - Parks Department
Community Fish & Game Assn.
Copeechan Fish & Game Club
Delaware River Shad Fisherman's Association
East Greenville Rod & Gun Association
East Penn Sportsmen's Club
Easton Environmental Advisory Committee
Easton Fish & Game Association
Easton Whitewater
Easton Whitewater Group/Appalachian
Mountain Club
Friends of the Delaware Canal
Grouse Hall Fish & Game Association
Guthsville Rod & Gun Club
Heidelberg Game Protective Association
Hellertown Sportsmen
Hokendauqua Trout Unlimited
Jim Thorpe Sportsmen's Association
Keystone Rod & Gun Club
Kunkletown Rod & Gun Club
Lafarge
Lafayette College
Lappawinzo Fish & Game Protective
Association
Lehigh Co. Federation of Sportsmen
Lehigh Coldwater Fishery Alliance
Lehigh County Conservation District
Lehigh County Fish & Game Protective
Association

Lehigh Gap Nature Center
Lehigh River Stocking Association
Lehigh University
Lehigh Valley Audubon Society
Lehigh Valley Kayak & Canoe Club
Lehigh Valley Whitewater
Little Lehigh Trout Unlimited
Lower Nazareth Rod & Gun Club
Lower Saucon Sportsmen's Association
Monocacy Creek Field & Stream Association
Monocacy Creek Trout Unlimited
Moravian College
Northampton Borough Municipal Authority
Northampton County Conservation District
Northampton County Federation of
Sportsmen's Clubs
Natural Resources Conservation Service
Nurture Nature Center
Pennsylvania Federation of Sportsmen's Clubs
Pennsylvania Fish & Boat Commission – Law
Enforcement
Palmerton Hunting & Fishing Association
Palmerton Rod & Gun Club
Penn Forest Sportsmen
Pioneer Fish & Game Association
Pohopoco Rod & Gun Club
Point Phillips Rod & Gun Club
Ranger Lake Rod & Gun Club
Raubsville Sportsmen's Association
Rural Sportsmen Association
Slatington Skeet & Sport Association
Steel City Rod & Gun Club
Tri-Borough Sportsmen's Assn.
Trout Creek Hunting & Fishing Association
Walnutport Canal Association
White Haven Sportsman Club



Region 5 - Fisheries
Fish Passage Team
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Hadley, Massachusetts 01035

FPT Review Comments

Project Name: Easton and Chain Dams – Fish Passage Improvement
Location: Northampton County, PA
Document Name: Lehigh River Fish Passage Improvement Feasibility Study

Date: 12/27/13
Reviewer: Brian J. Waz, P.E.

	Ref. Page / Para.	COMMENTS	Disposition
1.	General Concerns/ Comments	After cursory review of the Lehigh River Fish Passage Improvement Feasibility Study dated March 2013, PFBC Response to Public Comments dated September 2013, and correspondence with Ben Lorson from PFBC; a few general comments are below: <u>PFBC Response to Public Comments, 9. The study inaccurately portrays flooding relief under dam removal options:</u> After a thorough review of the Feasibility Study and HEC-RAS data and results; I agree with the study findings in regard to flood elevations post removal or lowering. The study states on page 40, “<i>In general, lowering or removing either dam will decrease flood elevations and increase flow velocity in upstream areas. These effects are more pronounced immediately upstream of the dams and in the flow condition where backwater from the Delaware River is not significant</i>”. The most important fact is that the backwater effects of the Delaware River were not considered during the modeling for the lowering and dam removal alternatives. There would be a decrease in flood elevations in the upstream areas if the Delaware River is not in a flood situation. Review of the Flood Profiles in the Flood Insurance Study for Northampton County, PA dated April 6, 2001 shows that the 100YR Flood Elevation for the Delaware River is approximately 190.5 ft. NGVD. The 100YR flood elevation of 190.5 ft. NGVD is higher than the dam crest for Easton Dam (+/- 170.5 ft. NGVD), and 1.5 feet lower than the Chain Dam crest (+/- 192.0 ft. NGVD). The backwater effects from the Delaware River would still contribute to the amount of flooding on the Lehigh River after dam removal if both rivers were experiencing flooding events. To what extent the Delaware River levels would affect the Lehigh River levels is unclear. These different flooding scenarios could be modeled using the already existing HEC-RAS model.	Comments provided to assist PFBC in addressing comments on the Feasibility Report. During the development of the detailed design report, the different flooding scenarios when both rivers are experiencing flooding should be modeled and reported. The modeling may not show much change for the more extreme flood events. The results could help alleviate questions and concerns from interested parties.

