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MASSACHUSETTS RIVERWAYS PROGRAM

BOSTON, MASSACHUSETTS

MILL STREET (TEL-ELECTRIC) DAM

PITTSFIELD, MASSACHUSETTS

NATDAM NO. MA01970

HYDRAULIC AND SCOUR ANALYSIS FOR DAM REMOVAL FEASIBILITY STUDY

JUNE 2006

Prepared by:

Kleinschmidt

Energy & Water Resource Consultants

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TABLE OF CONTENTS

LIST OF APPENDICES

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1.0 PURPOSE OF STUDY

The purpose of this study is to assess the hydraulic effects of the removal of the Mill Street dam, also known as the Tel-Electric dam, on the West Branch Housatonic River in Pittsfield, Massachusetts. Of specific interest is the potential scour around the railroad trestles and bridges upstream of the Mill Street dam. The study complements a dam removal feasibility study (Kleinschmidt, 2006) that assessed alternatives for dam removal.

The study included HEC-RAS hydraulic modeling for the West Branch Housatonic River in the vicinity of the Mill Street dam, including the mean annual flow, 2-year flood and 100-year flood. Hydraulic modeling for the mean annual flow was used to assess depth, wetted width and velocity changes that could occur after dam removal, which could have implications for aquatic species such as fish. HEC-RAS hydraulic results were also used to develop a tractive force analysis for this reach to assess the incipient diameter of particles that would be mobilized in the 2-year and 100-year floods. The HEC-RAS model was further used for a scour analysis of the three railroad trestles upstream of the dam for a 100-year flood.

Since limited information about the river geometry and substrates exists, the hydraulic analysis should be considered preliminary, based on existing data only. The primary purpose of the hydraulic modeling is to assess whether there are potential scour issues with structures upstream of the Mill Street dam, including railroad trestles and bridges. More refined estimates of the hydraulic effects of dam removal alternatives can only be prepared after better data are available on river geometry (cross sections), sediment characteristics, and structure foundations upstream of the dam.

2.0 SITE DESCRIPTION

2.1 Mill Street Dam

Limited information about the history of the Mill Street dam is known. According to the Massachusetts Department of Conservation and Recreation the dam was completed in 1920 and is presently owned by Mr. Kenneth Nash of Pittsfield, Massachusetts, who also owns the adjacent mill building. The construction of the dam may have been preceded by the construction of the railroad, including at least one of the river crossings (trestles) upstream of the dam. It is unknown if the Mill Street dam replaced another dam on the West Branch Housatonic River, or if it was the first dam to impound this reach. The dam was originally built to provide water power for a nearby mill.

The dam is approximately 20 feet high and 40 feet wide, with a 30 foot long, slightly curved spillway section. The crest of the main spillway is at elevation 986.7' (elevations in this report refer to National Geodetic Vertical Datum, NGVD, unless noted otherwise). On river left (looking downstream), just upstream of the main spillway, is a side spillway with a width of 15 feet and a crest at elevation 985.2'. When the headpond is lower than elevation 986.7', river flows only go over the side spillway, with the flows entering an abandoned 9-foot diameter penstock with invert elevation 978.6' at the entrance. This penstock discharges perpendicular to the river just below the dam. When the headpond is above elevation 986.7', the river flows over both the side and main spillways. An old gate opening through the dam's abutment on river left was filled with concrete at an unknown date.

A boring through the dam's main spillway verified that the dam is founded on bedrock (C.T. Male, 1985), and is constructed of masonry block overlain with concrete with a thickness of 11 inches at the crest. It is unknown if the dam was originally constructed of masonry block and later retrofitted with a concrete overlay, or if the concrete was part of the original construction.

The Massachusetts Department of Environmental Management inspected the dam on March 24, 2000 and found the dam to be in "poor condition" with "significant operational or maintenance deficiencies" (Mass. DEM, 2000).

2.2 River Crossings

Seven river crossings are in the vicinity of the Mill Street dam and the upstream impoundment. The concrete Mill Street bridge crosses the West Branch Housatonic River approximately 200 feet downstream of the dam. A 39" diameter sewer line crosses the river between concrete abutments on the downstream side of the bridge.

Approximately 60 feet upstream of the Mill Street dam is an abandoned railroad trestle that formerly supported one track. The age of the structure is unknown. The trestle is supported by steel piles with the depth of embedment unknown.

Approximately 120 feet upstream of the dam is a full-span railroad trestle supporting two tracks. The span is supported by a steel truss structure between masonry abutments topped with concrete. Approximately 20 feet upstream of this trestle is a second full-span trestle with the span supported by a riveted steel beam structure. The two full-span trestles use the same masonry and concrete abutments. There is a date of 1910 on the concrete portion of the abutments, although the masonry portion may be older.

The West Street bridge crosses the West Branch approximately 1,200 feet upstream of the Mill Street dam. The bridge is a concrete arch with a maximum clear width of 32'-6" and acts as a flow restriction during floods, creating a large drop across the structure between upstream and downstream water levels.

Two other bridges cross the West Branch, one 2,400 feet upstream of the Mill Street dam (Columbus Avenue bridge) and the other 3,900 feet upstream of the dam (Linden Avenue bridge). The Columbus Avenue bridge has a date on it of 1996, and the Linden Avenue bridge has a date of 1982, reflecting the dates when both bridges were rebuilt. Both bridges have wider spans and higher low-chord elevations than the West Street bridge, which is the principal hydraulic control for the river upstream of West Street.

2.3 Watershed Hydrology

Limited hydrologic information is available about the watershed of the West Branch Housatonic River. The West Branch is ungaged, with the nearest U.S. Geological Survey (USGS) streamgage located on the East Branch Housatonic River at Coltsville, Massachusetts, which has a contributing drainage area of 57.6 square miles.

Using Geographic Information System (GIS) coverages, it was determined that the drainage area at the dam is approximately 36.5 square miles. The watershed upstream of the dam is highly developed, although significant forested areas do exist around the headwaters of the West Branch. The mean basin elevation is approximately 1,414 feet, with the slope of the West Branch upstream of the Mill Street dam approximately 43 feet/mile (0.8%) between the points 10% and 85% of the total stream length above the site. The slope is higher in the headwaters of the West Branch, but diminishes greatly near the confluence of the West Branch with the Southwest Branch. Downstream of the Mill Street dam, the slope is reportedly as low as 18 feet/mile, or 0.3% (Mitchell, 2005).

The West Branch basin contains two large impoundments, Pontoosuc Lake and Onota Lake. Pontoosuc Lake is approximately 480 acres, with a contributing watershed of 13,607 acres (21.3 square miles). Onota Lake is approximately 617 acres, with a contributing watershed of 6,345 acres (9.9 square miles). The lakes exert an unknown amount of regulation on flows in the West Branch. However, based on the drainage areas, approximately 31.2 square miles (85%) of the basin upstream of the Mill Street dam also lie upstream of these lakes, so the lakes undoubtedly influence the hydrology (including low flows and floods) at the dam.

Peak flood flows have previously been calculated for the West Branch and reported in studies by C.T. Male (1985), the U.S. Army Corps of Engineers (1980) and others. The flood flows were reportedly calculated using either Soil Conservation Service (SCS) methodology and programs, or the U.S. Army Corps of Engineers' HEC-1 program, with the models routing synthetic design storms through a basin. The C.T. Male report listed peak flood flows of 1,085 cfs, 1,980 cfs and 2,550 cfs for the 10-year, 50-year and 100-year floods, respectively, and noted that the Corps had used a higher 100-year flood (3,150 cfs) in their study.

The 1980 Corps study contains a probability plot calculated for the West Branch, which can be used to estimate peak flood flows for several recurrence intervals. As derived from the plot, the following are the approximate peak flows for the 2-year flood up to the 100-year flood. The report lists the drainage area as being 36.1 square miles, although the precise location is not identified.

Flood	**Peak Flow (cfs)**
2-year	580
5-year	1,000
10-year	1,350
25-year	1,900
50-year	2,430
100-year	3,150

The peak flows for the 10-year, 50-year and 100-year floods are slightly greater than the corresponding flows in the C.T. Male report. The peak flow for the 2-year flood (580 cfs) derived from the Corps study is the best estimate that can be derived from existing information. The 2-year flood is of interest because flows of this magnitude are typically influential on river morphology and sediment transport.

For scour analyses, a 100-year flood is typically studied. For this analysis, Kleinschmidt used the 100-year flood flow (2,550 cfs) given in the C.T. Male report, since we also had the accompanying flood profiles prepared by C.T. Male. The 2-year flood flow (580 cfs) derived from the Corps data was also modeled to reflect a flow that could be influential on sediment transport and channel form.

In order to assess hydraulic conditions under more frequent flow conditions, such as those when fish might want to swim upstream past the dam site, Kleinschmidt also modeled an annual mean flow. Annual mean flow was derived using data from the East Branch Housatonic River streamgage. For 69 years of record, the annual mean flow was 107 cfs, which equates to 1.86 cfsm (cfs per square mile of drainage area) at the streamgage. Using the same 1.86 cfsm for the West Branch Housatonic River, the annual mean flow would be 68 cfs. This is an approximation, given the limited hydrologic data available for the West Branch Housatonic River, but is considered the best estimate of mean annual flow on the ungaged West Branch.

3.0 DAM REMOVAL ALTERNATIVES

3.1 Sediment Management Required for Dam Removal

As discussed in the feasibility study for the Mill Street dam (Kleinschmidt, 2006), the feasibility of dam removal alternatives depends on the different approaches to managing impounded sediments. Based on topographic mapping and dam drawings presented as part of the C.T. Male flood study (1985), there is a large volume of impounded sediment just upstream of the dam. On the upstream face of the dam, the sediment is at an approximate elevation of 980' (Figure 2). Downstream of the dam, the minimum elevation of the scour hole at the base of the dam is at an approximate elevation of 967', with the streambed rising to an approximate elevation of 971' downstream of the scour pool. The depth of sediment at the dam, therefore, is estimated to be approximately 13'. Bed elevations in the vicinity of the railroad trestles (Figure 1) are close to the 980' elevation of the sediment at the dam, suggesting that sediment is impounded in the vicinity of the trestles and probably extends farther upstream.

In free-flowing rivers, natural fluctuations in flow affect sediment transport and serve to create unique and diverse habitats for aquatic biota. Dam removal often redistributes sediments trapped behind the dam, restoring the river and its riverine habitats to pre-dam conditions. If the Mill Street dam is removed, the 13 feet of sediment on the upstream face of the dam would obviously not be stable. Although the gradation of the accumulated sediment is unknown, substrates smaller than cobbles would probably have difficulty maintaining bed slopes steeper than 1% to 2%. After removal of the dam a headcut would form and begin migrating upstream, flattening the bed slope in the reach as it erodes a channel through the impounded sediment. The rates of migration of the headcut progression upstream and sedimentation downstream depend on several factors, including slope, hydrology and the composition of the impounded sediments. Ultimately, the river may erode back to the channel geometry that existed prior to the reach being impounded.

Headcuts and other streambed erosion can increase scour around upstream structures such as bridge pilings, piers and abutments, and cause structural damage. The history of the railroad trestles upstream of the Mill Street dam is largely unknown. The first trestle upstream of the dam—for which the supported railroad tracks are no longer in use—is supported by steel piles, including single and double piles in the river. The depth of the piles is unknown, but this type of pile construction is often used for support in deep sediments, where the piles do not sit on bedrock or on large concrete footings. The use of single piles and double piles also suggests some level of deliberate design, since double piles are typically used in areas where the underlying soils provide less support. Therefore, this pile-supported trestle may have been built after the Mill Street dam was constructed, perhaps even after the impoundment had filled with sediment. This is largely conjecture, however, since the construction history of the pile-supported trestle is unknown. The structure would be subject to scouring around the piles after dam removal, as velocities increase with the shallower depths and impounded sediment is mobilized. Of all the structures upstream of the Mill Street dam, this pile-supported trestle is considered to be the most vulnerable to scour after dam removal, perhaps to the point of undermining the existing support. Since the trestle is abandoned, demolition and removal of this structure may be an option.

The two railroad trestles farther upstream span the river between masonry and concrete abutments, with no center (instream) piers. There is a date of 1910 on one of the trestles. According to data for the Mill Street dam supplied by the City of Pittsfield, the dam was completed in 1920. If these railroad trestles predate the construction of the dam, it may suggest that the trestles were constructed along a free-flowing reach of the river and were not designed to rely on impounded sediments for support or the slower velocities (*i.e.*, less scour energy) created by the dam's backwater. The City of Pittsfield, however, is investigating whether the Mill Street dam may have replaced an earlier dam. Regardless of the historical timeline of construction of the dam and trestles, the depth of the abutments for the trestles is unknown.

In the event of dam removal, the lowering of water levels in the vicinity of the full-span trestles would actually reduce the frequency of flow against the structures.

Abutment scour could still occur if significant quantities of channel sediments were removed or eroded. This would only have structural implications if the smaller volume of sediment allowed higher velocities to occur near the abutments (say, if the channel migrated against one of the abutments and undermined the abutment). Structural support could also be compromised if the trestles were designed using the mass of impounded sediment for bearing support. Overall, however, the scour potential for the abutments of full-span trestles is less than it would be for center (instream) piers.

The sediment volume impounded by the dam is unknown, and its characteristics must be inferred from the limited data available. Although the Mill Street dam has some backwater effect as far upstream as the wide floodplain near Wahconah Park, the upper reaches of the impoundment also have significant hydraulic control exerted by three bridges, especially the West Street bridge approximately 1,200 feet upstream of the Mill Street dam. The C. T. Male report concluded that lowering the Mill Street dam by more than three feet will not further lower flood water levels upstream of the Mill Street dam, due to hydraulic control shifting to the relatively narrow West Street bridge after the impoundment is drawn down. The report also noted that increasing the flow area at West Street would require removing bedrock from the channel bed, implying that the bridge may have been built at a ledge outcropping and that the depth of sediment is relatively shallow at the bridge compared to the sediment depth (13 feet) at the Mill Street dam. Therefore, most of the hydraulic changes following dam removal—and the resulting mobilization of sediment—are anticipated to occur between the Mill Street dam and West Street.

According to the C.T. Male report, the bed elevation at the West Street Bridge is at an approximate elevation of 984'. With the top of the sediment at an approximate elevation of 980' at the Mill Street dam, there is a 4-ft drop in grade over the 1,200 ft between the dam and the West Street Bridge, which equates to a slope of 0.3%. From the base of the dam at the scour pool (approximate elevation 967') to the West Street bridge (elevation 984'), the differential in elevation is 17 ft, which equates to a slope of 1.4%. However, after dam removal the scour pool at the base of the dam would likely fill in with sediment and the bed elevation in the vicinity of the dam would not go below the bed elevation just downstream, an approximate elevation of 971'. Between the Mill Street dam and the West Street Bridge, the elevation differential of 13 ft (between elevations 984' and 971') over the 1,200 ft distance equates to a slope of 1.1%. Assuming that minimal sediment would be mobilized upstream of West Street compared to the reach upstream of the dam, the depth of bed erosion could be a maximum of 13 ft at the dam, with the erosion getting shallower as one travels farther upstream, until there is little to no bed erosion at the West Street bridge.

3.2 Dam Removal Alternatives

As detailed in the feasibility study (Kleinschmidt 2006), three dam removal alternatives were considered, reflecting the three primary approaches to sediment management: controlled sediment removal, partial sediment removal, and controlled sediment transport.

3.2.1 Alternative A – Sediment Removal & Dam Removal

For Alternative A, impounded sediment upstream of the dam would be dredged and disposed of off site prior to a removal of the dam (Figure 6). The main intent of this alternative is to minimize the movement of impounded sediment – especially contaminated sediment – downstream. The new bed profile would be determined during final design, and could even be shaped by fluvial processes.

Contaminated sediment may require specialized removal and disposal. The feasibility of this option depends on the nature of the sediment, its contamination, and the upstream extent of dredging required, which will require further analyses (sediment profiles and sampling). Sediment and dam removal may also require scour protection around bridge abutments and pilings, particularly for the three railroad trestles immediately upstream of the dam. In fact, this alternative may require the excavation of bed materials below the existing abutments and pilings for the railroad trestles, and further investigation would be required to determine the elevations of the bottoms of these structures.

3.2.3 Alternative B – Constructed Riffle & Dam Removal

For this alternative, impounded sediment upstream of the dam would be partially dredged and a rock riffle (ramp) would be constructed upstream of the dam for grade control. The toe of the riffle would be a short distance downstream of the dam, with the riffle extending upstream. Two variations within Alternative B include a 5% riffle that ends just upstream of the abandoned, steel piling trestle, and a 3.3% riffle that extends upstream beyond all three trestles (Figures 3 and 4). The main intent of the rock riffle is to provide grade control and limit the upstream extent of headcut (*i.e.,* erosion of impounded material). The rock riffle also has the potential benefit of providing scour protection for the trestles. The riffle would be of similar construction to a rock ramp and would allow passage for aquatic organisms.

3.2.4 Alternative C – Staged Impoundment Drawdown & Dam Removal

This alternative looks at a longer timeframe for dam removal, and relies on natural river processes to transport some of the impounded sediments. The existing side spillway on river left (looking downstream) would be notched and lowered to the sill elevation of the spillway pipe around the dam. This may be done in stages, lowering it a few feet each year. The intent would be to gradually flush clean sediments from the impoundment and lower water levels upstream of the dam, which would allow for the planting of native riparian species in newly exposed stream margins and floodplains. The river would be monitored for bed scour (upstream of dam), deposition (downstream of dam), sediment transport, colonization by vegetation, etc., with the river's response being incorporated into final dam removal design. The final dam removal – say, after five years—could still require elements of Alternative A (dredging) or Alternative B (constructed riffle for grade control). The main intent of this option is to allow for a dam removal after some natural conditions have been restored to the river, namely the restoration and establishment of riparian vegetation, the restoration of presently sediment-starved morphology downstream of the dam, and a smaller volume of impounded sediment, if not the restoration of some natural morphology (*i.e.*, pool-riffle sequencing) upstream of the dam.

3.3 Alternatives Studied with Hydraulic Modeling

Limited data exist for the riverine geometry upstream and downstream of the dam, especially between the railroad trestles and the West Street bridge. Although hydraulic modeling had been prepared previously (e.g., C.T. Male study), the geometry used in the models was not available for our preliminary hydraulic analysis. Therefore, the following approach was used for the hydraulic analysis.

3.3.1 Existing Condition

The existing condition—with the dam in place—was modeled as the baseline hydraulic regime. This is important to assess because there is no guarantee that the existing conditions are sufficiently protecting against hydraulic effects such as pier or abutment scour.

3.3.2 Alternative A – Sediment Removal & Dam Removal

As described earlier, this alternative requires the partial or complete removal of impounded sediment down to unknown elevations, perhaps the original river bed. The original river profile, nature of the impounded sediments, and original bed materials are unknown, so it is currently impossible to model the geometry for this alternative. Based on bed elevations downstream of the dam, as well as the bed elevation at the West Street bridge, the overall slope in this 1,200' reach between the dam and bridge could become 1.1% to 1.4%.

Scour depths for the other alternatives were compared to the bed elevations that would occur if the channel slope fell to 1.4% between the scour pool downstream of the dam and the West Street bridge. That is, it is assumed that the physical removal of the substrates under Alternative A (*i.e.*, lowering the riverbed) is as great a concern for the railroad trestles as scour of the riverbed would be, especially if the trestles were constructed after a dam was built.

3.3.3 Alternative B – Constructed Riffle & Dam Removal

Since this alternative would require a built channel in the vicinity of where previous survey data is available, hydraulic modeling was prepared for Alternative B. Both the 1:20 (5%) and 1:30 (3.3%) constructed riffles were modeled.

4.0 HYDRAULIC MODELING

4.1 HEC-RAS Model

The U.S. Army Corps of Engineers computer program HEC-RAS version 3.1.2 was used to model the West Branch Housatonic River in the vicinity of the Mill Street dam. Since limited cross section data was available, the modeling should be considered preliminary, based on existing data only. Further surveys or cross sectional data are required to refine the model. The data limitations allowed the hydraulic modeling to assess the relative effects of dam removal on scour, particularly around the railroad trestles just upstream of the Mill Street dam. Hydraulic changes upstream of the railroad trestles, however, could not be reliably predicted based on the limited riverine geometry data available. This precluded a detailed analysis of dam-removal alternatives A and C, which require information on the stable bed and banks of the river.

Cross sections used in HEC-RAS were derived from spot evaluations on a 1980 survey originally presented in a U.S. Army Corps of Engineers flood study (COE, 1980). The survey was also presented in the C.T. Male study (1985). The most downstream cross section (A) is located between the Mill Street dam and Mill Street river crossing. There are six cross sections downstream of the dam (A through F), and ten cross sections upstream of the dam (G through P), based on the available survey data. The upstream cross section (P) is located above the railroad trestles. Cross section locations are indicated on profile drawings of the dam-removal alternatives (Figures 1, 3 ,4 and 6 in Appendix B). Since a drawing was available for the West Street bridge (Figure 7), the modeling was extended upstream to West Street. However, due to data limitations the cross sections between the upstream extent of the U.S. Army Corps of Engineers survey and West Street bridge had to be approximated, based on bottom elevations from the C.T. Male report and top widths derived from aerial photographs and topographic mapping. Although HEC-RAS water levels for the 100-year flood in the vicinity of the West Street bridge generally agreed with previous flood profiling (e.g., C.T. Male study), hydraulic effects based on the unknown channel geometry between the railroad trestles and West Street have a high degree of uncertainty and are, therefore, not presented. The dam removal feasibility study (Kleinschmidt, 2006) has an interpretation of the probable hydraulic effects in the vicinity of the West Street bridge and upstream reaches, based on a review of previous reports.

Based on observations of the river and previous flood profiles, the channel and overbank roughness coefficients ("Mannings n" values) were estimated to be 0.035 and 0.040, respectively. The hydraulic results in the vicinity of the dam are not appreciably sensitive to the roughness coefficients. The same roughness was assumed for both the existing (*i.e.*, dam in) and constructed riffle (*i.e.*, dam out) alternatives, so that the hydraulic changes reflect the changes in hydraulic control and cross section geometry after dam removal.

4.2 Scour Analysis

HEC-RAS computes scour using methods from the U.S. Army Corps of Engineers' Hydraulic Engineering Circular No. 18 (Brunner, 2002). There are three basic types of scour: contraction scour, pier scour and abutment scour.

Contraction scour results when a structure—such as a bridge—narrows the channel width from its approach width. Depending on the degree of contraction and the bed material, the riverbed tries to scour downward to compensate for the reduced flow area.

Pier scour occurs when the flow accelerates around the piers, forming a "horseshoe vortex". A scour hole is created if the vortex is able to remove bed material from the base of the piers. Pier scour is related to pier width, pier shape, flow approach angle, bed material, channel profile and channel geometry.

Abutments that project out into the channel may be subject to abutment scour, localized scour that results from the formation of vortices along the abutments.

Contraction and abutment scour were modeled for the three railroad trestles upstream of the Mill Street dam. The pile-supported trestle, just upstream of the dam, was also modeled for pier scour. Scour is reported as total scour, which includes the effects of contraction scour, pier scour and abutment scour.

Since the gradation of bed substrates is unknown—as is the bed load in the river—scour calculations relied on clear water scour, rather than live bed scour.

4.3 Tractive Force Analysis

Rivers move sediment along with water. Sediment transport is a naturally occurring, continuous process in all rivers. Typically, rivers are in dynamic equilibrium between sediment deposition and scour, usually resulting in a stable channel configuration. Local changes in this equilibrium can result from, among other things, high flow events, erosion from adjacent upland sources, or changes to the hydraulic characteristics of a river reach due to a new or changed infrastructure (e.g., bridge, dam or culvert). Just as rivers move sediment along with water, dams also impound sediment as well as water. Thus, it can be assumed that some amount of sediment migration would accompany dam modification or removal.

A tractive force analysis is a methodology to assess potential changes in the way that the river would transport sediment with the dam removed. Typically the analysis is performed for a "bankfull" flow. Bankfull flow, which would occur almost annually, is sometimes referred to as the "channel forming" or "channel maintenance" flow because it is highly influential in determining channel width, planform (e.g., bends and meanders), and the gradation of bed substrates. The bankfull flow also has a high enough velocity to initiate particle motion but is shallow enough to allow turbulent flows to interact with the channel bed and is therefore representative of the flow most significant in moving sediment. Bankfull flow usually occurs at a flow less than a 2-year flood. Since the bankfull flow for the West Branch Housatonic River is unknown, it is being approximated as a 2-year flood for modeling purposes.

For the Mill Street dam, a tractive force analysis was prepared for both the 2-year flood and 100-year flood. The 2-year flood, representing the bankfull flow, occurs frequently enough to influence sediment transport and channel form. The 100-year flood has less probability than a 2-year flood, but could result in the movement of bed and bank materials such as boulder riprap used to protect against scour and bank erosion.

The tractive force analysis uses energy gradeline slope and channel depth to calculate the incipient diameter of particles that would begin to be moved by a given flow. For non-cohesive bed materials greater than one centimeter in diameter, the tractive force (in kilograms per square meter) is approximately equal to the incipient diameter of the riverbed particles (in centimeters), a guideline sometimes referred to as Lane's relationship. The incipient diameter is the diameter at which individual particles subjected to a shear stress begin to move. While sediment transport is a very complex phenomenon, changes in tractive force from one cross section to another, or from one condition to another (e.g., dam repair vs. dam removed), may predict changes in sediment transport and channel maintaining processes.

For a given tractive force, the corresponding incipient diameter of the substrate can be classified using any of several soil classification systems. For this analysis, the Unified Soil Classification System (USCS) was used. The soil gradations for the USCS are as follows.

Sediment Type	**Diameter (mm)**	**Diameter (in)**
Fines (Silt, Clay)	< 0.075	< 0.003
Fine Sand	0.075 – 0.425	0.003 – 0.02
Medium Sand	0.425 – 2.00	0.02 – 0.08
Coarse Sand	2.00 – 4.75	0.08 – 0.19
Fine Gravel	4.75 – 19	0.19 – 0.75
Coarse Gravel	19 – 75	0.75 – 2.95
Cobbles	75 – 300	2.95 – 11.8
Boulders	> 300	> 11.8

5.0 HYDRAULIC MODELING RESULTS & INTERPRETATION

5.1 HEC-RAS Results

Tables 1 through 3 in Appendix C summarize the results of the HEC-RAS analysis for the river reach just upstream of the Mill Street dam. As discussed earlier, cross section data upstream of the railroad trestles was not available, and hydraulic results from the HEC-RAS modeling between the trestles and West Street bridge have too much uncertainty to report.

Figures 8 through 10 illustrate the water surface profiles for the existing condition, 1:20 (5%) constructed riffle, and 1:30 (3.3%) constructed riffle, respectively.

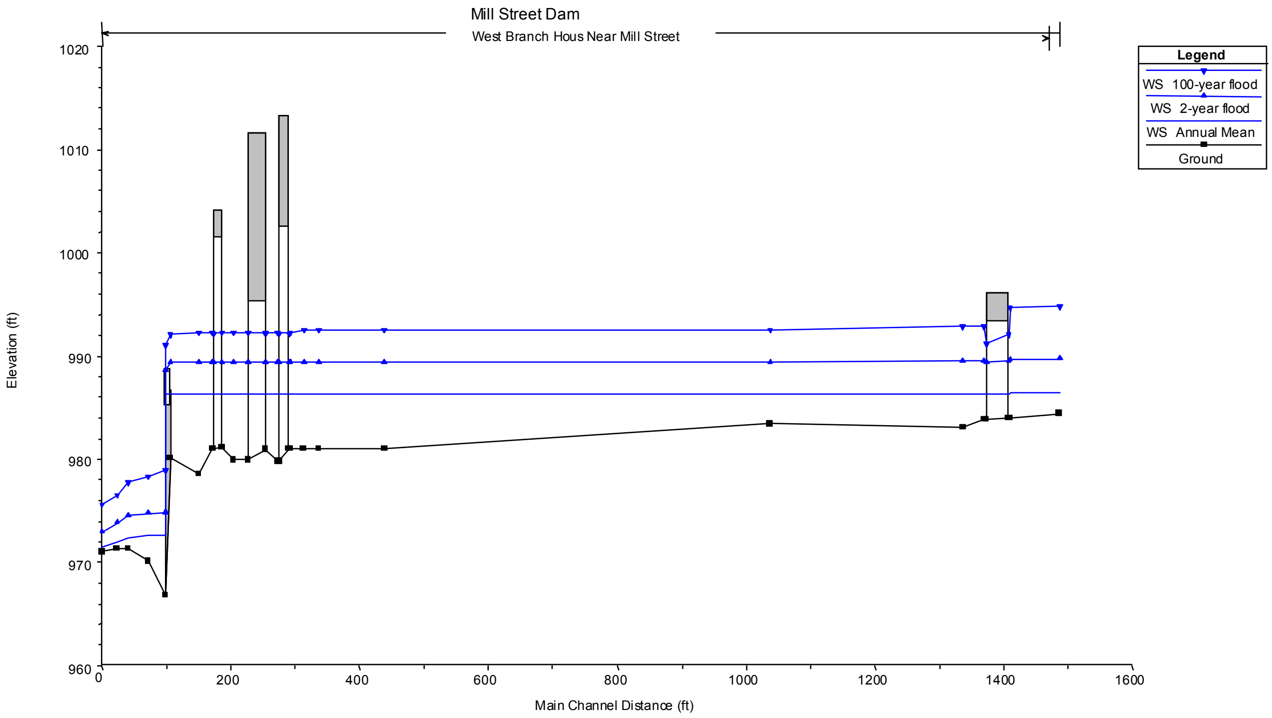

Figure 8: HEC-RAS water surface profiles under existing conditions.

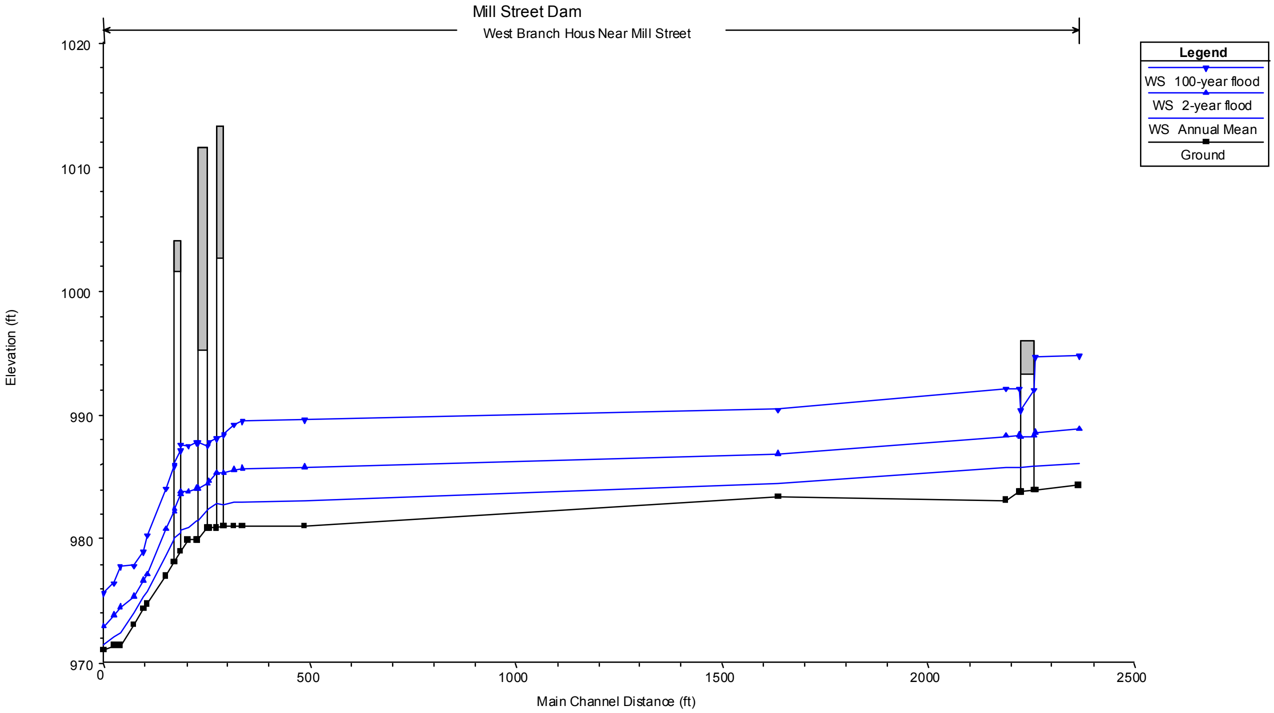

Figure 9: HEC-RAS water surface profiles with 1:20 (5%) constructed riffle after dam removal.

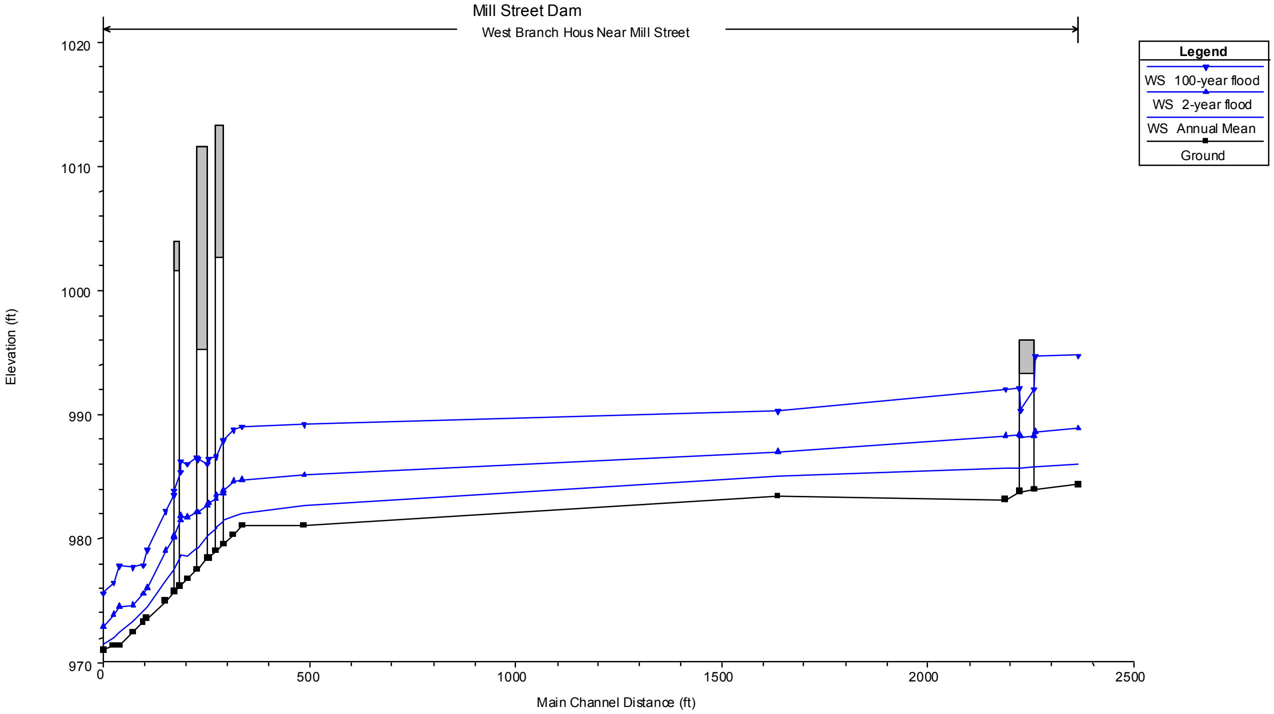

Figure 10: HEC-RAS water surface profiles with 1:30 (3.3%) constructed riffle after dam removal.

5.2 Scour Analysis

The results of the scour analysis for the 100-year flood are summarized on Table 4. The calculated scour is different for each railroad trestle, depending on its method of construction and geometry. All scour calculations are approximate, and are based on the limited survey data available.

5.2.1 Pile-supported Trestle

For the pile-supported trestle, just upstream of the Mill Street dam, pier scour would occur. The trestle does not significantly constrict the river width, so that contraction scour is not anticipated to occur. For the existing (dam in) condition, pier scour would occur as deep as 4.0', down to a minimum elevation of 977.7' (Figure11). All views are looking downstream.

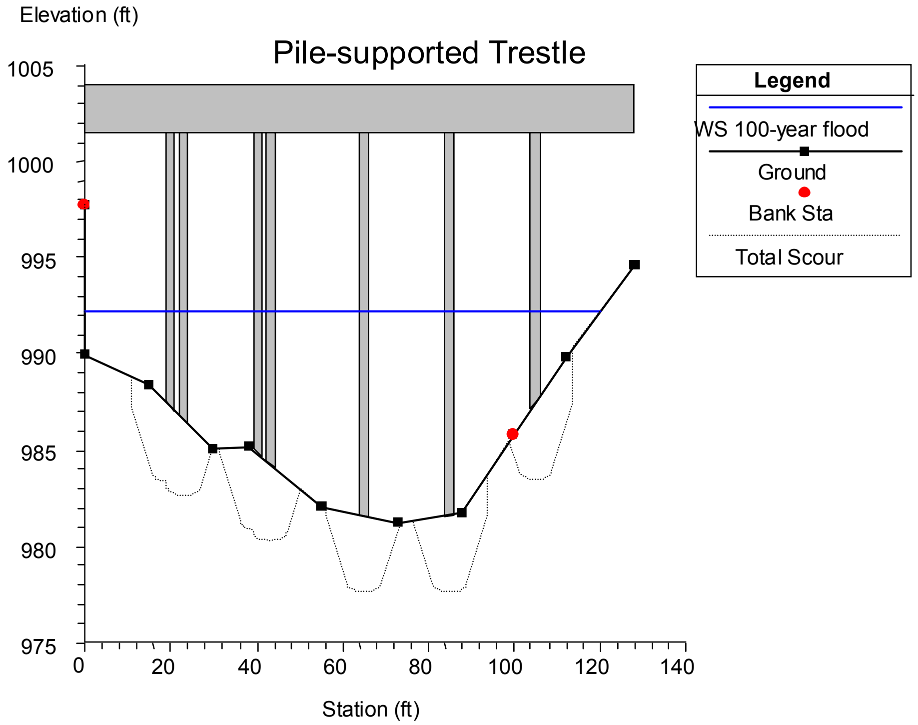

Figure 11: Pile-supported trestle under existing conditions.

As noted previously, it is not possible to model the alternative with the dam and impoundment sediments removed (Alternative A), due to unknowns about the original river morphology and substrates. However, if a 1.4% bed slope was restored between the tailwater scour pool and West Street, the thalweg would be at an approximate elevation of 973.5’ in the vicinity of the pile-supported trestle. This elevation is below the minimum scour elevation predicted for the existing conditions.

The maximum scour depth increases with the 1:20 constructed riffle, as illustrated in Figure 12.

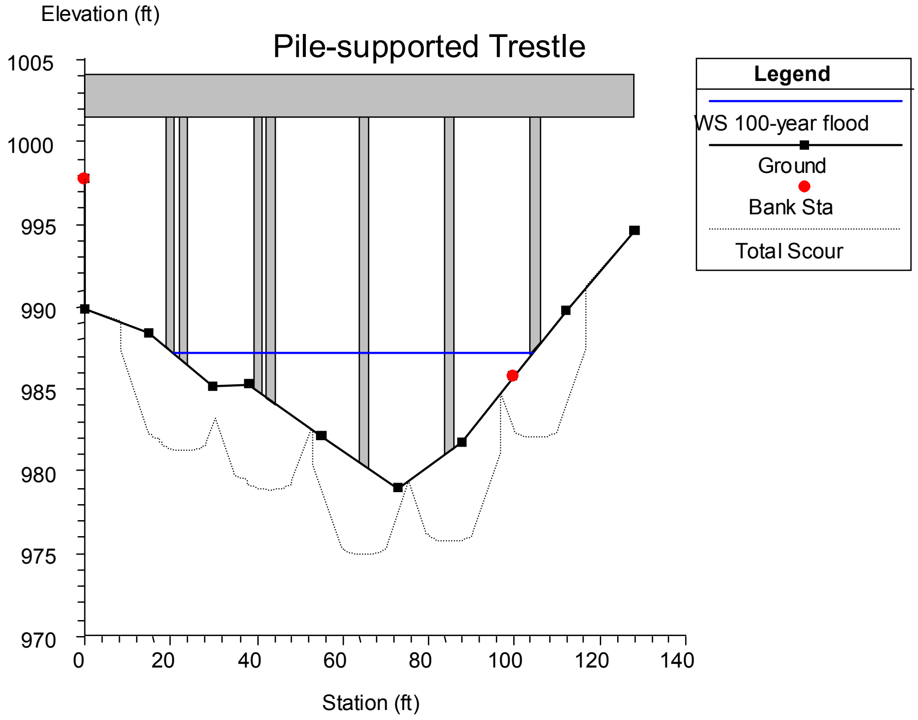

Figure 12: Pile-supported trestle with 1:20 (5%) constructed riffle.

The increase in pier scour results from the lower water level and increased velocities after dam removal. In addition to the increased scour depth, the minimum scour elevation is also influenced by the bed elevation being lowered from existing conditions, and replaced with a constructed riffle with a 5% slope. For the 5% constructed riffle, the maximum scour depth would be 5.4’ with the minimum scour elevation 975.0’, which is lower than the scour predicted for existing conditions.

As illustrated in Figure 13, the constructed riffle with the 3.3% slope would result in a maximum scour depth of 5.7’ and a minimum scour elevation of 971.7’. Again, the scour is related to the increased velocities after dam removal and the lowering of the bed elevation. The minimum scour elevation is 6.0’ lower than the predicted scour under existing conditions.

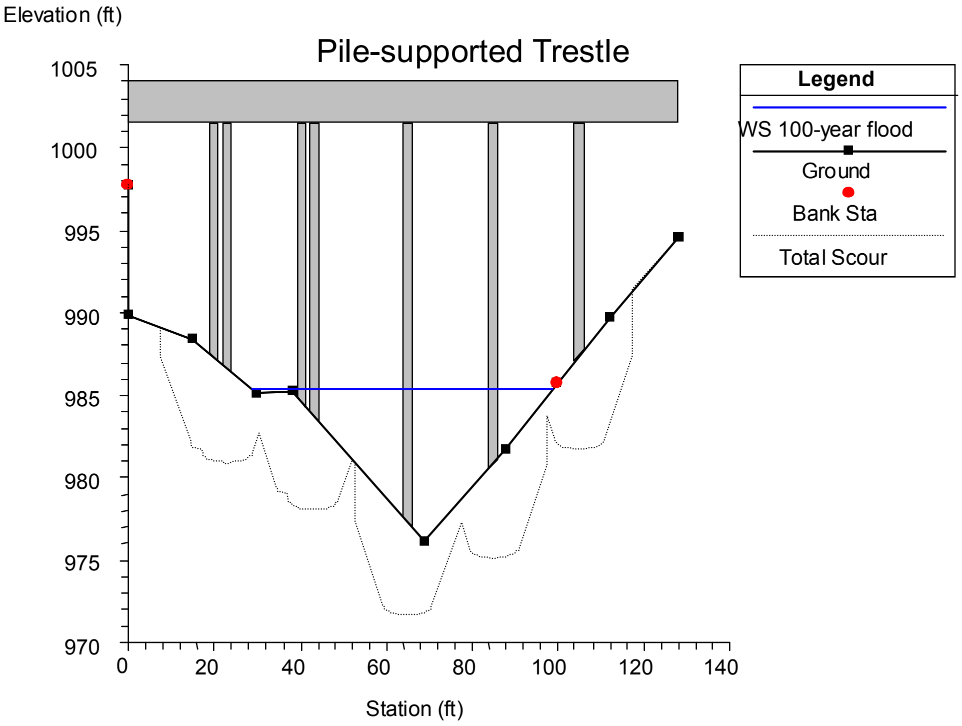

Figure 13: Pile-supported trestle with 1:30 (3.3%) constructed riffle.

The scour that is computed to theoretically occur at the outermost piles, with bed elevations above the 100-year flood level, seems counterintuitive, and is partly related to the scour computation which relies on maximum approach (*i.e.*, mid-channel) velocities and depths. However, scour around the inboard piles will likely migrate outward, destabilizing the bed near the outboard piles and causing scour around those piles as well.

The scour modeling indicates that the pile-supported trestle, just upstream of the dam, is subject to pier scour under existing conditions. The depth of the piles, and the presence of any footings or existing scour protection, is unknown.

Therefore, there are no assurances that the trestle is protected against scour under existing conditions. However, it is apparent that dam removal alternatives will lower the scour elevations, both by lowering the riverbed and increasing velocities around the piles. Since the predicted minimum scour elevations are much lower than the existing bed elevation and the predicted scour under existing conditions, dam removal design would have to carefully evaluate scour around this trestle. Given that this pile-supported trestle is abandoned, removal of this trestle may be the most feasible option to protect against pier scouring and the undermining of the trestle's pile supports.

5.2.2 Center Trestle

The center trestle, upstream of the pile-supported trestle, fully spans the river between abutments. The river widens slightly from its upstream width, so that no contraction scour is predicted by HEC-RAS. As illustrated in Figure 14, there is a maximum scour depth of 4.6' under existing conditions, due to abutment scour at the left abutment, with a minimum scour elevation of 978.6'

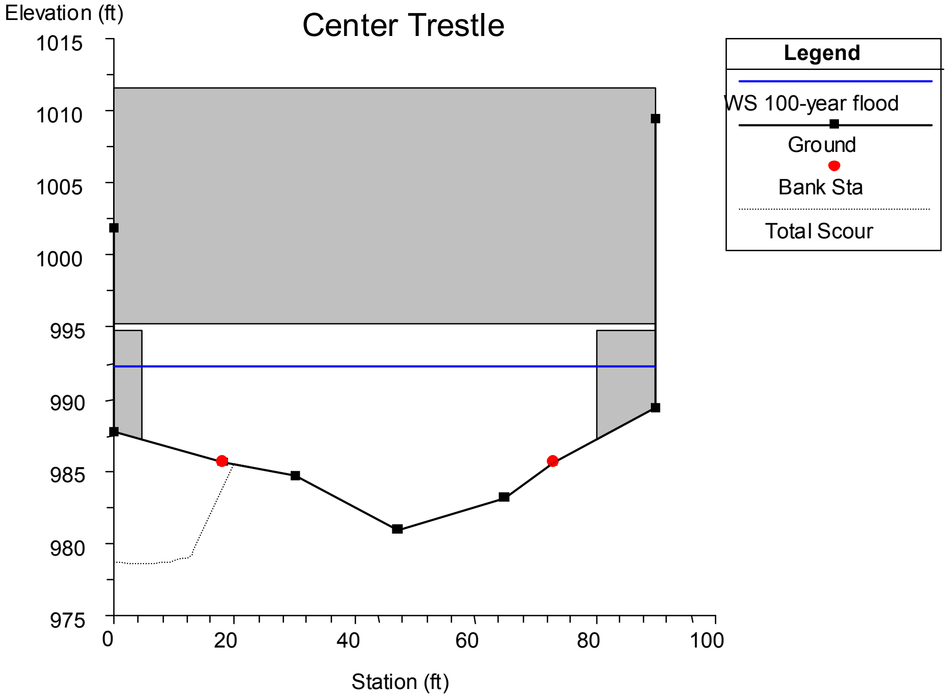

Figure 14: Center trestle under existing conditions.

The center trestle does not abruptly restrict the channel width; in fact, the river widens slightly in this location on the right side of the channel (looking downstream). Therefore, there is no contraction scour predicted by HEC-RAS, and no predicted scour against the right abutment. This is not to say that there will not be any scour against the right abutment, just that HEC-RAS views the right abutment as being protected by the upstream channel geometry. In reality, there may be scour on the right abutment due to eddying, or bank erosion just upstream of the right abutment. These are conditions that cannot be reliably modeled by HEC-RAS with the existing geometric information. However, given that the greatest scour would still probably occur against the left abutment—with its greater exposure—we can conclude that there will be abutment scour under existing conditions against the left abutment, and perhaps even the right abutment.

If a 1.4% slope is restored between Mill Street dam and West Street, the thalweg elevation at the center trestle would be at an approximate elevation of 974.4’. This is deeper than the minimum scour elevation predicted under existing conditions.

For the constructed riffle at a 5% slope, the maximum scour depth would be 2.0’ and the minimum scour elevation would be 985.2’ (Figure 15, left abutment). For the center trestle, HEC-RAS predicts that the abutment scour would decrease after dam removal. Although velocities would increase after dam removal, the water level is lowered considerably so that the flow barely reaches the abutments, thereby reducing the scour potential. However, this will only occur if the riverbed is stable and does not downgrade.

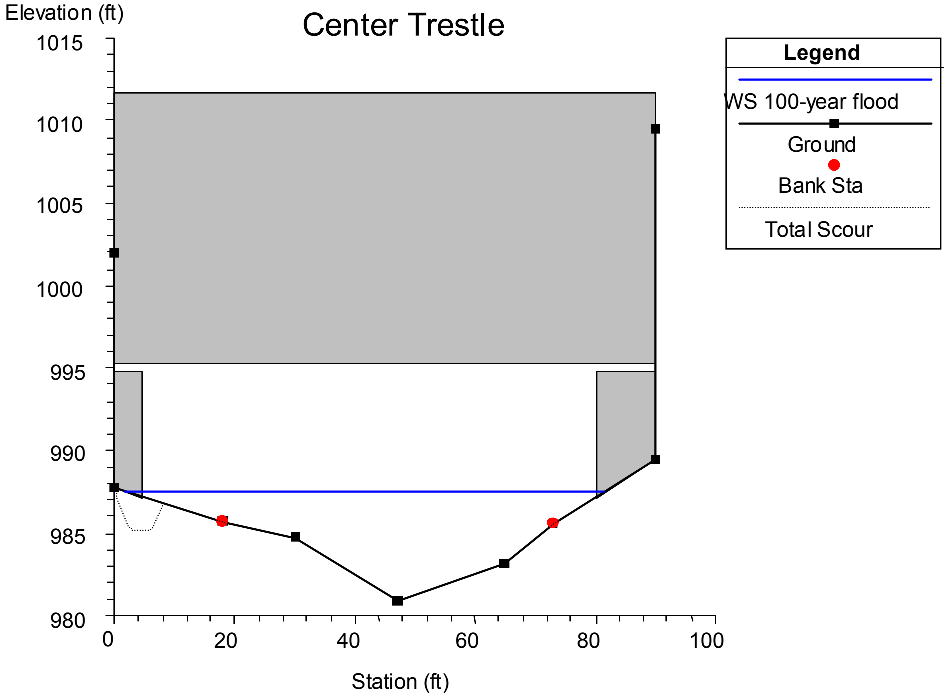

Figure 15: Center trestle with 1:20 (5%) constructed riffle.

The constructed riffle with a 3.3% slope lowers the riverbed in the vicinity of the center trestle, so that the elevation of the 100-year flood does not reach the abutments (Figure16). Again, a stable riverbed is assumed. If the bed downgrades, erosion could occur near the abutments.

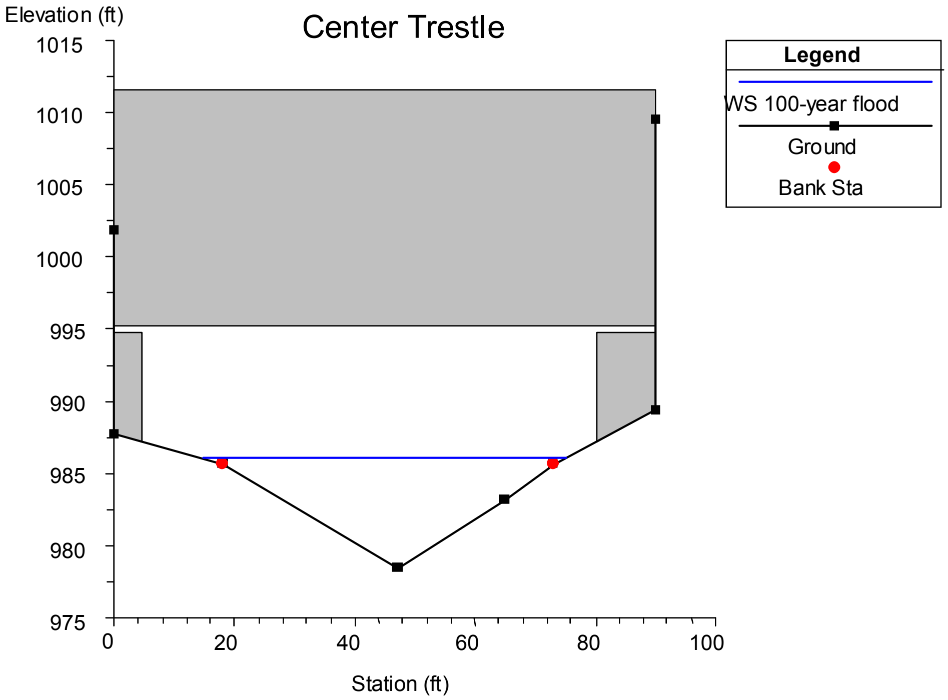

Figure 16: Center trestle with 1:30 (3.3%) constructed riffle.

The depth of the abutments at the center trestle, and information about any abutment footings, are unknown. For the center trestle, there should be concern about excavating sediment below the minimum scour elevation that occurs under existing conditions, as might occur under Alternative A. If the depth of excavation is minimized, with grade control provided by a constructed riffle, the decrease in water levels should help keep erosive velocities away from the bases of the abutments and thereby decrease the scour potential. For the lower-gradient riffle (3.3% slope), there would be a deeper excavation required than for a constructed riffle with a 5% slope. While detailed analysis of geotechnical issues is outside the scope of this analysis, it should be noted that further geotechnical investigations may be required to verify that lowering bed elevations in the vicinity of this trestle will not reduce the bearing capacity of soils at the bases of the abutments.

5.2.3 Upstream Trestle

The upstream railroad trestle fully spans the river between abutments. Scour modeling indicates that under existing conditions, both contraction and abutment scour would occur (Figure 17). The maximum depth of scour would be 9.8’, with a minimum scour elevation of 969.3’.

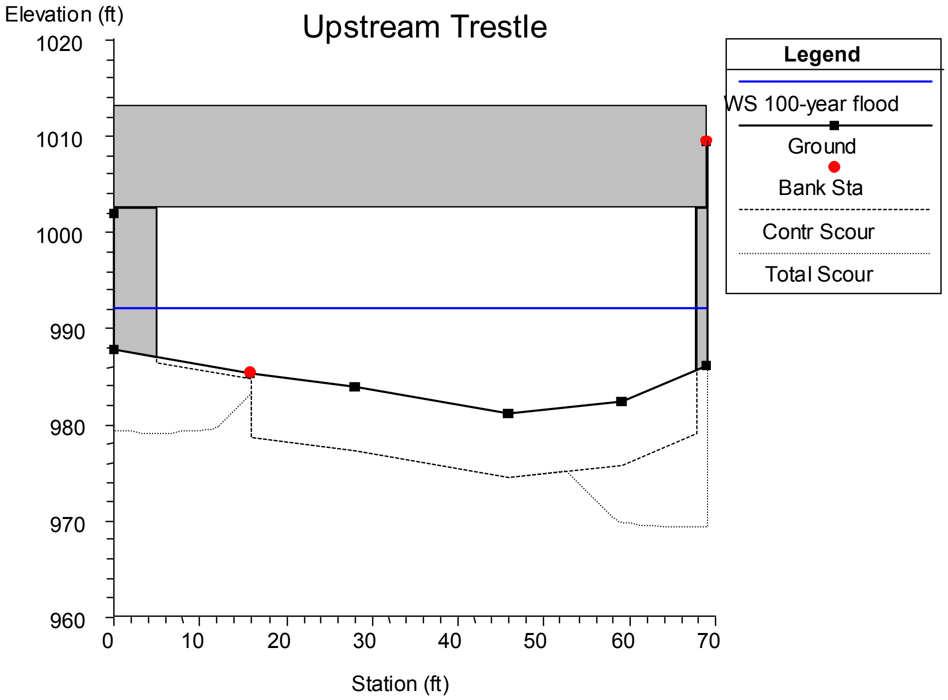

Figure17: Upstream trestle under existing conditions.

If a 1.4% bed slope is restored between the Mill Street dam and West Street, the approximate thalweg elevation at the upstream trestle would be 974.9’. Although this elevation is above the minimum scour elevation predicted for existing conditions, it does not mean that this alternative would protect the abutments. The scour under this alternative cannot be predicted unless the geometry after the dredging of impounded sediments is known, but it is likely that some scour would occur.

With the dam removed and a 5% riffle constructed, the 100-year flood level would fall appreciably (Figure18). However, there would still be flow at the base of the abutments, and an overall acceleration of channel velocity, so that the scour is still appreciable. The maximum scour depth would be 11.0’ with a minimum scour elevation of 968.1’, slightly lower than the predicted scour for existing conditions.

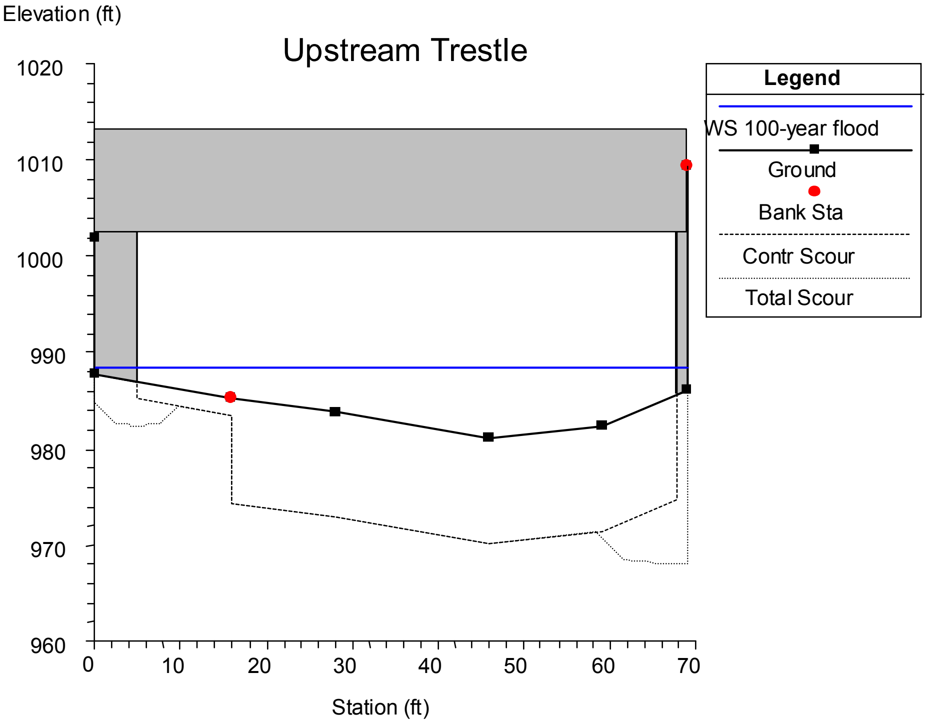

Figure 18: Upstream trestle with 1:20 (5%) constructed riffle.

The 100-year flood level for the constructed riffle with a 3.3% slope would be slightly lower than for a 5% slope, decreasing the flow depth at the abutments (Figure 19). However, the river would still span the channel between the abutments, so that contraction scour and abutment scour would occur. For this alternative, the maximum scour depth would be 11.2’ with a minimum scour elevation of 968.5’, also slightly lower than the predicted scour under existing conditions. For the upstream trestle, therefore, there is scour potential under existing conditions, and a slightly greater scour potential if the dam is removed.

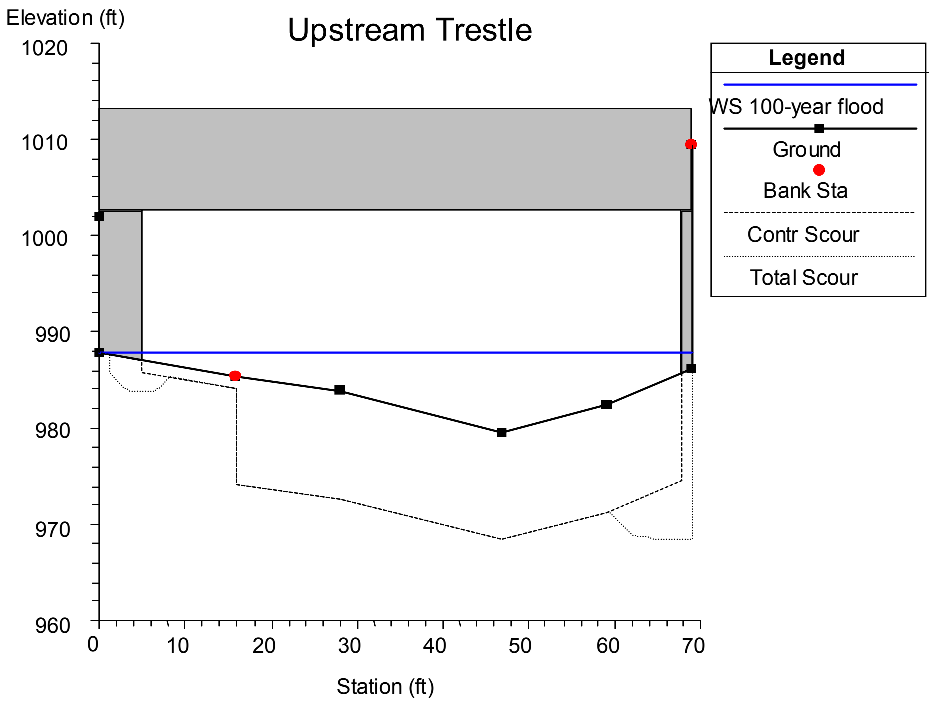

Figure 19: Upstream trestle with 1:30 (3.3%) constructed riffle.

5.3 Tractive Force Analysis

As summarized on Tables 5 and 6, the dam removal would increase the incipient diameter of particles that could be moved during a 2-year flood and 100-year flood. Under existing conditions, a 2-year flood would be expected to transport fines and fine gravel, much of which might be deposited against the upstream face of the dam. A 100-year flood could potentially move larger substrates, mostly coarse gravel but also cobbles. With the dam removed, the incipient diameter of particles increases dramatically, with the river able to move cobbles and boulders during either a 2-year or a 100-year flood event.

The tractive force analysis indicates that after dam removal the reach just upstream of the dam—in the vicinity of the trestles—will likely become dominated by coarse substrates. Smaller substrates (*i.e.*, fines, sands and gravels) are likely to be entrained by flood flows, resulting in a channel dominated by cobbles and boulders. For the constructed riffles, it will be necessary to provide rocks of a sufficient size—greater than the incipient diameter—to create a stable riverbed.

5.4 Mean Annual Flow

As discussed earlier, limited hydrologic information is available for the West Branch Housatonic River. An average annual flow of 68 cfs for the West Branch Housatonic River was estimated based on prorated streamgage data from the East Branch Housatonic River, although this flow is considered approximate.

Hydraulic properties for the mean annual flow may be representative of the depths and velocities that would typically be encountered by aquatic species, such as fish. Large increases in velocity, or large decreases in channel depth, may indicate potential upstream passage barriers for some species. However, these changes can also result in positive ecological benefits as well, such as increased aeration (*i.e.*, dissolved oxygen) and coarser substrates favored by some fish and macroinvertebrates.

Tables 1 through 3 summarize the HEC-RAS modeling, including an analysis of the estimated mean annual flow. As anticipated, the removal of the dam's backwater and the placement of constructed riffles will increase velocities and decrease depths. Tables 7 through 9 provide further summaries of the estimated hydraulic changes for the constructed riffle alternatives. As discussed earlier in the report, the hydraulic changes that would result from dredging impounded sediments upstream of the Mill Street dam cannot be reliably predicted, due to a scarcity of data about the original bed profile. However, this alternative would also result in an overall increase in velocity and decrease in channel depth compared to the existing backwatered conditions.

For some cross sections, velocities are slightly higher for the constructed riffle with a 3.3% slope, compared to a constructed riffle with a 5% slope. This is counterintuitive, since steeper gradients usually imply increased velocity. The effect is due to the overall change in channel width, as summarized on Table 9. The constructed riffle with the 3.3% slope requires a deeper excavation and lower bed profile, which results in a narrower channel unless channel side slopes can be steepened. In actual design, the channel geometry would be designed to maximize the available width, maximize depth and minimize velocity while allowing for stable side slopes.

On a percentage basis, the increases in velocity after dam removal seem very high. However, velocities after dam removal are only a little higher than the velocities downstream of the scour pool at the base of the dam, where there are riffles that are probably representative of a natural morphology for this reach of the river (cross sections A, B and C). Increases in velocity at the base of the dam (cross sections D and E) result from the filling in of the scour pool with the tail of the constructed riffle.

APPENDIX A

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REFERENCES CITED

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APPENDIX B

FIGURES (DRAWINGS OF EXISTING STRUCTURES AND ALTERNATIVES)

APPENDIX C

TABLES