Preliminary Assessment and Conceptual River Restoration Plans

for the

Mad River between NH Route 11 and Tappan Street

Farmington, New Hampshire

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Subject: Preliminary Assessment and Conceptual River Restoration Plans for the Mad River between Route 11 and Tappan Street, Farmington, NH

Dear Lorie:

We have completed a preliminary assessment of approximately one-half mile of the Mad River between NH Route 11 and Tappan Street (the "study reach") and prepared conceptual plans and a cost estimate for restoring the river adjacent to the St. Peter's Church parking lot. Our findings should be considered preliminary as they are based on limited observations, measurements, and document review, including the following:

- Field observations made during our site visit on October 8, 2009;
- Measurements made during our October 8 site visit, including two cross-sections and a longitudinal channel profile surveyed in the reach bordering the Church parking lot;
- Surficial geology mapping provided by the NH Geological Survey (NHGS) and a brief report by Shane Csiki (NHGS Fluvial Geomorphology Specialist) contained in an email dated August 21, 2009;
- USGS topographic maps covering the Mad River watershed (Alton, Baxter Lake, Farmington, and Parker Mountain 7.5 minute quadrangles);
- Aerial photographs captured 1942 (month unknown), October 1953, and October 1974;
- A July 2008 orthophotomap;
- Regional hydraulic geometry curves for New Hampshire (2005) and Vermont (2006);
- FEMA Flood Insurance Rate Map (FIRM) number 33017C0114D;
- FEMA Flood Insurance Study (FIS) for Strafford County, NH dated May 17, 2005; and
- A portion of a report prepared by the U.S. Army Corps of Engineers New England Division titled "The work of the U.S. Army Corps of Engineers in New Hampshire 1989".

Surficial Geology and Valley Characteristics

The river channel through the study reach is bordered and underlain by a heterogeneous mixture of unconsolidated material ranging in size from sand to boulder. With the exception of an area of exposed bedrock which spans the channel at the Route 11

Bridge, the river bed and banks are comprised of erodible material. In general, the surficial geology mapping shows alluvium in the valley bottom, glaciomarine deposits on the south side of the river, and anthropogenic fill on the north side of the river. A copy of the surficial geology map is attached in Appendix 2.

The following observations concerning channel and valley materials and characteristics were made during our site walk:

- Terraces border the left (north) bank from the Tappan Street Bridge to a point just downstream from the Route 11 Bridge. The height of these terraces varies with the lowest located near the upper end of the study reach. All terraces appear to be above the active floodplain elevation and some are high enough to be above the flood prone area. The surficial geology map shows anthropogenic (human-placed) fill along the left bank through most of the reach; however, we observed what appears to be native alluvial deposits on the banks in most locations (see photo 9 in Appendix 1). The left bank at the lower end of the reach (in the vicinity of the Church parking lot) does appear to be comprised of human-placed fill.

- Terraces border the right (south) banks in many areas; however, high valley walls form the right bank at the upstream end of the study reach and at the sharp meander bend where mass-wasting of the slope is occurring (see photos 6 and 7 in Appendix 1). The valley wall at the mass-wasting site is comprised of glaciomarine deposits which were observed as a loose mixture of sand, gravel, cobble, and boulders. Where terraces border the right banks, they were observed to be of similar elevation and composition as those bordering the left banks.

- A pebble count to classify channel materials was not performed; however, we estimate that the mean particle size (D_{50}) is in the cobble size range. Channel materials appeared to be somewhat finer at the downstream end of the study reach than at the upstream end.

- Forested areas border the channel in most areas. Dominant species include sugar maple, white pine, white ash, and red oak. The width of these forested buffers varies and is narrowest along the left bank in the upstream portion of the reach and along the right bank in the vicinity of the mass-wasting site. Woody vegetation has been cleared along approximately 150 feet of the left bank in the middle of the reach (see photo 10 in Appendix 1) and along the left bank at the Church parking lot and on the upstream abutting property.

The valley is considered partly confined as terraces have formed in most areas, though the river makes contact with the valley walls in a few locations. Given the valley and surficial geology characteristics, the stable channel form is expected to be a single-thread, meandering channel bordered by active floodplains – a C stream type per the Rosgen stream classification system. Due to the non-cohesive, erodible materials, vegetation likely has a strong influence on bank stability in the absence of artificial revetments.

Anthropogenic Modifications

The channel and overbank areas appear to have been directly and indirectly impacted by human activities including channel dredging and straightening, removal of riparian vegetation, and construction of riverbank revetments, a water main across the river, and the bridges at Route 11 and Tappan Street. Of these, channel dredging has likely had the greatest adverse impacts to channel stability.

Channel Dredging and Straightening

Windrows of material dredged from the riverbed were observed along the left bank at several locations within the study reach. Trees growing in this material suggest that at least some of the dredging occurred decades ago.

What appears to be a headcut knickpoint was observed approximately 600 feet downstream from the Route 11 Bridge (see photos 4 and 5 in Appendix 1). Below the knickpoint the channel is incised, bank heights are greater, and there is extensive active bank erosion. Above the knickpoint the degree of channel incision is less, the banks are lower, and there is little active erosion.

The Army Corps report cited above describes modifications made to the Cocheco and Mad Rivers in Farmington as part of the “Cocheco River Local Protection Project”. This flood control project was constructed by the Corps in 1956 and 1959. Construction occurred along approximately 7,800 feet of the Cocheco River below the Central Street Bridge and approximately 600 feet of the Mad River above its confluence with the Cocheco River. Per the Corps report, this work included:

- Straightening about 600 feet of the Mad River at its confluence with the Cocheco River;
- Enlarging and straightening about 3,100 feet of the Cocheco River between the Central Street and South Main Street Bridges;
- Constructing about 3,000 feet of earthen dike along the left bank of the Cocheco River between the Central Street and South Main Street Bridges using material excavated from the channel; and
- Widening and deepening about 4,000 feet of the Cocheco River downstream from the South Main Street Bridge.

Per the report, the project was repaired on two occasions due to flood damage – once in 1964 and again in 1985. A portion of the Corps report is included in Appendix 6.

Channel incision observed below the knickpoint is likely a result of the dredging which occurred within the study reach and/or as part of the Corps flood control project. The knickpoint may continue to advance upstream, but is unlikely to proceed beyond the exposed bedrock which controls the riverbed grade at the Route 11 Bridge.

Reproductions of 1942, 1953, 1974, and 2008 aerial photographs, with tracings of the approximate riverbank locations from each year overlaid, are attached in Appendix 3. To produce these exhibits, the 1942, 1953, and 1974 photos were scanned and the digital images were “rubber-sheeted” to the 2008 orthophoto using three landmarks common to each photo – the center of the Tappan Street Bridge, the intersection of High

and Maple Streets, and the intersection of Central Street and Perkins Avenue. Once all of the images were scaled and aligned, the approximate riverbank locations were digitally traced on each photo. Magnification of the original 1953 and 1974 photos was also utilized to identify features indicative of the riverbanks on those photos (the original 1942 photo was not available for use, only the scanned image). Due to ground obscured by forest canopy and shadows, limited resolution, and distortion of the 1942, 1953, and 1974 photos, the riverbank locations are only approximate.

Comparisons of the various riverbank locations suggests that the meander bend at the upstream end of the Church parking lot was realigned in a manner which increased the meander radius and shifted the river about 30 to 40 feet to the south. This realignment appears to have occurred sometime between 1953 and 1974, which is also the time frame within which the Church and parking lot were constructed.

The photo comparison also appears to indicate that the river alignment between the Church parking lot and the mass-wasting site has shifted, but that the overall channel length and sinuosity between the Route 11 and Tappan Street Bridges have not changed substantially over the photography period of record. The following table summarizes the approximate channel lengths and sinuosities measured from the aerial photographs.

Year	Channel Length	Sinuosity
1942	2,650 ft	1.10
1953	2,720 ft	1.13
1974	2,640 ft	1.10
2008	2,670 ft	1.11

Riparian Vegetation Removal

The 1942 and 1953 aerial photographs show the land on the north side of the river between what is now the Church parking lot and a point about 1,200 feet upstream from the Church parking lot being mostly cleared of woody vegetation. With the exception of the upper 150 feet of this area, much of it has since reverted to woodland. Woody vegetation has also been cleared along the left bank at the Church parking lot and on the upstream abutting property. Although removal of woody vegetation may have adversely affected bank stability, channel incision caused by dredging of the riverbed has likely been a greater factor in destabilizing the banks. As the bed has lowered the bank heights have increased, rendering the rooting depth insufficient to protect the lower banks where erosive forces are greatest and occur most frequently. Photos 5 and 11 in Appendix 1 show active bank erosion despite the presence of woody vegetation along the banks.

Riverbank Revetments

Large stone, granite blocks, and pieces of broken concrete have been placed along portions of the left bank adjacent to the Church parking lot and on the upstream abutting property (see photos 13 through 20 in Appendix 1). These revetments do not blanket the entire bank in most locations. Large boulders have been placed along the toe of the bank at the upstream end of the parking lot and on the abutting property and appear to have been effective at limiting erosion in these areas (see photos 14 – 16 in Appendix

1). The bank in this area is actively eroding where revetments have not been placed (see photo 19 in Appendix 1).

Boulders were also placed along both banks for a short distance immediately downstream of the Route 11 Bridge to protect the abutments. It also appears that boulders were removed from the riverbed and randomly strewn along the banks in the upper end of the study reach between the knickpoint and the Route 11 Bridge, though it is possible that these may be naturally occurring. No other artificial revetments were observed within the study reach.

Water Main Crossing

An iron water main crosses the river about 100 feet upstream of the Tappan Street Bridge. The water main, which is no longer in service, is exposed on the riverbed and has been encased in concrete (see photo 17 in Appendix 1). The pipe and concrete control the riverbed elevation and have created an artificial pool with backwater extending about 150 feet upstream during low flow conditions. The low flow water level drops approximately 1.8 feet (22 inches) from the pool above the water main to a scour pool which has formed immediately below the water main (see Existing Longitudinal Channel Profile in Appendix 4). The height of this drop likely prevents the passage of most Eastern Brook Trout, especially the smaller size classes.

The water main and concrete are sloped across the channel with their lowest point being at the toe of the left bank. This forces the thalweg to be located at the toe of the bank and causes the maximum erosive forces to be exerted in the near-bank region. In addition, backwater created by the water main may be contributing to bedload deposition along the right bank above the crossing where a gravel point bar has formed; however, neither the size of the bar nor the magnitude of deposition appears excessive.

Route 11 and Tappan Street Bridges

The Route 11 Bridge has a span of approximately 30 feet and is founded on exposed bedrock. The bridge is located in a location where the valley is confined and floodplains are not present. As a result, the bridge and roadway approaches do not appear to have substantially reduced channel or overbank conveyance areas or adversely impacted channel stability.

The Tappan Street Bridge has a span of about 42 feet. The road crossing has no provisions for conveying overbank flows; however, due to the incised condition of the channel, there is currently little potential for floodwaters to overtop the banks. The flood profiles in the FEMA Flood Insurance Study (attached in Appendix 5) show backwater extending upstream from the bridge approximately 100 feet during the 10-, 50-, and 100-year floods. This typically indicates the potential for channel instability resulting from in-stream bedload deposition in the low-energy backwater zone; however, no substantial depositional features were observed immediately upstream of the bridge opening.

Stream Morphology and Channel Evolution Stages

The watershed is primarily forested and, with the exception of the portion of Farmington Village surrounding the study reach, is sparsely developed. River flows are not regulated. The Mad River has a drainage area of about 11.0 square miles at the study reach (see Watershed Delineation in Appendix 2). Using this drainage area, the New Hampshire and Vermont regional hydraulic geometry curves predict the following bankfull channel geometry for a riffle bed feature.

	NH Curves (2005)	Vermont Curves (2006)
Bankfull Channel Width	39 ft	38 ft
Bankfull Cross-Sectional Area	94 sq ft	75 sq ft
Mean Bankfull Depth	2.4 ft	2.0 ft

The NH curves predict a bankfull discharge of 376 cfs.

The following measurements were made at the two surveyed cross-sections at the Church parking lot (see cross-section plots in Appendix 4). Note that both cross-sections are located at glide bed features (i.e. at the tail-out of pools). Therefore, the measured bankfull cross-sectional areas and depths are expected to be greater than those predicted by the regional curves, which were developed from measurements at riffle and step bed features.

	Cross-Section above Water Main (profile sta 2+04)	Cross-Section below Water Main (profile sta 2+52)
Bankfull Channel Width	37 ft	43 ft
Bankfull Cross-Sectional Area	107 sq ft	90 sq ft
Mean Bankfull Depth	2.9 ft	2.1 ft
Width-to-Depth Ratio	13	20
Maximum Bankfull Depth	4.7 ft	3.8 ft
Width of Flood Prone Area	56 ft	51 ft
Entrenchment Ratio	1.5	1.2

The average channel slope of the study reach measured between the 280- and 320-foot contours on the USGS quadrangle is 1.4%.

A longitudinal profile was surveyed along 280 feet of the channel adjacent to the Church parking lot (see existing profile plot in Appendix 4). The average water surface slope measured between the top of a riffle near the upper end of the profiled reach and the top of a riffle at the downstream end of the profiled reach was 1.38%.

A pebble count to classify channel materials was not performed; however, we estimate that the mean particle size (D_{50}) is in the cobble size range.

The degree of channel incision, which is expressed as the ratio of the lowest bank height divided by the maximum bankfull depth (both measured from the thalweg), is an important metric in evaluating channel stability (see channel incision exhibits in Appendix 7). Values around 1.0 indicate that the channel is connected to its floodplain at or near the bankfull stage. Values from 1.1 to 1.3 indicate slight incision, values between 1.3

and 1.5 indicate moderate incision, and values greater than 1.5 are indicative of deep incision. The higher the value, the greater the flood flow needs to be before floodwaters overtop the lowest bank. The lack of floodplain access results in greater velocity, depth, shear stress, and stream power in the channel during flood events – conditions which can cause streambed degradation (scour) and bank erosion.

A narrow floodplain bench has formed at the bankfull stage along the right bank at cross-section 2+04. As a result, the degree of channel incision is 1.0 at the cross-section (note that due to the narrow width of the floodplain bench, the channel is still considered entrenched at that location). The degree of channel incision at cross-section 2+52 is approximately 3.4 as the lowest bank is well above the bankfull stage and a new floodplain has not formed at that location. Channel incision varies throughout the study reach. The channel appears to be deeply incised below the knickpoint where new floodplains have not formed. Where new floodplains have formed, the channel is not considered incised. Above the knickpoint the channel appears to be slightly or moderately incised.

Bedform characteristics within the profiled reach are strongly influenced by the water main crossing which has created a backwater pool above the crossing, a cascade over the crossing, and a scour pool below the crossing. Over the entire reach, a defined sequence of bed features was not observed. Rather, the general bedform is best described as plane-bed. It is possible that the rather featureless riverbed is a result of channel degradation which scoured away the former bed features. Given the valley setting, a stable channel would likely have riffle-pool bedforms; however, due to the relatively steep channel slope and coarse materials, plane-bed features, small step/pool bedforms, and/or isolated scour pools downstream of boulders or other obstructions (rather than channel-wide lateral scour pools) could also be expected.

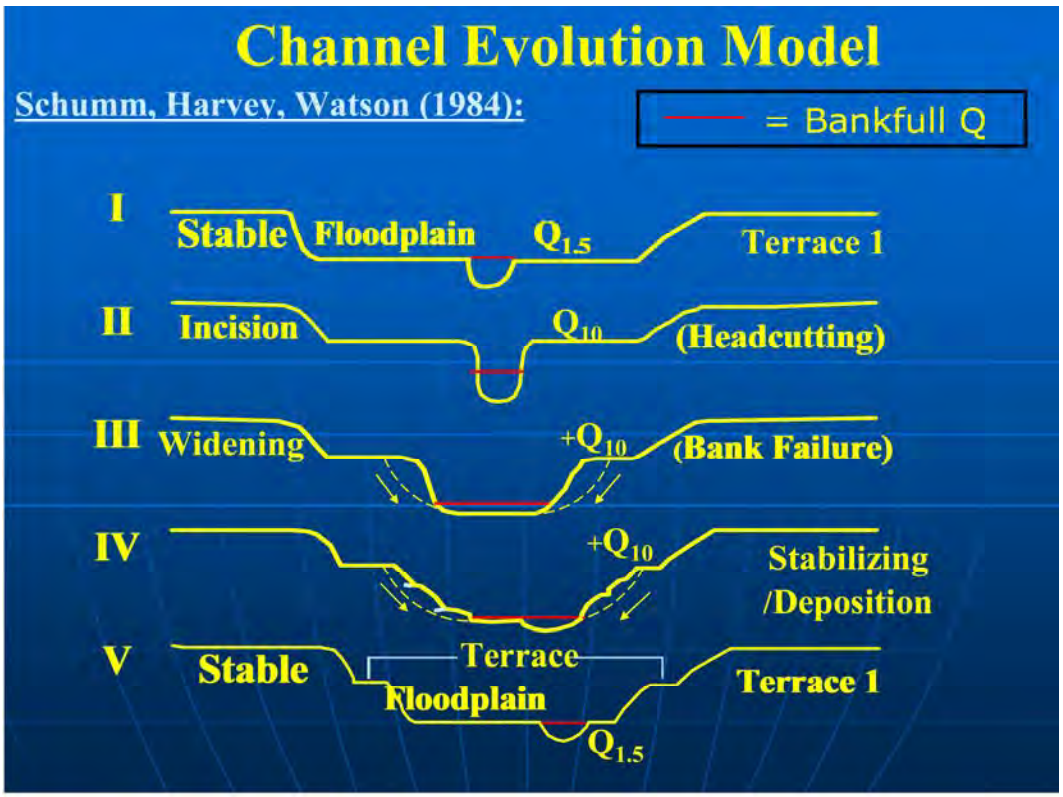
Bank erosion potential appears high to extreme below the knickpoint, except where artificial revetments have been installed. The banks above the knickpoint have low to moderate erosion potential. Bank erodibility is a function of several factors including bank materials, bank height, rooting depth, rooting density, and bank angle. Given the unconsolidated, erodible materials, the remaining factors take on a greater role in stabilizing the banks; however, channel incision has had direct, adverse impacts on these other factors as follows:

- Bank heights have increased;
- Rooting depths and densities have decreased with respect to the bank heights; and
- Bank angles have increased.

The river in the vicinity of the Church parking lot keys out to an F stream type per the Rosgen stream classification system (see the stream classification key in Appendix 7). Throughout the study reach the stream type appears to vary between C and F. C stream types exist where the channel has not incised, where channel incision has not been so severe that the abutting terraces lie above the flood prone area, and where the channel has widened and created new floodplains at elevations corresponding to the new riverbed level. The upper portion of the study reach above the knickpoint and the wide, bifurcated channel segment near the middle of the reach appear to be C stream types. F stream types exist where the channel has incised to a depth where the flood

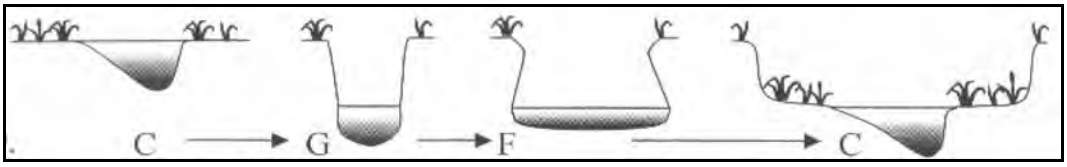
prone area does not extend substantially beyond the banks (i.e. where the flow width during a large flood is not significantly greater than the bankfull flow width). It is also likely that portions of the study reach would key out to a Bc stream type. These are areas where the channel is transitioning from an F to a C stream type via channel widening and deposition of new floodplains. The new floodplains at these locations are wide enough to have increased the entrenchment ratio (calculated by dividing the width of the flood prone area by the bankfull width) beyond the maximum threshold for an F stream type, but not wide enough to meet the lower entrenchment ratio threshold for a C stream type. An example of this appears to exist at the mass-wasting site where a narrow floodplain surface has deposited on the inside of the meander bend.

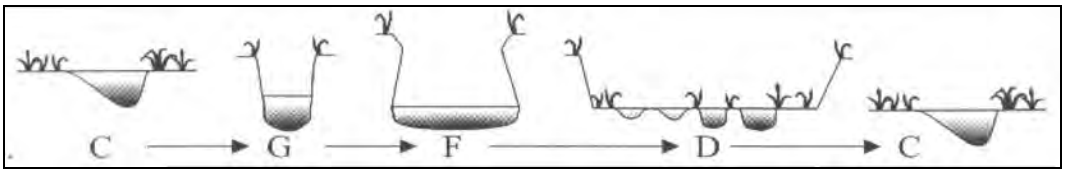
The physical evolution of incised channels typically follows a relatively predictable series of morphological changes as depicted in the following channel evolution model by Schumm et al.

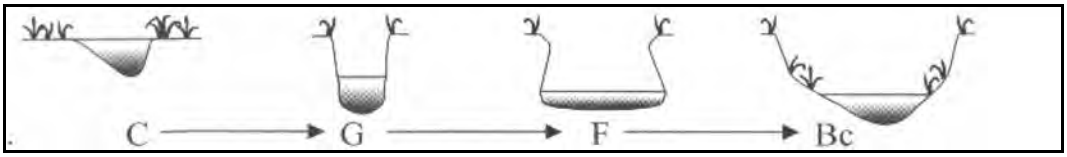


As the model indicates, there are five evolution stages. It appears that stages I, II, III, and IV are all represented at various locations within the study reach. The reach above the knickpoint is still at stage I as it has not been affected by the headcut. The area in the vicinity of the knickpoint is at stage II as it is still actively incising. Stages III and IV are occurring nearly everywhere below the knickpoint where the banks are failing, the channel is widening, and new floodplains are being deposited. It does not appear that any channel segments below the knickpoint have stabilized at the new base level (i.e. reached stage V).

Using the Rosgen stream classification system, one of the following channel evolution scenarios are likely to occur if the channel is allowed to freely adjust. It would likely take decades for the river to reach its stable evolutionary endpoint.







River Restoration Recommendations

For the portion of the study reach along the Church parking lot, we recommend channel alterations which will convert the entrenched F stream type to a stable, moderately entrenched Bc stream type. The conceptual cross-sections in Appendix 4 illustrate the proposed channel modifications which include creating a floodplain bench at the bankfull elevation (i.e. a bankfull bench) along the left bank. The bench would be heavily planted with woody riparian shrubs and flow deflection structures (or similar) would be installed to reduce stress on the new bank while the vegetation becomes established. A gradual slope would be created between the existing parking lot and the back edge of the bench. This technique would promote bank and channel stability by:

- Reducing the degree of channel incision by lowering the height of the eroding left bank to the bankfull elevation;
- Increasing the rooting depth and rooting density;
- Decreasing the bank angle; and
- Reducing channel velocity, shear stress, and stream power during flood events by creating overbank conveyance areas.

This method would, however, reduce the size of the Church parking lot.

Restoration of other incised portions of the study reach should be done in a similar manner. Moderately incised, deeply incised, and fully entrenched segments of the channel should be converted to moderately entrenched Bc or slightly entrenched C stream types with a degree of channel incision of 1.0.

We also recommend removal of the water main and concrete and modifying the channel profile so that the current grade drop over the water main is taken up over a much longer

distance. This will eliminate the fish passage barrier and alleviate any sediment transport impairment the water main crossing currently creates. Several grade control structures are recommended to stabilize the riverbed grade and prevent additional headcutting after the water main crossing is removed. Rock cross-vanes, which serve as both grade control and flow deflection structures, would likely be appropriate at this site.

The knickpoint should be stabilized to prevent its upstream advancement and preserve the stable channel above it. This could likely be accomplished with a few grade control structures (rock cross-vanes or similar).

Shifting the river alignment to the north at the mass-wasting site should be considered as this would allow a bankfull bench to be constructed at the toe of the eroding slope. This would prevent additional undercutting of the slope and allow eroded material to accumulate on the bench so that the slope can regain its angle of repose. It would also increase the meander radius which would decrease the erosive forces on the cut bank.

Converting the bifurcated segment in the middle of the study reach to a single-thread channel should be considered as this would likely improve sediment transport competence and channel stability.

Revegetation using riparian trees and shrubs should be a component of any restoration plan. Due to the erodibility of the materials comprising the riverbanks, deep, soil-binding roots are important for bank stability. Streamside vegetation is also important for riparian and in-stream habitats.

When the Tappan Street Bridge is replaced, the new bridge should be long enough to span the main channel and narrow bankfull benches on either side of the channel. This would likely alleviate any sediment transport impairment currently caused by the restricted bridge opening.

The aforementioned restoration recommendations can only be accomplished if the land bordering the river is not developed. The Mad River is not subject to the regulations of the Comprehensive Shoreland Protection Act and the FEMA floodplain and floodway only cover the river channel itself. We have not researched local land use regulations as part of this study; however, if there currently are no local regulations concerning development along the river, it appears this area can be developed. Therefore, measures to preserve a corridor of land which, at a minimum, encompasses the river's meander belt should be considered. Conservation easements or local land use ordinances are possible methods of achieving this goal.

Finally, the Town of Farmington participates in the National Flood Insurance Program (NFIP). This enables property owners in the community to purchase federally-subsidized flood insurance; however, the Town's participation in the NFIP is contingent upon the adoption and enforcement of a local floodplain management ordinance that meets or exceeds the minimum NFIP standards set forth in the Code of Federal Regulations (CFR) Title 44, Chapter I, Subchapter B. Therefore, any modifications to the channel must comply with these minimum standards or the local ordinance, whichever is more restrictive.

Both a floodplain and a floodway have been identified along the study reach; however, the floodway completely overlaps the floodplain so that their boundaries are identical. A copy of the Flood Insurance Rate Map is attached in Appendix 5. Regulations pertaining to floodways are much more stringent than those governing floodplains. Minimum NFIP standards for floodways are set forth in 44 CFR §60.3(d). These regulations require that the community "*Prohibit encroachments, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not result in <u>any</u> increase in flood levels within the community during the occurrence of the base flood discharge."* CFR §60.3(d)(4) allows encroachments within the floodway which increase flood elevations only if a Conditional Letter of Map Revision (CLOMR) is applied for and issued by FEMA. CLOMR's for projects which raise flood elevations are difficult to obtain as, among other things, landowners along the affected river reach must consent to the flood level increases.

The restoration techniques presented herein generally involve decreasing the degree of channel incision through the excavation of bankfull benches. This excavation would be expected to increase the available flood conveyance area and decrease, rather than increase, flood stages. These modifications are therefore likely be in compliance with the governing floodplain management regulations; however, as required by the minimum NFIP standards, detailed hydraulic analyses would be required to demonstrate the effect of any such construction.

Cost Estimate

The design, permitting, and construction costs for restoring the lower 250 feet of the study reach along the Church parking lot are estimated to be $75,000. This estimate is based upon a project which would include:

- Removing the water main and concrete;
- Re-grading approximately 250 feet of the channel bed;
- Installing four rock cross-vane grade control/flow deflection structures;
- Excavating a bankfull bench along approximately 150 feet of the left bank;
- Planting 110 nursery-grown containerized riparian trees and shrubs on the bankfull bench and slope;
- Spreading humus, a cold season grass mix, and erosion control blankets on the bankfull bench and slope;
- Constructing an asphalt curb along the edge of the parking lot to prevent uncontrolled stormwater runoff from flowing down and eroding the slope;
- Constructing a shallow swale armored with turf reinforcement matting to convey parking lot runoff collected along the curb down the slope in a non-erosive manner;
- Performing final project design including field surveys of the project area; surveys of a comparable, stable, reference reach; hydraulic modeling to evaluate impacts to flood stages; and development of construction plans;
- Preparing an application for a standard dredge and fill permit from the NHDES Wetlands Bureau;
- Preparing bid and contract documents; and
- Providing on-site construction supervision.

The project outlined above includes rather rudimentary provisions for managing stormwater runoff from the parking lot which address conveyance but not treatment. It may be possible to incorporate stormwater treatment into the final design; however, due to uncertainties with respect to feasibility and design, costs for incorporating stormwater treatment have not been included. A line-item cost estimate is included in Appendix 8.

I may be contacted at (603) 444-2544 or sean@headwatershydrology.com if you have any questions.

Best regards,

Sean P. Sweeney, P.E., CWS
Manager
Headwaters Hydrology, PLLC

APPENDICES

Appendix 1 – Photo Location Plan and Photos of Study Reach

Appendix 2 – Surficial Geology Map and Watershed Delineation Plan

Appendix 3 – Aerial Photography/River Alignment Exhibits

Appendix 4 – Existing and Conceptual Longitudinal Profiles and Cross-Sections

Appendix 5 – FEMA Flood Insurance Rate Map (FIRM) and selected portions of the Strafford County Flood Insurance Study (FIS)

Appendix 6 – Corps of Engineers Report (selected portions)

Appendix 7 – Stream Classification Key, Channel Incision Exhibits, and Channel Evolution Model Schematic Drawings

Appendix 8 – Cost Estimate