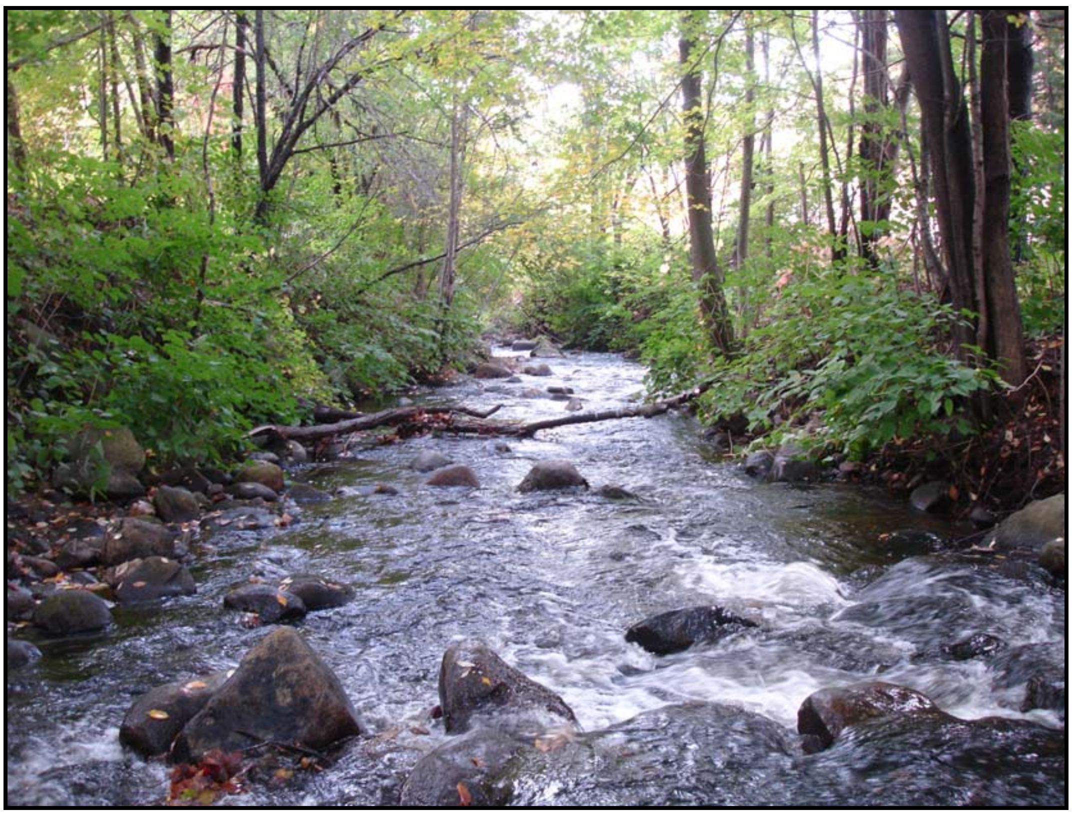
BEAVER BROOK RESTORATION PLAN

STREAM MORPHOLOGY, WILDLIFE HABITAT, AND LAND USE ASSESSMENT



Moosewood Ecological LLC
Innovative Conservation Solutions for New England
PO Box 9—Chesterfield, NH 03443
jeff@moosewoodecological.com
(603) 363-8489

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KEENE, NEW HAMPSHIRE

JEFFRY N. LITTLETON[1]
Conservation Ecologist

SEAN P. SWEENEY[2]
P.E., C.W.S.

MICHAEL H. SIMPSON[3]
Senior Environmental Scientist

CRAIG OSHKELLO[4]
Landscape Architect

JENNIFER HOLTON[5]
Research Assistant

Moosewood Ecological LLC[1]
PO Box 9
Chesterfield, NH 03443
(603) 363-8489
Jeff@moosewoodecological.com
www.moosewoodecological.com

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2-Headwaters Hydrology PLLC
3-MHS and Associates
4-Londello Consulting
5-Antioch University Masters Candidate

TABLE OF CONTENTS

EXECUTIVE SUMMARY

South of Old Concord Road, Beaver Brook is characterized as highly urbanized. Several changes to the brook and its riparian zone have occurred over the past couple of centuries. Changes such as streamside developments, human-made streambank supports, channelization, stormwater drainage, and loss of forest cover and adjacent floodplain wetlands have resulted in cumulative impacts to the riparian and in-stream habitats.

In 2008, Moosewood Ecological LLC conducted a multi-disciplinary assessment of Beaver Brook. The purpose of this project was to assess Beaver Brook's current state in order to develop recommendations for restoration. The main goal was to develop a plan to improve habitat for cold water fish species and other wildlife that use the brook, as well as to return the brook and riparian zone to a more natural state to the greatest degree feasible. As such, the primary objectives set forth were to:

- Assess the stream morphology and channel stability
- Assess the wildlife habitat using volunteer data
- Assess the adjacent land use
- Prepare recommendations for restoration and conceptual designs
- Prepare cost estimates, where applicable

These recommendations, in combination with the conceptual designs, were developed to create innovative solutions to stream restoration, to spur renewed interest in Beaver Brook by the community, to encourage participation of local landowners and business owners within its watershed, and to increase community awareness and education.

As such, this report should be viewed as a starting point for restoration planning, as opposed to a final vision. Additional site-specific planning will be required to continue to build upon the findings and recommendations set forth. Finally, it was not the intent of this project to negatively impact or contribute to flooding or to increase flood stages but rather to improve wildlife habitat and increase flood storage potential.

The stream morphology, channel stability, and wildlife habitat assessments concluded that parts of Beaver Brook were not functioning to its fullest potential nor was it providing optimal aquatic or riparian habitats. This is particularly true of the brook south of Woodlawn Cemetery where the broad, low-gradient valley would typically support extensive active floodplains but no longer occurs due to entrenched stream segments within this area.

As a result of this entrenchment, many sections of the brook do not have access to active floodplains, which limits the availability of backwater refuges for fish and other wildlife during flood events. These entrenched channel conditions also have adverse impacts on riparian habitats, which are dependent upon frequent overbank floods for seed dispersal and deposition of silts, organic matter, and nutrients. Furthermore, these conditions support low in-stream habitat diversity (riffles, runs, pools, and glides) that is needed to support a robust cold-water fishery, whereby limiting species diversity, as well as production of viable offspring.

Several potential barriers to fish passage were noted within the study area, including the following locations: Harrison Street bridge, Concrete channel between Harrison Street and Spring Street, Roxbury Street bridge, sewer main crossing between George and Giffen Streets, and Giffen Street bridge.

Non-native, exotic invasive plants have become prevalent along various segments of Beaver Brook. These invasive plants alter the species composition, excluding native plants that have evolved to associate within riparian habitats. Many of these segments have resulted in dense patches of these plants due to current management practices. Japanese knotweed and purple loosestrife, in particular, have created a serious issue, especially in Woodlawn Cemetery, Carpenter Field, and the brook north and south of Baker Street (near Route 101).

Adjacent land use practices have also played a key role in altering riparian and in-stream habitats due to loss of wildlife habitats and issues associated with pollution. Issues associated with these impacts are a cumulative result of the loss of upland and wetland riparian habitats, stormwater drainage, pollutants associated with residential, commercial, and roadway activities, as well as streambank erosion.

Several sites along Beaver Brook afford various opportunities for restoration. Of these, three sites offer the best opportunities to maximize restoration efforts and habitat improvements, including: Woodlawn Cemetery, Carpenter Field, and the area between Baker Street and NH Route 101. These sites were identified as priorities due, in part, to their size, relative absence of streamside development and human-made streambank supports, and prospects for invasive species management and consequent re-vegetation of riparian habitats.

In light of budgetary constraints, top priorities for immediate restoration efforts include:

- Invasive species management in Woodlawn Cemetery and Carpenter Field
- Eliminate all streambank mowing practices, where applicable
- Removal of the soil berm in the area between Baker Street and NH Route 101
- Re-vegetation of the riparian area within Woodlawn Cemetery, Carpenter Field, and the area between Baker Street and NH Route 101
- Targeted outreach and education for landowners adjacent to the brook, as well as the general residents of Keene
- Changes in operating procedures by the Public Works Department regarding the cleaning of storm basins, plowing or dumping of snow within riparian areas, and re-routing stormwater runoff to natural vegetated buffers
- Track outfalls into the brook to determine the source and their potential hazards

Other recommendations for long-term restoration activities include:

- Elimination of the fish passage barriers
- Creation of a small pilot channel within the concrete bottom of the brook between Harrison and Spring Streets
- Replace bridges to accommodate bankfull channels and active floodplains
- Creation of small floodplains and increased sinuosity of the brook within the Woodlawn Cemetery, Carpenter Field, and the area between Baker Street and NH Route 101
- Streambank stabilization
- Revamping storm drains to decrease sedimentation and associated toxicants
- Decrease stormwater runoff from impervious surfaces by the installation of infiltration and evaporation swales, establishment of rain gardens, and reduction of the width of impervious shoulders by replacing it with permeable materials

Overview

The headwaters of Beaver Brook begin just south of the Bears Den Natural Area in Gilsum, NH, which eventually forms a third order stream just north of Keene. The brook then continues south along Route 10 and along a portion of Route 9. Once it reaches Old Concord Road it becomes an urban brook, illuminating the characteristics of dense residential, commercial, and industrial developments and flood control techniques, and then traverses through the city until its confluence with The Branch along Route 101 (Exhibit 1). This segment of Beaver Brook (approximately 2.65 miles) was the primary focus of this project, especially the area south of Woodland Cemetery.

The purpose of this project was to assess Beaver Brook's current state in order to develop recommendations for restoration. The primary objectives set forth were to:

- Assess the stream morphology and channel stability
- Assess the wildlife habitat using volunteer data
- Assess the adjacent land use
- Prepare recommendations for restoration and conceptual designs
- Prepare cost estimates, where applicable

The content of this report represents recommendations based on potential opportunities to assist in addressing the project's objectives. These recommendations, in combination with the conceptual designs, were developed to create innovative solutions to stream restoration, to spur renewed interest in Beaver Brook by the community, to encourage participation of local landowners and business owners within its watershed, and to increase community awareness and education. As such, this report should be viewed as a starting point for restoration planning, as opposed to a final vision. Additional site-specific planning will be required to continue to build upon the findings and recommendations set forth. Finally, it was not the intent of this project to negatively impact or contribute to flooding or to increase flood stages but rather to improve wildlife habitat and increase flood storage potential.

Stream Morphology Assessment of Beaver Brook

Introduction

Stream channels and adjacent riparian areas form the physical habitat for fish, benthic macroinvertebrates, and other aquatic and semi-aquatic species. The stability and characteristics of stream and riparian areas directly influence habitat quality. Stable channels with well-vegetated riparian buffers typically provide the highest quality aquatic habitats. Degraded, unstable channels typically provide poor quality habitat.

The morphology (physical form) and stability of Beaver Brook and adjacent riparian areas were evaluated to determine which areas are providing high quality habitat, which areas are not, and, for those areas not functioning at their potential, how the channel and adjacent areas can be altered to improve aquatic and riparian habitats in a manner which would promote channel stability and likely comply with federal floodplain regulations.

Methods

The stream morphology assessment included an evaluation of valley types, stream types, bankfull hydrology and hydraulic geometry, lateral channel stability, bridge and culvert crossings, and potential barriers to fish passage. Field work was performed in June and September 2008.

Valley Types

The study area was divided into distinct reaches based upon valley characteristics with reach breaks occurring where valley morphology changes significantly. Valleys were classified into one of the eleven types described below[1].

> *Valley Type I*: "V" notched canyons, rejuvenated side slopes, typically associated with A and G stream types.
>
> *Valley Type II*: Moderately steep, gentle sloping side slopes, often in colluvial valleys, typically associated with B stream types.
>
> *Valley Type III*: Alluvial fans and debris cones, typically associated with A, G, D, and B stream types.
>
> *Valley Type IV*: Gentle gradient canyons, gorges, and confined alluvial valleys, typically associated with F and C stream types.

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[1] Rosgen, D.L. 1996. *Applied River Morphology*. Wildland Hydrology Books, Pagosa Springs, Colorado.

Valley Type V: Moderately steep valley slopes, "U" shaped glacial trough valleys, typically associated with C and D stream types.

Valley Type VI: Moderately steep, fault controlled valleys, typically associated with B, C, and G stream types.

Valley Type VII: Steep, highly dissected fluvial slopes, typically associated with A and G stream types.

Valley Type VIII: Wide, gentle valley slope with a well developed flood plain adjacent to river terraces, typically associated with C and E stream types.

Valley Type IX: Broad, moderate to gentle slopes, associated with glacial outwash and/or eolian sand dunes, typically associated with D stream types.

Valley Type X: Very broad, gentle slopes, extensive flood plains, lacustrine valleys, typically associated with E stream types.

Valley Type XI: Deltas.

As noted in the valley type descriptions above, certain stream types are typically associated with certain valley types. For instance, low-gradient, meandering streams (C and E stream types) are typically associated with broad, unconfined valleys (valley types VIII and X). An entrenched stream (G or F stream type) in this valley setting would likely be unstable or provide less than optimal aquatic and riparian habitats.

Stream Types
Each reach was subdivided into discrete segments based upon stream type. One channel cross-section was surveyed in each stream segment and one pebble count was performed in each reach. Channel slope was field measured within three segments and the average slope of each reach was estimated from USGS topographic mapping. The cross-section, slope, and pebble count information was used to determine the stream type of each segment using the Rosgen stream classification system[2]. A copy of the stream classification key is attached (Exhibit 2).

Bankfull Hydrology and Hydraulic Geometry
The watershed area was determined at the upstream and downstream end of the study area (Exhibit 3). This information was used to estimate bankfull channel dimensions (width, mean depth, and cross-sectional area) using both the NH and Vermont Regional Hydraulic Geometry Curves (Exhibit 4). The channel dimension estimates were used to verify that the field-identified indicators of the bankfull stage, which is the level at which width, depth, cross-sectional area, and other morphological indices are measured, were accurate. [Note that the bankfull stage is the water level associated with the bankfull, or channel-forming,

[2] Rosgen, D.L. 1994. *A Classification of Natural Rivers*, Catena, Vol 22, 169-199, Elsevier Science, B.C. Amsterdam.

discharge. In unregulated streams, the bankfull discharge is equaled or exceeded about two out of every three years on average.]

Lateral Channel Stability

Lateral channel stability was evaluated along the entire length of the study area via an assessment of bank erosion potential. The stream banks were divided into discrete segments with each segment having similar characteristics. Bank erosion potential estimates were based upon seven variables as follows:

- *Ratio of Bank Height to Bankfull Height*
  This variable, often referred to as the bank-height-ratio (BHR), expresses the height of the bank in terms of the bankfull height. A BHR of 1.0 would indicate the top of bank is at the bankfull stage, a BHR of 2.0 would indicate the bank is twice as high as the bankfull depth, etc. Low BHR's are typically associated with stable banks. Bank and bankfull heights were measured at representative locations within each bank segment using a hand level and grade rod.

- *Ratio of Rooting Depth to Bank Height*
  Rooting depth was directly measured where roots were exposed or estimated where roots were not exposed. A ratio of 1.0 would indicate that vegetation roots extend to the toe of the bank. A ratio of 0.1 would indicate that roots extend only ten-percent of the bank height. High ratios indicate well vegetated banks and are typically associated with stable banks.

- *Weighted Root Density*
  This variable is used to estimate overall root mass within the bank. Ocular estimates of root density (%) were made for the portions of each bank segment covered by roots. Root density was multiplied by the ratio of rooting depth to bank height to estimate the rooting density for the entire bank. High values indicate dense roots and are typically associated with stable banks.

- *Bank Angle*
  Bank angle was measured at a representative location within each bank segment using a clinometer. Low bank angle are typically associated with stable banks.

- *Surface Protection*
  This variable expresses the percentage of the bank face which is covered by roots, sod mats, moss, vegetation, woody debris, boulders, or other erosion-resistant materials (including rip-rap). High values are indicative of stable banks.

- *Bank Materials*
  The dominant grain sizes comprising each bank (boulder, cobble, gravel, sand, or silt/clay) were estimated and this information was used to adjust the overall bank stability rating. In general, coarse and cohesive materials are associated with stable banks, though well vegetated banks comprised of sand and gravel can also be stable.

- *Stratification*
  The overall bank stability rating was adjusted if lenses of fine-grained materials exposed to erosion forces were observed.

The values of the first five variables were converted to numerical indices as shown on the attached sample "BEHI Form"[3] (Exhibit 5). Index values were also assigned to the observed bank material and stratification characteristics. The numerical indices were summed to produce a total index value which was then converted to an overall bank erosion potential rating – very low, low, moderate, high, very high, or extreme. Banks comprised of concrete, stone masonry, dry-laid stone, or stone rip-rap were assigned a very low rating.

Bridge and Culvert Crossings and Fish Passage Barriers
Undersized bridge and culvert crossings can create channel instability and fish passage barriers. The size of each stream crossing was measured and compared to measured bankfull channel widths to determine if it accommodates the bankfull channel or causes a constriction which could lead to channel instability. The type of each crossing (bridge, culvert, etc.) and bottom materials were noted along with any conditions such as perch or supercritical flow which could present a barrier to fish passage. Potential fish passage barriers not associated with stream crossings were also documented.

Miscellaneous Observations
Other observations indicative of aquatic habitat quality, channel stability trends, and past channel alterations were also noted. These include the presence of large woody debris, bedload sediment supply, and channelization.

Additionally, one cross-section was surveyed upstream from the study area in the vicinity of Washington Street Extension. With the exception of Three Mile Swamp Dam, the watershed upstream from this cross-section site is relatively undeveloped and therefore unaffected by hydrologic and anthropogenic influences that have affected the study area.

Results

Valley Types
Two stream reaches have been identified within the study area – reach 1 and reach 2. These are labeled R1 and R2 on the attached plans (Exhibit 6).

Reach 1 is about 10,900 feet (2.06 miles) long and extends from the confluence with the Branch to a point just downstream from George Street. This reach flows through the remnant lakebed of glacial lake Ashuelot. The valley type is 'X' (lacustrine valley). It appears that George Street crosses the brook at about the northerly end of the glacial lake. The valley slope is very gentle – about 0.12%. The stable stream type in this valley setting is E.

[3] Wildland Hydrology, Inc. April 2003. *River Restoration and Natural Channel Design Field Guide.*

Reach 2 is about 2,800 feet (0.53 miles) long and extends from a point just downstream from George Street to the upstream limit of the study area at Old Concord Road. The valley type is 'V' and the average valley slope is approximately 2.8%. The stable stream types for this setting are B or Cb.

Stream Types

Reach 1 was divided into nine segments, labeled R1S1 to R1S9, and reach 2 was divided into three segments labeled R2S1 to R2S3 (Exhibit 6). Pebble counts performed in reach 1 and reach 2 resulted in median channel materials particle sizes of medium gravel and large cobble respectively (Exhibit 7). Channel slopes measured within segments R1S9, R2S2, and R2S3 were 0.10%, 2.82%, and 2.44% respectively. The average slopes of reach 1 and reach 2 measured from USGS topographic maps were 0.10% and 2.8% respectively. Bankfull channel geometry was measured at a representative cross-section within each stream segment (Exhibit 8). Plots of each cross-section are attached (Exhibit 9). The following table summarizes the stream morphology variables and the resulting stream type for each segment.

Segment	Bankfull Width (ft)	Width-to-Depth Ratio	Entrenchment Ratio	Sinuosity	Channel Materials	Slope (%)	Existing Stream Type	Stable Stream Type(s)
R1S1	28.2	14.1	2.1	1.31	gravel	0.12*	C4	C4 or E4
R1S2	21.4	9.3	1.8	1.01	gravel	0.12*	G4c	E4
R1S3	15.9	6.9	> 3.1	1.07	gravel	0.12*	E4	E4
R1S4	24.5	10.7	1.6	1.11	gravel	0.12*	G4c	E4
R1S5	15.5	5.7	3.4	1.07	gravel	0.12*	E4	E4
R1S6**	20.4	6.8	1.6	1.21	gravel	0.12*	G4c	E4
R1S7	26.5	11.0	4.3	1.00	gravel	0.12*	E4	E4
R1S8	15.5	6.2	1.4	1.02	gravel	0.12*	G4c	E4
R1S9	19.9	8.0	> 6.0	1.09	gravel	0.10	E4	E4
R2S1	19.3	8.8	1.3	1.02	cobble	2.80*	G3	B3 or C3b
R2S2	26.3	20.2	3.5	1.11	cobble	2.82	C3b	B3 or C3b
R2S3	24.0	13.3	1.3	1.02	cobble	2.44	G3	B3 or C3b
WSE***	21.0	16.2	8.4	1.03	cobble	2.33	C3b	B3 or C3b

* average reach slope measured from USGS topographic mapping

** between Harrison and Spring Streets channel materials are concrete and the bankfull width is 16.0 feet, but the stream type is still Gc

*** cross-section surveyed upstream from study area in vicinity of Washington Street Extension

The presence of G, or gully, stream types in both reaches is an indication that those segments are not functioning to their fullest potential nor providing optimal aquatic or riparian habitats. This is particularly true of reach 1 where the broad, low-gradient valley would typically support extensive active floodplains. G stream types are entrenched and do not have access to an active floodplain. As such, flood flows are typically confined to the channel during all but the most extreme floods, which can lead to channel instability due to elevated shear stresses. This flow confinement also limits the availability of backwater refuges for fish during flood events. The presence of gully stream types in reach 2, though not desirable, is less problematic as the brook in this reach flows through a steeper, more confined valley which would typically support relatively narrow floodplains.

The entrenched channel conditions in G-type stream segments has adverse impacts on riparian habitats which are dependent on frequent overbank floods for seed dispersal and deposition of silts, organic matter, and nutrients. Healthy riparian areas in-turn promote high quality in-stream habitats through bank stabilization, water filtration, flood storage, groundwater recharge (which returns to the stream via groundwater discharge during low flow periods), nutrient retention and transformation, thermal regulation (shading) that promotes higher dissolved oxygen concentrations, supply of large woody material for physical habitat, supply of organic matter as a benthic macroinvertebrate food source, and wildlife corridors.

Furthermore, G stream types support little of the bed form diversity (riffles, runs, pools, and glides) needed to support a robust cold water fishery. Riffles are the most productive areas for benthic macroinvertebrates, runs and pools provide feeding and resting areas for fish, and glides are typically used for their spawning and rearing.

Bankfull Hydrology and Hydraulic Geometry

The watershed area at the upstream end of the study area is approximately 7.1 square miles (Exhibit 3). The drainage area of Beaver Brook at its confluence with The Branch is about 10.4 square miles. Using these drainage areas, the New Hampshire and Vermont Regional Hydraulic Geometry Curves predict the following bankfull channel dimensions and discharges (Exhibit 4).

Drainage Area (sq mi)	Bankfull Width (ft)		Bankfull Cross-Sectional Area (sq ft)		Mean Bankfull Depth (ft)		Bankfull Discharge (cfs)	
	NH	VT	NH	VT	NH	VT	NH	VT
7.1	32	31	67	54	2.1	1.7	250	n/a
10.4	38	37	90	72	2.4	1.9	355	n/a

Bankfull channel dimensions measured in C stream type segments, which are free to adjust their boundaries, are summarized in the following table.

Segment	Bankfull Width (ft)		Bankfull Cross-Sectional Area (sq ft)		Mean Bankfull Depth (ft)	Stream Type
	measured	% of predicted*	measured	% of predicted*		
R1S1	28.2	91	56.6	105	2.0	C4
R2S2	26.3	85	35.2	65	1.3	C3b
WSE**	21.0	68	26.7	49	1.3	C3b
Average	**25.2**	**81**	**39.5**	**73**	**1.5**	

* based on the bankfull width and cross-sectional area predicted by the Vermont Regional Hydraulic Geometry Curves for a 7.1 square mile watershed area.
** Washington Street Extension cross-section

Bankfull channel dimensions measured in E stream type segments, which are free to adjust their boundaries, are summarized in the following table.

Segment	Bankfull Width (ft)	Bankfull Cross-Sectional Area (sq ft)	Mean Bankfull Depth (ft)	Stream Type
R1S3	15.9	35.8	2.3	E4
R1S5	15.5	41.2	2.7	E4
R1S7	26.5	64.5	2.4	E4
R1S9	19.9	49.4	2.5	E4
Average	**19.5**	**47.7**	**2.5**	

As the data demonstrates, the channel dimensions within the study area are substantially smaller than those predicted by both the NH and Vermont Regional Curves. This suggests that the bankfull discharge would also be less than that predicted by the curves. Potential explanations for this include:

- Three Mile Swamp Dam, which attenuates flood flows and reduces peak flood discharges;
- the long, narrow shape of the watershed, which results in longer flow paths, longer times of concentration, desynchronization of flood peaks from tributaries, and lower peak flows; and
- the relatively low elevation of the drainage basin.

Lateral Channel Stability
Bank erosion potential ratings are shown on the attached color-coded Bank Erosion Hazard Plans to visually illustrate bank stability throughout the study area (Exhibit 10). Spreadsheets containing the bank erosion potential data and calculations are also attached (Exhibit 11).

Although some bank segments have a high bank erosion potential, bank erosion hazards are very low, low, or moderate throughout the majority of the study area and relatively little active bank erosion was observed. This is likely due to four main factors:

1. many of the streambanks have been armored with concrete, stone masonry, gabion baskets, stone rip-rap, or dry laid stone walls;
2. channel straightening has minimized shear stresses on the stream banks by directing flow vectors parallel to, rather than into, the banks;
3. most of the streambanks are vegetated to some degree (though invasive species such as knotweed, loosestrife, and honeysuckle are dominant in many areas); and
4. the channel appears to be competent at passing what little bedload sediment is supplied from its watershed.

The most stable streambanks in Reach 1, aside from those which have been armored, are those along an active floodplain (top of bank elevation at the bankfull stage) that are densely vegetated with native riparian shrubs such as silky dogwood, speckled alder, willow, and common elderberry. Not coincidentally, these areas also exhibited some of the highest quality aquatic habitats within the study area.

Naturally stable banks in reach 2 are a result of both vegetation and the coarse, erosion resistant bank materials (cobble and boulder).

Unstable banks are generally high (top of bank elevation above the bankfull stage) with shallow rooting depths and low rooting densities.

Bridge and Culvert Crossings and Fish Passage Barriers
A total of sixteen road crossings and two building crossings (Kingsbury Corporation) are located within the study area. The following table summarizes the location, type, size, and bottom materials of each crossing. This information is also provided on the attached Bridge and Fish Passage Barrier Plan (Exhibit12).

In addition, the table includes a column in which the span of each crossing is divided by the average bankfull width measured for the stable stream type at each crossing site (i.e. 19.5 feet for E stream types in reach 1 and 25.2 feet for C stream types in reach 2). Values less than 1.0 indicate the span is less than the average channel width and that the crossing may create a flow constriction. The lower the value, the greater the constriction. Spans less than the bankfull width can create backwater above the structure that can exacerbate flooding, create sediment transport discontinuity, and lead to channel instability.

Crossing	**Stream Segment**	**Type**	**Size**	**Bottom**	**Span/ Bankfull Width**
Route 12	R1S2	Twin corrugated metal squash pipes	10’ span x 6.5’ rise (each)	Corrugated metal	1.03
Route 101	R1S2/R1S3	Concrete bridge with concrete abutments	15’ span x 8’ rise	Concrete	0.77

Baker Street	R1S3/R1S4	Concrete bridge with concrete abutments and two continuous concrete piers	3 – 8’ span x 7.5’ rise cells	Concrete with gravel deposition	1.23
Marlboro Street	R1S4	Concrete bridge with concrete abutments and two continuous concrete piers	3 – 7’ span x 8.5’ rise cells	Natural substrate	1.08
Kingsbury Corporation downstream	R1S4	Concrete arch beneath building	30’ span x 8’ rise	Natural substrate	1.54
Kingsbury Corporation upstream	R1S4	3 concrete box culverts beneath building	8’ span x 7.5’ rise (each)	Natural substrate	1.23
Kingsbury Corporation bridge	R1S4/R1S5	Concrete and steel bridge with concrete abutments	18’ span x 8.3’ rise	Natural substrate	0.92
Rail Trail	R1S5	Single span steel bridge	70’ span x 11’ rise	Natural substrate	3.59
Water Street	R1S6	Concrete arch	20’ span x 8’ rise	Natural substrate	1.03
Harrison Street	R1S6	Concrete bridge with concrete abutments	17.5’ span x 6’ rise	Concrete	0.90
Church Street	R1S6	Concrete and steel bridge with sloping concrete abutments	13.5’ span x 6’ rise	Concrete	0.69
Roxbury Street	R1S6	Concrete bridge with concrete abutments	15.5’ span x 6.5’ rise	Concrete	0.79
Spring Street	R1S6	Concrete bridge with concrete abutments	18’ span x 5.3’ rise	Natural substrate	0.92
Beaver Street	R1S8	Concrete bridge with concrete abutments	11’ span x 10’ rise	Natural substrate	0.56
Cemetery bridge	R1S9	Steel and concrete bridge on stone abutments	15.5’ span x 5.6’ rise	Natural substrate	0.79
George Street	R2S1	Concrete bridge with concrete abutments	13.5’ span x 7.5’ rise	Natural substrate	0.54
Giffin Street	R2S1/R2S2	3-sided concrete bridge	14’ span x 6’ rise	Natural substrate	0.56
Old Concord Road	R2S3	3-sided concrete bridge	14’ span x 7’ rise	Natural substrate	0.56

As the above table indicates, many of the crossing spans are smaller than the channel width. Despite this, no evidence that these constrictions have caused channel instability were observed. This is possibly due to what appears to be a relatively low supply of bedload sediment.

Several potential barriers to fish passage were noted within the study area as follows.

- *Harrison Street*
  A concrete sill on the downstream side of the bridge creates a water level drop at low flow of approximately eight inches. This likely precludes passage of about half of all brook trout five inches or less in length.[4]

- *Concrete channel between Harrison Street and Spring Street*
  The concrete lined channel may present a passage barrier during low flows due to shallow, uniform flow depth, high velocities, length of the concrete channel section (~1,220 feet), and lack of resting areas. It is possible that this section of the brook poses a passage barrier at all flow levels for similar reasons.

- *Roxbury Street*
  A prominent rise exists in the bed of the concrete channel beneath the Roxbury Street Bridge. It appears that this is an encasement of an existing buried utility line, possible sanitary sewer. The top of the rise is about fifteen inches higher than the downstream channel bottom. The channel bottom slopes between the top and bottom of the rise. Flows down this slope were observed to be supercritical. The combination of the height of the rise, supercritical flow characteristics, and absence of a resting pool at the bottom may render this a barrier to fish passage.

- *Sewer Main Crossing*
  A concrete encased sanitary sewer main crosses the brook between George and Giffin Streets. The concrete is exposed on the channel bottom and 2.2-foot water level drop was measured across this structure. This drop likely precludes passage of nearly all brook trout five inches or less in length.[4]

- *Giffin Street*
  A concrete sill on the downstream side of the bridge creates a low flow water level drop of about eight inches. This likely precludes passage of about half of all brook trout five inches or less in length.[4]

[4] Kondratieff, M.C. and Myrick, C.A. 2006. *How High Can Brook Trout Jump? A Laboratory Evaluation of Brook Trout Jumping Performance*, Transactions of the American Fisheries Society 135:361-370.

Miscellaneous Observations

- *Channelization*
  The majority of reach 1 has been channelized. This appears to be responsible for the conversion of E stream types to entrenched G stream types. The total stream length has likely been reduced and resulted in a reduction in the amount or aquatic habitat, an increase in channel slope, and elimination of channel meanders and associated bed form diversity. Dredge spoils were observed along the banks in stream segments R1S3, R1S4, and R1S9. Deposition of these spoils has created dikes in some areas which has increased channel incision (see cross-section plots R1S3 and R1S4). Invasive species dominate many of these spoil deposition areas.

- *Streamside Development*
  Residential and commercial development borders the brook in many areas, particularly stream segments R1S2, R1S4, R1S5, R1S6, R1S7, R1S8, R2S1, and R2S3. The proximity of the development to the brook limits opportunities for stream restoration and habitat improvements in these areas.

- *Beaver Activity*
  Three beaver dams were present within reach 1 – one in segment R1S4 between Marlboro and Baker Streets and two in the upper portion of segment R1S9. These dams add diversity to the aquatic habitat by varying flow depths and velocities.

- *Incision of E Stream Types*
  Although the stream type of segments R1S3, R1S5, R1S7, and R1S9 is E, which is the stable stream type for this valley setting, portions of these segments are incised (i.e. the top of the lowest bank is higher than the bankfull stage such that the channel does not have access to a floodplain at flows just above the bankfull discharge). However, the degree of incision is not to the degree that these segments are entrenched or have converted to a different stream type. Although these are E stream types, opportunities for stream restoration and habitat improvements still exist in these areas.

- *Sediment load*
  Relatively little in-stream depositional features were observed within the study area. This, in combination with the limited active bank erosion (which can be a significant sediment source), suggests that there is a relatively low supply of bedload sediment to the brook. Channels with low bedload sediment supplies are less likely to react adversely to channel alterations.

- *Large Woody Debris*
  Very little large woody debris (LWD), which adds aquatic habitat diversity, was observed within the channel and the majority of the woody material was found in reach 2 where the banks and riparian areas are forested in most areas. With the exception of a few pieces in segment R1S1, no LWD was present in reach 1. Most of the banks and riparian areas in reach 1 support little or no trees, an indication that

the source of LWD is limited. It should be noted that riparian areas bordering E-type streams are often naturally dominated by riparian shrubs and/or emergent vegetation. Significant amounts of LWD would not typically be present in these settings.

In-stream and Riparian Wildlife Habitat Assessment Of Beaver Brook

Methods

During the 2007 field season, a habitat assessment was conducted by volunteers using the attached data form (Exhibit 13). Volunteers were trained by state and City officials to collect a variety of information on Beaver Brook as a means to assist with the restoration planning process.

In September 2008, a subset of the volunteer data form was developed to rapidly assess the accuracy of the data, as well as to qualitatively assess steam modifications and presence of invasive plants along the riparian corridor. Two observers walked along the majority of the brook within the study area, including Old Concord Road through Woodlawn cemetery and from Harrison Road to the confluence with the Branch. The area between Beaver Street and Harrison Street was assessed from roadway crossings.

To help characterize the current status of the brook the following variables were documented in the field and using spatial analysis in ArcGIS: habitat type (pools, riffles, glides/runs, and cascades), linear distance, average length, average depth, dominant riparian vegetation, presence and relative abundance of invasive plants, the presence and type of fish cover, and stream modifications. Volunteer data from 2007 was supplemented when applicable. Habitat types were mapped according to the reach and segment breaks identified in the stream morphology section. Incidental wildlife observations were also recorded.

To help understand the water quality of Beaver Brook benthic macroinvertebrates were assessed for their presence in four sites along the study area and one reference site upstream of Old Concord Road. At each site, two replicates of 4 random samples were gathered, for a total of 8 samples per site. For each sample, a D-frame net was placed downstream while the substrate directly upstream was agitated by hand. This agitation helped to loosen benthic macroinvertebrates along the substrate to be sampled, collected, and identified in the lab. This methodology follows that of the VT Department of Environmental Conservation[5].

Results

In-stream Habitats

In-stream habitats were mapped from the confluence with The Branch to Old Concord Road (Exhibit 14) and data tabulated (Exhibit 15) by reach and segment breaks.

Overall, glide/run habitats represent the majority of the study area and coincidentally occur throughout reach 1 (R1). Conversely, riffles were known to dominate reach 2 (R2). This is

[5] *VT Department of Environmental Conservation. 2004. Macroinvertebrate Sampling, Processing, and Metrics. http://www.vtwaterquality.org/bass/htm/bs_macro.htm*

not altogether surprising since R2 is characterized as having a steeper gradient and generally a higher velocity, while R1 is within a valley setting that has a lesser gradient, resulting in slower velocities. This is more typical of streams within valley bottoms.

Consequently, there were no cascade habitats present. The upper area of R2 has cascade-like features but the slope precludes its classification as such. This habitat type can be found in the Beaver Brook Falls Natural Area located north of the study area.

Backpack electrofishing was conducted within selected sites during October 2003 and September 2008 by NH Fish and Game Department. These surveys resulted in 13 native species and 2 introduced species, including largemouth bass and yellow bullhead (Exhibit 16). Given the current conditions of the brook, most of these species were expected to be present. Atlantic salmon, however, was known to exist due to reintroduction efforts performed by the City.

Three species were noted as significant. The Atlantic salmon and eastern brook trout are target species since they inhabit cold water streams. These two species were mainly found in northern section of the study area. However, the brook trout was also surveyed in the Water Street area. The third species of significance is the tessellated darter, which is the host fish for the endangered dwarf wedge mussel. While there are no known occurrences of this mussel in Beaver Brook they are known to exist in the Ashuelot and Connecticut Rivers.

Gabe Gries (NH Department of Fish and Game Region 4) indicated that there are no known records of fish species historically found in Beaver Brook. He speculates that, historically, the upper section (R2) was probably a trout stream while the lower section (R1) has always been a low gradient, slow-moving stream that's more indicative of warmer water species.

To this end, temperature data loggers were set in 4 locations of Beaver Brook from July 20 to September 21, 2007, a 64 day period (Exhibit 14). From these data loggers, daily average temperatures were plotted against cold water species to demonstrate their tolerance thresholds (Exhibit 17). Optimum temperature range for brook trout is 55-64 degrees Fahrenheit. Data loggers indicated that the daily average water temperatures were within the optimum range at all four stations during 24 of the 64 days that the stream was monitored, with most of these days occurring in late August and September. Daily average temperatures exceeded the optimal range for brook trout at least one of the four stations a total of 40 days (20 days at Station 1, 35 days at Station 2, 40 days at Station 3, and 34 days at Station 4) This temperature data is consistent with the finding that the best habitat was located within R2 (where Station 1 was located). Throughout the study all daily average temperatures were below the maximum lethal temperature of 78.1 degrees Fahrenheit. This may indicate that restoration activities could have a positive impact on this species if sufficient shading of the brook can be achieved.

Regarding Atlantic salmon, the main focus was on juveniles. The optimum temperature range for salmon is 46-66 degrees Fahrenheit. Data loggers indicated that the daily average temperatures fell within the optimum range at all four stations for just over half (33 days) of the total days monitored. Conversely, out of a total of 64 days, daily average water temperatures exceeded the optimal range for juvenile Atlantic salmon for 31 of those days at least one station (17 days at Station 1, 30 days at Station 2, 31 days at Station 3, and 27 days at Station 4). The temperature data for Atlantic salmon, therefore, is also consistent with the finding that the best habitat was located within R2. Also, several spikes in the graph indicate that water temperatures nearly reached a point in which juveniles stop feeding. If this trend continues then it could have negative impacts on the stocked populations. The most important aspect here is to improve habitat needs for juveniles, which would be best achieved in R2 and Woodlawn Cemetery, as discussed in Section 'Recommendations – Stream Morphology and Wildlife Habitat.' This can help to ensure that juveniles or fry can develop into the smolt stage and move downstream into the Ashuelot River.

It is important to note that stream temperatures change throughout the day and vary across the stream's course depending on such factors as depth, shade and velocity. Trends in daily average temperature as collected on Beaver Brook provide a seasonal snap-shot of the overall suitability of the stream for a particular species based on their temperature preferences. While fish such Atlantic salmon and brook trout will seek refuge from high temperatures in deep pools and shaded areas, and often survive these periods, if such conditions continue year after year, the stream will not be able to support healthy cold water fish populations. This fact also emphasizes the importance of stream heterogeneity because in order for fish to find refuge from rising water temperatures, there must be deep pools, large boulders, and shading for them to escape to.

Macroinvertebrate functional feeding groups (FFGs) are often used as a method of analyzing the ecological condition of a stream because the ecological role of macroinvertebrates depends largely on their feeding behavior. An assessment of FFGs provides information on the balance of feeding strategies in the benthic assemblage, and thus on the balance of food sources, such as coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), periphyton, and prey. Without relatively stable food dynamics, an imbalance in FFGs will results, a reflection of stressed conditions. A healthy stream will have a diverse, balanced, and relatively stable complement of FFGs present throughout its course. Typically, macroinvertebrates can be classified into five primary groups: gathering collectors, filtering collectors, scrapers/grazers, shredders, and predators, based on the way they function and process energy in the stream ecosystem. Using these categories allows for a more simplified assessment of stream macroinvertebrates because it requires the study of a small number of groups rather than hundreds of different taxa.

For FFGs, macroinvertebrates are categorized based on their mechanisms for obtaining food and the particles size of the food, but not specifically on what they eat. Following are brief descriptions of each of the five groups and their expected response to increasing perturbations or disturbances (i.e., sedimentation, pollution, toxicants).

- Gathering Collectors: Collect/gather FPOM (i.e. detritus) and/or small organisms from the stream bottom. Response to increasing perturbation is variable due the broader range of acceptable food materials they can survive on. In some cases Gathering Collector populations may increase due to disturbance and in others they may decrease, but in general these types of macroinvertebrates will not be as impacted by perturbation as other more specialized feeders.
- Filtering Collectors: Use filter mechanisms to collect primarily FPOM and/or small organisms from the water column. Response to increasing perturbation is variable due the broader range of acceptable food materials they can survive on. In some cases Filtering Collector populations may increase due to disturbance and in others they may decrease, but in general these types of macroinvertebrates will not be as impacted by perturbation as other more specialized feeders...
- Scrapers/Grazers: Scrape and graze biofilms, including Diatoms and Cyanobacteria, off of exposed surfaces. Increasing perturbation is predicted to result in a decrease in the percent of scrapers/grazers relative to entire macroinvertebrate population.
- Shredders: Shred and chew leaf litter or other CPOM, including wood. Increasing perturbation is predicted to result in a decrease in the percent of shredders relative to entire macroinvertebrate population.
- Predators: Attack and engulf other insects and macroinvertebrates as a main food source. Response to increasing perturbation varies depending on the response of the other insects and macroinvertebrates that they feed on.

Specialized feeders, such as scrapers and shredders, are more sensitive to pollution and otherwise stressed conditions. Generalists, such as gathering and filtering collectors, have a broader range of acceptable food materials and are therefore more tolerant of disturbed conditions. Therefore, healthy streams are generally expected to support a diverse mixture of both specialized and generalist taxa, while an impacted stream will likely be dominated by generalists.

Five sites along Beaver Brook were surveyed for macroinvertebrates in the fall of 2008, including a reference site north of the study area in a less impacted portion of the watershed (Exhibit 14). A total of 333 organisms from 14 families were surveyed (Exhibit 18). The charts displayed in “Summary of Invertebrate Functional Feeding Group (FFG) Composition, Beaver Brook (2008)” illustrate the relative percentages of FFGs found at each site, moving in the downstream direction (Exhibit 19). The reference site and site 1 show the most balance between feeding groups and specifically between the specialized groups (i.e. shredders and scrapers) and the generalist groups (i.e. gathering and filtering collectors). As we sampled down the stream corridor, generalist species become much more dominant, with close to 80% of macroinvertebrates in sites 3 and 4 falling into the filtering and gathering collector groups. Furthermore, while the percentage of shredder populations remain relatively stable moving downstream, the percentage of scrapers decrease, and the overall number of macroinvertebrates collected at each site generally decrease in the downstream direction, indicating a decrease in overall macroinvertebrate populations. While a more rigorous sampling is needed to statistically confirm this finding, these observations are consistent with expectations based on current stream and riparian conditions.

One interesting incidental observation that was made during sampling for macroinvertebrates was the presence of juvenile spring salamanders at sampling site 2 just north of the Woodlawn Cemetery wetland. This is a type of stream salamander that can help to serve as a biological indicator of stream health. Spring salamanders are known to be found in cold streams with good to excellent water quality. While these juveniles most likely originated upstream they do provide additional evidence of Beaver Brook's ecological integrity in the northern portion of the study area. Spring salamanders are also known to exist in the upper section of Hurricane Brook in Keene.

Riparian Habitats
Exhibit 14 demonstrates the adjacent land use and forest cover within 100 feet of Beaver Brook. As one can see, much of the brook's natural buffer has been removed by development or habitat alteration. This aspect, which is further addressed in the Land Use section below, can have major effects on the brook's ecological health.

Another major concern regarding the riparian area is the presence of invasive plants. At least nine species were identified throughout the entire study area during 2007 and 2008 field seasons. These included:

- Japanese knotweed
- Purple loosestrife
- Multi-flora rose
- Buckthorn *species*
- Honeysuckle *species*
- Black swallow-wort
- Burning bush
- Norway maple
- Autumn olive

The most aggressive invasion sites include R2S2, the Woodlawn Cemetery (R1S9), Carpenter Field (R1S6), R1S5, R1S4, R1S3, and R1S2. Japanese knotweed has densely colonized each of these sites and has been exacerbated by management activities, mostly by periodic mowing. Purple loosestrife has heavy infestations in the Woodlawn Cemetery and R1S3. The other reaches/segments have less heavy infestations. Finally, the seven other species were noted throughout the study area but were in low abundance. However, these species should also be eradicated or managed as well. It's usually easier to eliminate or manage various small infestations than larger, more extensively infested sites with well-established populations and a copious seed bank.

In addition to the above noted species incidental wildlife observations were recorded during the 2008 season. The table below lists the six amphibians, eight mammals, and 18 birds. This list does not represent a comprehensive survey of Beaver Brook's wildlife.

Incidental wildife observations in Beaver Brook in 2008.

Amphibians	*Mammals*	*Birds*	
wood frog	gray squirrel	woodcock	blue jay
pickerel frog	domestic canine	pileated woodpecker	common yellowthroat
spring salamander	domestic feline	great-blue heron	cedar waxwing
two-lined salamander	woodchuck	wild turkey	American goldfinch
dusky salamander	deer	rock dove	song sparrow
spring peeper	raccoon	white-breasted nuthatch	black-capped chickadee
	skunk	gray catbird	downy woodpecker
	beaver	American robin	tufted titmouse
		American crow	mockingbird

Adjacent Land-use Practices and Non-point Source Pollution Assessment of Beaver Brook

Introduction

Impacts to streams occur by a combination of in-stream and out-of-stream alterations to the landscape. Anthropogenic activities can both impact aquatic habitat and migratory connectivity. Land-use changes adjacent to the riparian corridor can have the greatest detrimental effect on stream water quality, which, in turn, influences the limiting factors and associated carrying capacity for aquatic and associated riverine biotic assemblages.

Based upon a review of the literature, a number of criteria have been developed to ascertain activities that could impact riparian corridors (Exhibit 20). These can be categorized as riparian buffer conditions, potential land-use hazards and in-stream disturbances. These indicators often interact and can exacerbate the overall impact to stream biota.

For Beaver Brook a methodology was designed to act as a rapid assessment for documenting non-point source (NPS) pollution threats from land directly adjacent to the stream. NPS pollutants from this area, the riparian corridor, have the greatest potential to enter the stream simply because of its juxtaposition to the stream.

As a rapid assessment, field observations were made over a limited period, providing a general snapshot of the existing conditions. Designed to be a planning tool, this documentation of potential NPS threats can help prioritize actions to improve water quality.

Causes for degraded water rarely falls on one specific landowner or type of activity; often there are a large number of minor threats which can be easily remedied through educational and outreach. Conversely, larger threats may be identified, requiring more significant funding, expertise, collaboration, and time to remedy.

Without knowing what and where the issues are, it is difficult to develop an effective action plan to improve water quality. This type of assessment is a great place to start to begin working towards improving water quality in your watershed. This analysis can be supplemented with additional in-depth visual assessment or water quality sampling[6], to better assess where the City may want to target resources for mitigating the sources of NPS.

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[6] *The water quality parameters that might be assessed would include temperature, dissolved oxygen, biological oxygen demand, inorganic nitrogen, total phosphorus and coloform. Such tests might be conducted during both seasonal high and low water flow conditions.*

Key factors in determining the threat of an activity as a pollutant source are:

- proximity to the water body,
- slope of the land,
- type and amount of vegetation present between the problem and the water, and
- amount of impervious surface, and
- properties of soil, namely hydrologic soil group and permeability, on the problem site.

In general, the closer the activity is to the water, the more likely it is to be a problem. Likewise, activities located on moderate to steep slopes slanted towards the water pose a greater threat as water picks up speeds and more pollutants as it flows downhill towards the stream. Vegetation between the activity and the stream is a good thing as it can help reduce the threat of pollutants. Commonly referred to as a buffer or vegetated buffer, plants help slow the movement of water which causes some soil particles to settle. Plants also allow water to soak into the ground where roots absorb excess nutrients. The length, width, composition and complexity of plant types are key factors in a buffer's effectiveness. Buffers are also an important habitat feature; trees provide shade for the stream, as well as food and protective structure for aquatic organisms.

Soil types also factor into the ability (and rate) of water to soak into the ground or tendency to runoff. Two properties of soil, hydrologic soil group and permeability, describe these tendencies. Soils with low permeability, like clay or rocky areas, usually yield more runoff.

Similarly, impervious surfaces prevent water from soaking into the ground, thus increasing the amount of runoff (water flow over the surface). Water flowing over the ground may also increase speed as it moves over impervious surfaces, areas of compacted soil, or areas with little vegetation. Since there is little in the water's path to slow it down it is able to pick up and transport more pollutants associated with specific activities occurring across the landscape.

What follows is a more detailed description of the rapid assessment approach, which includes the definitions of the criteria used in ranking the parcels along the brook.

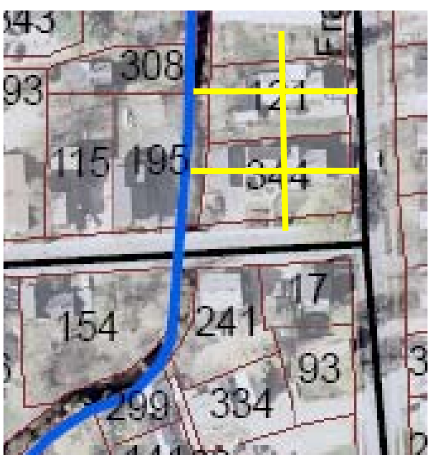
Methods

This rapid assessment methodology was a combination of desk-top spatial analysis combined with visual site assessments along the riparian corridor. The output of these two activities was a parcel-by-parcel analysis of land-use mediated impacts to the stream corridor.

Desktop

Spatial analyses included utilization of ArcGIS to develop a co-occurrence of data layers imported from Keene and/or the NH *GRANIT* system. These included soils information, specifically, soil erodability and permeability. The former influences both bank stability, as well as the potential of soil movement to and down the stream. And because most phosphorus movement on a watershed is due to attachment to soil particles, erodibility index can show potential for loading of this NPS pollutant. Soil permeability indicates the potential of water percolation as it moves towards the stream as sheet flow. Thus, reduction in run-off reduces potential pollutant into the stream, as well as reducing the potential for erosion. Exhibits 21 and 22 demonstrate soils erodibility and permeability (respectively) adjacent to Beaver Brook.

Soil permeability is significantly compromised for a stream corridor in an urban environment, which is the case for the Lower Beaver Brook, which has seen historical build-out right to the stream edge in some stretches of the riparian corridor. This means that a high percentage of the land has moved from natural soils and vegetative cover to one that is dominated by impervious surfaces. The following exhibit demonstrates the resolution of the spatial analysis used to ascertain the extent of impermeable conditions along the brook.



The percentage of the parcel covered by impervious surface is subsequently used as one of the primary criteria for the ranking analysis and was best determined at the desk-top with the use of aerial photography and tax maps.

Field
The field assessment utilized a number of criteria that could be divided into primary topographic/geologic factors such as slope and vegetated buffer. These factors are considered "primary" because they either mitigate or exacerbate the NPS risk from land-use activities adjacent to the stream.

The secondary factors include a variety of activities that range from those that structurally impact the riparian corridor, e.g. erosion sediment or deposition of garbage; those that can exacerbate depression of stream oxygen, e.g. loading of fertilizers or dumping yard waste into the stream; and/or to introduction of toxics that would directly impact the stream biota, e.g. lawn pesticides/herbicides.

Both primary and secondary factors were given a qualitative ranking of: "Good", "At Risk", and "Impacted" based on pre-defined criteria. These criteria describe specific indicators to be observed in the field, or interpreted from spatial analysis, in order to assign a ranking.

The criteria utilized in this assessment method are found below. Not only were individual parcels assessed along the riparian corridor, but roadways that paralleled or crossed the brook were also delineated and assessed.

The citations associated with each criteria reference the documentation supporting the choices for field indicators. The qualitative modifies indicated below and found on the data sheet (Exhibit 23), were subsequently transcribed as numeric values.[7] Then, based on how primary factors exacerbated or mitigated secondary factors a "weighted"[8] score was assigned to each parcel.

Primary Factors

<u>Slope</u>
Flat – 0-3%
Moderate – 4-8%
Steep – greater than 9%

(Criteria Sources: 27, 28, 55, 56)

<u>Vegetated Buffer</u>
<u>Width</u>
Good – buffer is greater than or equal to 100 feet wide

[7] *For example Impacted (1); At Risk (2); Good (3)*
[8] *See Exhibit 26 for the weighting algorithm.*

At Risk – buffer is between 25 and 100 feet wide

Impacted – sparse, minimal, or no buffer; buffer is less than 25 feet wide

(Criteria Sources: 5, 17, 27, 28, 50, 55, 56, 60)

<u>*Continuity*</u>

Good – trees and shrubs spaced close together, and well established; no straight pathways for water flow through buffer

At Risk - trees are young and/or spread between 10 and 20 feet apart, other vegetation present with some shrubs OR concentrated pathways of direct flow (<3 feet wide) through buffer to stream

Impacted - trees are absent, young and/or spread between 10 and 20 feet apart; other vegetation present with some shrubs but gaps between shrubs as well OR large pathways of direct flow (>3 feet wide) through buffer to stream

(*Criteria Sources: 5, 12, 16, 17, 20, 22, 23, 26, 27, 52, 53, 60)*

<u>*Canopy Integrity*</u>

Good – stream is more than 80% shaded; complex structure containing trees, shrubs, and tall grasses or flowers (canopy or overstory, midstory vegetation and ground cover); trees and shrubs spaced close together and well established;

At Risk – stream 50 to 80% shaded; buffer lacks complex structure – trees are absent, young and/or spread between 10 and 20 feet apart, other vegetation present with some shrubs <u>OR</u> some invasive species present

Impacted – stream less than 50% shaded; sparse/minimal to no buffer (less than 25 feet) <u>OR</u> buffer dominated by grasses <u>OR</u> few trees and shrubs, spaced more than 20 feet apart <u>OR</u> pavement, or bare ground along stream, right up to water's edge <u>OR</u> buffer dominated by invasive species

(Criteria Sources: 2, 5, 7, 10, 11, 12, 16, 17, 60, 20, 22, 23, 27, 28, 50, 55, 56)

<u>**Impervious Surfaces**</u> (Desktop & field check)

High – lot has more than 50% impervious area; impervious surfaces next to stream, with "at risk" to "impacted" or no vegetated buffer (see above) between pavement and stream

Moderate – lot has 10 to 50% impervious area; impervious area near stream with "good" to "at risk" vegetated buffer (see above) between pavement and stream

Low – lot[9] has less than 10% impervious; 90 to 100% natural ground cover; "good" to "at risk" vegetated buffer (see below) between impervious surfaces and stream

(Criteria Sources: 3, 7,11, 20, 21, 27, 35, 45)

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[9] *"Lot" means all of parcel, inclusive of natural areas, manicured areas and all structures' foot prints, including the driveways.*

Soil Properties (Desktop)

Permeability
High – more than 6.0 inches of water in an hour *(good, less runoff)*

Moderate – between 0.2 and 6.0 inches of water per hour

Low – less than 0.2 inches of water in an hour *(bad, more runoff)*

Erosion k-Factor

High – greater than 0.4 *(bad, more erosion)*

Moderate – between 0.2 and 0.4

Low – between 0.05 and 0.2 *(good, less erosion)*

(Criteria Sources: 13, 36, 39, 40, 44, 47, 48, 49)

Secondary Factors

Pesticides/Herbicides

Good – small lawn or garden (less than 10% of lot around structure[10] is lawn or garden) with diverse vegetation; un-manicured lawn; "good" buffer present between lawn and stream (see above); land "flat" (see above) or sloped away from stream; no dead zones (areas with no vegetation or insects)

At Risk – medium sized (between 10% - 50% of lot around structure is lawn or garden), manicured lawn or garden small patches with small patches of diverse vegetation near stream OR away from stream on "hilly" slope (see above) towards water; "at risk" buffer (see above) between lawn/garden and stream OR dead zones away from stream

Impacted – large lawn or garden (greater than 50% of lot around structure is lawn or garden) with no diversity of vegetation and has "impacted" to no buffer between lawn/garden and stream OR has pesticide flags OR identified lawn/garden chemicals are stored near stream OR dead zones present along stream bank

(Criteria Sources: 3, 7, 13, 19, 21, 24 , 35, 40)

[10] "Lot around structure" is the remainder of the lot not taken up by structures (houses, apartments, and sheds, commercial buildings, including driveways and parking areas).

Driveways and Pathways

Good – flat driveway OR cars not parked on driveway (garage storage) OR no staining OR "good" buffer (see above) between end or edge of driveway/pathway and stream OR driveway or pathway curved/meandering, has water bars or other water slowing device if located on "hilly" slope (see above) OR unpaved driveway is stabilized with gravel; pathway stabilized with gravel, mulch, brick or other pervious material OR no signs of erosion

At Risk – driveway/pathway sloped towards stream with straight shot down driveway /pathway to stream OR staining on driveway where one to two cars are parked OR "at risk" buffer (see above) between driveway and water OR evidence of some erosion (rills); some soil transport offsite OR unpaved driveway/pathway not stabilized by gravel or mulch (bare dirt surface)

***Impacted* –** driveway/pathway on "hilly" slope towards stream (see above) with straight shot down driveway/pathway to stream; no water bars or other slowing devices; water flows down tire ruts; or rill or gully erosion on dirt driveway/pathway OR washout OR "impacted" to no buffer (see above) between end or edge of driveway/pathway and stream OR staining from multiple cars (three or more) parked on driveway OR shoulder of driveway eroding OR turbid water leaving drive/pathway OR sediment deposition downstream

(Criteria Sources: 7, 16, 18, 19, 20, 22, 35, 53)

Hazardous Materials, Waste, Storage, and Disposal

***Good* –** Small amount of small trash[11] or litter (less than a pick-up truck load) spread over confined area with easy access, litter not in stream or readily transported to stream; no hazardous item among litter OR hazardous materials[12] stored away from stream, on an impervious surface with a spill barrier and covered, not stacked or likely to be knocked over easily

***At Risk* –** Fairly large amount (up to 2 pick-up truck loads) of small and large trash or litter items in a small area with easy access; trash dumped over long period of time, but readily cleaned up in a couple of days; some litter in the stream, with small alteration to stream hydrology OR hazardous materials stored near stream, directly on the ground or with no spill barrier or cover or materials stacked with potential to be knocked over easily OR hazard identified by state[13], but file is deemed closed

***Impacted* –** large amount of trash (more than 2 pick-up truck loads) of small and large[14] trash items spread out over large area; large trash items common; area difficult to access for clean up; trash dumped over long period of time and will take more than a few days to clean up and may require large equipment to clean up and deposited material has substantially altered the hydrology of the stream OR hazardous trash items present (especially leaking containers); lots of trash in stream; dumpster or trash barrels located next to stream or ditch that drains to stream - noticeable "dumpster juice" leaking onto ground OR hazardous

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[11] *cans, papers, small plastic containers, etc.*
[12] *open or leaking oil containers, automobile fluid containers, paint cans, household cleaning product containers, junked cars, rusting equipment, construction waste, biomedical waste, above and underground storage tanks (oil especially). All of these put the stream "At Risk" unless there is a visible spill and direct pathway to the water, in which case it is "Impacted".*
[13] *sites documented in NH's Department of Environmental Service's ONE-STOP database of hazardous waste sites*
[14] *tires, carts, junked cars, etc.*

materials storage with clear signs of leaks (leaking fluids, chemical burn marks or kill zones) or materials stored in a way that water can easily move the material OR hazard identified by state.

(Criteria Sources: 4, 7, 8, 9, 10, 13, 14, 22, 23, 27, 40, 60)

Fertilizers

Good – small (less than 10% of lot around structure[15] is lawn or garden); sparse lawn or garden; diverse vegetation - native grasses, wild flowers, shrubs, trees; "good" buffer (see above) present between lawn and stream; land flat or sloped away from stream

At Risk – medium sized (between 10% - 50% of lot around structure is lawn or garden) lush, green, manicured lawn (not associated with septic failure) with patches of diverse vegetation; "at risk" buffer between lawn and stream; "hilly" slope towards stream (see above)

Impacted – large (greater than 50% of lot around structure is lawn or garden) lush, green, manicured lawn with no diversity of vegetation AND land sloped towards stream or "impacted" to no buffer between lawn and stream OR fertilizer flags or hose mixer observed OR lawn chemicals stored near stream

(Criteria Sources: 3, 12, 19, 20, 21, 24, 27, 28, 29, 35, 37)

Yard Waste

Good – organic debris[16] not piled on site, or is piled well away from stream and storm drains OR lawn clippings left in place to self mulch

At Risk – organic debris piled close to stream or storm drain, but on flat slope, no signs debris washing/blowing towards stream

Impacted – organic debris piled next to or into stream or leachate seen to be flowing towards stream from piles; debris piled on pavement near storm drain or ditch that drains to stream

(Criteria Sources: 12, 23, 18, 20, 27, 28, 29, 44, 51)

Pet and Animal Waste

Good – no evidence of pets or all pet waste scooped OR few wild animals with waste spread over large area

At Risk – pet(s) or pet area[17] present but located away from stream with potential pathway for runoff; some pet waste not scooped OR some wildlife, but scat spread out over large area

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[15] *"Lot around structure" is the remainder of the lot not taken up by structures (houses, apartments, and sheds, commercial buildings, including driveways and parking areas).*
[16] *lawn clippings, compost, leaves, twigs, etc.*
[17] *area designated for pet walking, dog run, kennel, or small fenced in area for pet, pet litter pile*

***Impacted* –** multiple pets or pet area present next to stream with definite pathway for runoff to stream or community pet recreation area (i.e. dog park, doggie daycare, popular trail/path); several piles of pet waste OR waterfowl or wildlife gathering area with lots of animal waste present in common area OR pet/animal waste in water

(Criteria Sources: 20, 21, 23, 27, 28, 50)

Bare Soil

***Good* –** small patches of bare soil (covering a total of < 10% of the lot) on flat slope and not next to stream, buffer between bare patch and stream

***At Risk* –** medium sized patches of bare soil (covering a total of 10-30% of the lot) on "hilly slope" (see above) towards stream with "at risk" to "impacted" buffer (see above) between soil and stream OR potential for direct erosion (via sheet flow) to stream OR signs of rill erosion with some sediment movement and transport but not off site and "at risk" buffer between bare soil and stream OR soil stockpiled on "hilly slope" (see above) but soil is covered or has surrounding sediment controls

***Impacted* –** large patches of bare soil (covering a total of >30% of the lot) on a "hilly" or "steep" slope (see above) towards the stream OR bare areas located adjacent to stream or drainage ditch OR "at risk" to "impacted" buffer (see above) between bare soil and stream OR soil stockpiled on steep slope, adjacent to stream or drainage ditch leading to stream and soil is uncovered, lacks surrounding sediment controls or has at risk to impacted buffer between soil and stream/ditch OR evidence of substantial erosion– rills and or gullies, turbid water leaving site, soil transport offsite – with direct pathway(s) towards streams or sediment build-up downstream from site

(Criteria Sources: 10, 20, 22, 27, 28, 32, 36, 47, 48, 49, 39)

Stream Aeration

Good – For the length of the parcel, the majority (greater than 50%) of the stream is characterized by riffles[18]

At Risk – For the length of the parcel, the between 25-50% of the stream is characterized by riffles

***Impacted* –** For the length of the parcel, the less than 25% of the stream is characterized by riffles

(Criteria Sources: 1, 15, 25, 37, 38, 40, 42, 49, 59)

Paved Roads

Good – Roads located away (>100 feet) from stream OR "good" buffer (see above) between road and water OR light vehicle traffic and little staining on roads OR road crowned so water doesn't pool on road surface; no potholes; and road shoulder intact OR road runoff does not flow to stream; runoff is "treated" by vegetated buffer

[18] Generally, the water surface is broken up by turbulence, normally shallow reaches of a stream (1-4% gradient) characterized by small hydraulic jump over rough bed of material causing small ripples, waves, and eddies.

At Risk – Roads located near stream (25-100 feet away) with "at risk" or "impacted" buffer (see above) between roads and stream OR road crown pitches towards stream OR water pools on road due to lack of road crown and under heavy precipitation can move to stream OR moderate vehicle traffic with occasional, scattered, and localized staining on road, or occasional potholes OR road runoff is diverted to a non-buffered area or man-made mitigation area (examples: wet pond, detention pond) OR sediment build up on pavement (from potholes, road shoulder, winter sand, or "urban sediment" - tire bits, metal flakes, crumbled pavement) with potential to be transported off of the road surface but not carried to stream

***Impacted* –** Roads located adjacent to stream (within 25 feet) OR road on steep slope OR water pools in holes or on road surface due to lack of crowning OR pavement is crumbling, numerous potholes, or road shoulder eroding (rills or gullies present) OR heavy vehicle traffic; lots of staining on road (stains overlap or in continuous line) or runoff has oily sheen OR; washouts OR build up of winter road sand and other sediment (bits of tire and metal flakes) on pavement or shoulder and sediment transported off of road and into stream or ditch or drain leading to stream OR "impacted" to no buffer between road and stream OR road runoff discharges directly into stream

(Criteria Sources: 4, 8, 20, 29, 30, 31, 40, 43, 44)

Unpaved Roads

Good - Roads located away (>100 feet) from stream OR "good" buffer (see above) between road and water OR light vehicle traffic OR road shoulder intact and no grader or plow berm OR road well crowned so water does not pool on road and road regularly graded to smooth out potholes and wash boarding

At Risk - Roads located near stream (25-100 feet) OR "at risk" to "impacted" buffer (see above) between roads and stream OR road crown pitches towards stream OR road not adequately crowned causing water to pool in road and under heavy precipitation can move to stream OR moderate vehicle traffic OR road shoulder beginning to erode; localized grader and plow berms causing spotty pools of water on road OR road surface erosion (rills); sediment transport off road but no deposition in stream or ditch leading to stream

Impacted – Roads located adjacent to stream (<25 feet) OR "impacted" to no buffer (see above) between road and stream OR continuous grader and plow berms causing water to pool on road OR road not crowned causing water to pool on road OR road located lower than surrounding land or lack of roadside ditching or ditch capacity exceeded OR road surface and shoulder erosion (rills and gullies) with sediment deposition downstream or in ditches leading to stream OR road washout

(Criteria Sources: 9, 13, 16, 20, 22, 27, 48, 49, 53)

Roadside Ditches and Storm Drains

***Good* –** ditches stable, vegetated, adequate size for volume of flow; not located on steep slopes or BMPs (check dams, turnouts, vegetation or armoring) in place; ditch does not discharge to stream, rather ditch discharges to well vegetated area or "good" buffer away from stream OR storm drain designed for fine sediment capture and not emptying directly into the stream or stream buffer or no evidence of fine sediment build up in stream channel downstream from storm drain outfall

At Risk – slight ditch erosion (rills); ditches discharge directly to stream but water generally flow clear OR lack of adequate roadside ditch (water pools on road, erodes shoulder, or ditch capacity exceeded) OR storm drain designed for coarse sediment capture and not emptying directly into the stream OR storm drain straight discharge pipe into stream but no signs of sediment deposition in stream channel below storm drain outfall (sediment deposits lower than water level)

Impacted – long ditch on steep slope, no turnouts or other BMPs (best management practices) in place; ditch capacity exceeded or lack of adequate ditch, turbid water in ditch, direct discharge to stream, rills or gullies in ditch bed, ditch washout; sediment accumulation in ditch leading towards stream OR storm drain straight pipe discharge into stream with minimal sediment capture and sediment build up in stream channel downstream from storm drain outfall

(Criteria Sources: 2, 10, 16, 22, 26, 55, 56, 60)

Culverts

Good – culverts in good repair – not crushed, aligned at angle to road (30˚ to 35˚ angle down slope of perpendicular to road), culvert pitched for water flow through culvert (2% grade ideal), inlet/outlet stable with vegetation or armoring, no sedimentation below culvert, culvert covered by road material at least 12" deep (or ½ diameter of culvert diameter in depth, whichever is greater) to reduce frost heaving

At Risk – culvert misaligned (set perpendicular - 90˚ angle - to road), culvert not pitched for ideal water flow (greater than 2% grade increases potential for erosion, less than 2% leads to pooling and sedimentation), slight erosion around inlet or outlet, no sedimentation below culvert; hanging culvert with no erosion on downhill side outlet; pooling of sediment on uphill side of culvert (above inlet); culvert covered with less than 12" of road material (potential for increased frost heaving)

Impacted – culvert misaligned; crushed ends, unstable and eroding inlet or outlet; culvert washed out or exposed, sediment build-up below culvert, culvert not pitched for water flow, silt lined culvert; evidence of flooding above culvert's head wall (sedimentation or debris deposition above headwall)

(Criteria Sources: 2, 7, 16, 20, 22, 27, 41, 43, 50)

Road and Bridge Crossings

Good – at intersection of stream and road, road pitched away from stream or into ditches that flow away from stream OR no erosion around bridge supports OR no direct runoff or drainage from bridge surface into stream OR "good" vegetated buffer (see above) exists between road run-off and stream

At Risk – at intersection of stream and road, storm drains or road pitch directs run-off from the intersection towards stream into "at risk" vegetated buffer (see above) exists between road run-off and stream OR road runoff possible at bridge edge, but no drain from bridge into stream and bridge elevated from road surface (uphill slope approach to bridge crossing) OR evidence of road runoff entering stream but no signs of rill or gully erosion

Impacted – at intersection of stream and road, evidence of bank erosion or undercutting caused by road runoff OR direct conveyance of runoff to the stream (impacted or no buffer between stream and road) OR water drains from bridge directly into stream OR bridge lower than road (downhill slope approach to bridge) creating entry point for road runoff into the stream

Comments – make note of the contributing catchment area[19] and parcels to include in second tier assessment

(Criteria Sources: 16, 17, 20, 23, 26, 27, 28, 35)

Streambank Condition and Stability

Good **–** bank is stable and naturally vegetated, no exposed roots, no exposed soil

At Risk **–** bank is unstable and shows signs of erosion, bare soil, exposed roots but not undercut, some vegetation OR majority of bank is artificially stabilized (riprap, concrete, etc)

Impacted **–** bank is unstable and undercut or slumping, bare soil, little to no vegetation OR bank is not natural and is not stable

(Criteria Sources: 5, 10, 20, 22, 23, 26, 27, 28, 35, 50, 60)

Pipe Outfall

Good **–** no pipes present OR pipes present but no dry weather discharge and small volume (compared to size of pipe and stream flow) of wet weather discharge, wet flow is clear, colorless, and odorless and no pipes 4” or less in diameter (either PVC or other material)

At Risk **–** pipes present; very small volume of dry weather discharge (trickle), discharge is clear, colorless, and odorless; moderate volume of wet weather discharge AND discharge is clear, colorless, and odorless OR pipes 4” or less in diameter, not made of PVC, flowing or not flowing

Impacted **–** both dry and wet weather discharge; large volume of wet weather discharge; discharge has distinct color, odor, or is foamy; discharge is causing erosion problems below pipe OR PVC pipes 4” or less in diameter present and flowing

(Criteria Sources: 4, 9, 10, 14, 23, 27, 28)

[19] *the contributing catchment is the area of roads and associated parcels that direct water towards and into the stream corridor*

Results

The results from this analysis can be viewed from two different perspectives. The first is a spatial analysis of parcels bordering Beaver Brook where of all categories of land-use and riparian corridor conditions are combined to develop a comparative weighted ranking system. The other is specifically looking at the major type of impacts that predominate for each parcel. By looking at the data through these different lenses, it can aid the City in developing a multi-tiered strategy to intervene in improving the water quality of this urban drainage.

Comparative Parcel[20] *Analysis*
This analysis allows one to focus upon those parcels of greatest concern, and because public road crossings were also part of this analysis these are also included in the ranking (Exhibit 24). The raw data is also provided in tabular format (Exhibit 25). This raw data afford one the opportunity to look at the parcels by individual criteria to help inform an intervention plan.

A weighted ranking[21] is summarized below and spatially shown on the comparative parcel analysis map (Exhibit 24). The reason for weighting the raw scores from the collected data was that if all secondary factors were equal for two parcels, but they had different primary factors, such as a steeper slope, greater amount of imperviousness, less ability for soil permutation and increased erosion and/or absence of buffer, this would exacerbate the impact to adjacent riparian corridors.

The following tables are divided by qualitative categories of *impacted*, *very at risk*, *at risk*, and *good*[22]. These qualitative modifiers reflect a division of the weighted scores as indicated below.

Category	Numeric score range
impacted	.1 - 3
high risk	3.1 - 4
lower risk	4.1 - 6
good	6.1 - 9

[20] *Parcel numbers reflect tax map number or road-stream intersection*
[21] *See Exhibit 26*
[22] *The color coding on the attached map has Red as Impacted; Pink as High Risk, Orange as At Risk and Green as Good. The colors are visual qualitative groupings based on the weighted scores categorization.*

Parcels qualified as *impacted* can be considered those points along the riparian corridor, that have a number of contributing land-use factors, combined with natural features, that suggests these are specific areas of high concern in regards to water quality impacts along the brook.

Parcels Impacted
(weighted)

Parcel	Ranking
DPW Concord Rd & Old Concord Rd	2.3
DPW Baker St	2.3
DPW Griffin St & May St	2.5
DPW Church St	2.5
DPW Roxbury St	2.5
DPW Marlboro St	2.5
DPW Rte 101	2.7
DPW Spring St	2.8
DPW Water St	2.9
323	2.9
76	2.9
DPW Rte 12	3.0
226	3.0
344	3.0

Parcels qualified *at risk* can be considered as those points along the riparian corridor, that have a number of contributing land-use factors, combined with natural features, that suggests these are some areas of concern in regards to water quality impacts along the brook. Those that are considered at *very at risk* might be included with impacted identified parcels for further investigation and/or education and outreach.

Parcels At Risk
(weighted)

Parcel	Ranking
315	3.1
121	3.1
6, 7, 8	3.1
143	3.1
303	3.1
2	3.2
259	3.2

30	3.2
232	3.2
166	3.3
179	3.4
191	3.5
299	3.5
DPW Martel Ct	3.5
322	3.5
345, 346, 347	3.5
DPW George St	3.5
44	3.5
0	3.6
186	3.6
207	3.6
DPW Harrison St	3.6
261	3.6
233, 66, 161	3.6
58	3.7
195	3.8
198	3.8
DPW Beaver St	3.8
91	3.8
310	3.9
89	3.9
113 + 169	3.9
31	3.9
DPW Concord Rd & Wash St Ext	4.0
190	4.0
286	4.0
188	4.0
312	4.0
308	4.2
273	4.2
279	4.2
301	4.2
21	4.2
43 + 316	4.2
154	4.2
251	4.2
35	4.2

283	4.2
126	4.2
177	4.3
72	4.3
1	4.4
215	4.4
269	4.5
92	4.5
304	4.6
138	4.6
54	4.6
61	4.6
102	4.6
184	4.7
298	4.7
208, 245	4.7
338	4.7
14	4.7
102	4.7
194	4.7
59	4.8
139	4.8
79	4.8
277	4.8
235	4.8
340	4.9
241	5.0
98	5.0
146	5.0
342	5.0
242	5.1
20	5.1
192 + 196	5.2
64	5.3
151	5.3
307	5.3
12	5.3
27	5.3
331	5.4
120	5.5
3	5.5

53	5.6
25 + DPW Upper Knight St	5.7
220	5.7
140	5.8
210	5.8
306	5.9
34	5.9
254	6.0

Finally, parcels qualified as *good* can be considered as those points along the riparian corridor, that have a number of contributing land-use factors, combined with natural features, that suggests these are currently not a significant threat to the water quality of the brook.

Parcels Good
(weighted)

Parcel	Ranking
135	6.3
260, 341	6.4
289	6.4
60	6.4
257	6.5
32	6.6
32	6.7
49	6.7
187	6.8
165	7.0
94	7.0
225	7.4
174	7.6
330	8.0

This ranking should be considered as guidance to help the City to decide where and how it might allocate resources to address non-point source pollution along Beaver Brook. Such future action can range from simple citizen/parcel owner out reach or more formalized education efforts to actual restoration activities.

Land-Use Impacts
A summary of the raw data is provided below. It is organized into the categories of *Good, At Risk* and *Impacted* as they apply to specific field criteria for each category. Generally

impacted can be interpreted as the current state of the land-use directly contributing to the degradation of the stream.

As one would expect in an urban environment, the percentage of impervious area for parcels adjacent to the stream is quite high; as is the fact that historic development has had build-out right up to the stream edge in many locations. Thus, the buffer-width, between upland land-use activities and the stream waters, has been significantly reduced. Also, related to this and contributing to the overall stream degradation, is that in many locations, the buffer continuity is often interrupted and the canopy structure of the buffer often sub-optimal.

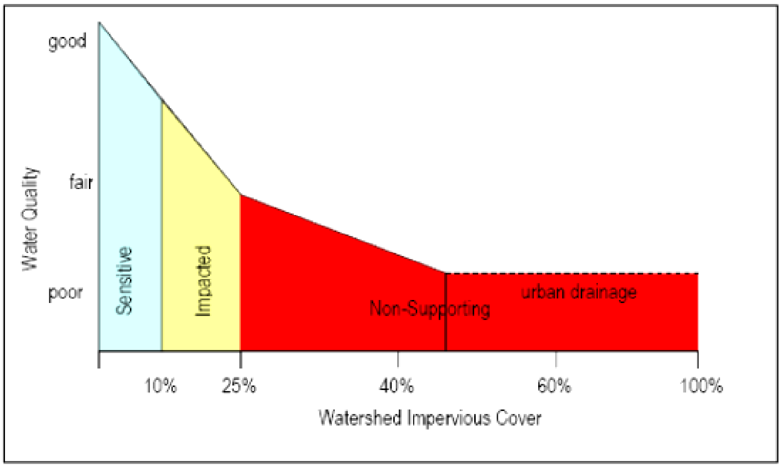
List of Problems for Parcels with an Overall Score of 3.9 or less

Category	***Good***	***At Risk***	***Impacted***	***N/A***
Slope	16	12	6	0
Impervious	2	5	27	0
Buffer Width	1	3	30	0
Buffer Continuity	3	12	19	0
Buffer Integrity	2	8	24	0
Pesticides/Herbicides	30	0	0	4
Driveway	15	17	2	0
Hazardous Waste	27	4	3	0
Fertilizer	26	0	0	8
Yard Waste	17	2	4	11
Pet Waste	19	2	0	13
Bare Soil	27	5	0	2
Stream Aeration	9	1	24	0
Bank Condition	10	24	0	0
Pipe Outfall	25	7	2	0
Ditches/Drains	0	2	1	31
Permeability	14	1	19	0

Impervious Surfaces

While impervious surfaces are potentially source of various pollutants, they are of equal concern for the sheer volume of water discharged quickly to surface waters. Impervious surfaces do not allow water to soak into the ground, instead water runs off and it runs off quickly compared to naturally vegetated areas, which presents concerns of erosion and increased flood potential. Quickly moving water is able to carry more pollutants from the landscape to a stream or lake.

Numerous studies have show that as imperviousness on the landscape increases water quality is impacted.



Pollutants associated with impervious surfaces are primarily related to automobiles. A variety of toxic fluids – antifreeze, oil, gasoline, brake fluid, etc. - may be leaked or spill from cars, trucks, and SUVs onto pavement. Washing cars on pavement may cause the detergent to flow down a nearby storm drain, drainage ditch or to the stream directly. Detergents are a concern because they may contain the freshwater limited nutrient phosphorus.

Other pollutants associated with automobiles and transportation routes include metal flakes from rusty vehicles, tire debris, crumbled pavement, or winter road sand. These pollutants are likely to stay on the pavement until the next rainfall. Rain water will wash these pollutants off the pavement in what is commonly referred to as "the first flush".

With a good buffer between an impervious area, runoff may be slowed enough to allow pollutants to settle out or to be absorbed by vegetation. A good buffer may also slow water enough so it does not pick up as many additional pollutants from the surrounding landscape before the remaining runoff enters a nearby water-body. Without an adequate buffer or other best management practice (wet pond, detention pond, etc.) in place, water running off the impervious surface may be moving quickly enough for it to pick up additional pollutants, such as fertilizers, pesticides, sediment, and nutrients, and may carry pathogenic bacteria from animal wastes, as the water flows over the surrounding land cover (grass, bare soil, etc).

An additional concern from impervious areas is thermal pollution – i.e. heated water entering a stream or lake. Warm water inputs are of particular concern for cold water fisheries, where fish rely on the oxygen rich cold water. Warm water holds less oxygen, causing stress for many cold water fish, as well as aquatic insects and other macro-invertebrates. Paved areas, roofs, and stream-bank stabilizing materials, like riprap, are all surfaces that usually heat up in the sun and have the potential to warm up rain water before it flows into a stream.

Vegetated Buffer

While not necessarily a source of pollution itself, the absence or poor condition of vegetated buffers may allow for more pollutant deposition into a stream. Vegetated buffers have a few key features that drive their ability to reduce the threat of nonpoint source pollutants. With sediment as a leading NPS concern, it is easy to see part of the role vegetation plays in preventing soil erosion. The root system that holds soil in place is perhaps the most recognized feature that makes buffers effective at reducing NPS pollution threats.

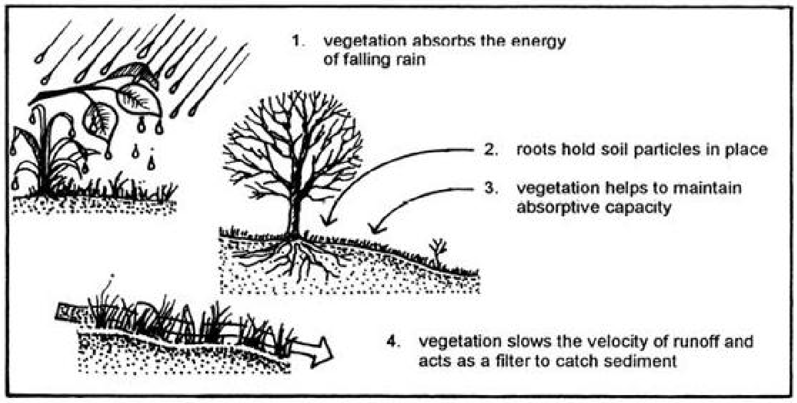
Perhaps less obvious is the role of the buffer's upper canopy (the layer of leaves on the tall, mature trees). Leaves intercept rain water, which means leaves change the course of a raindrop falling from a cloud directly to the ground. Many canopy structures are inherently designed to divert water from leaves and down the trunks/stems of the over-story. When a raindrop lands on a leaf its speed is slowed before the drop hits the ground. With less momentum, the raindrop will dislodge less soil when it hits the ground. A complex, multiple-layered canopy will be especially good at slowing raindrops as they fall to the ground as they are intercepted at multiple levels.

The canopy also lends to a buffer's ground cover. As plants drop their leaves or needles, a layer of organic debris (known as the duff layer) builds up and may cover areas of bare soil. The duff layer is also important, as is ground covering vegetation, for slowing the velocity of runoff. The organic debris can absorb a fair amount of water, and provides a slight unevenness to the ground which creates places for water to soak into the ground.

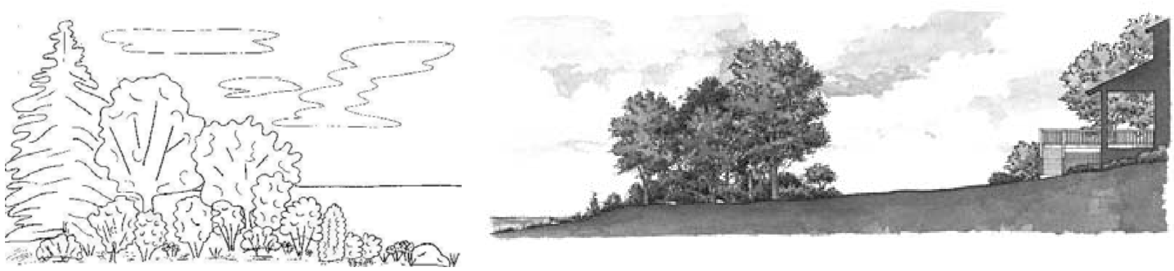
Stems and trunks from larger plants like shrubs and trees create additional "obstacles" for water to flow around; when water hits these obstacles, it also slows the velocity (speed) of runoff. Again, slower moving water will pick up fewer pollutants, and slowing the flow of runoff allows sediment to settle out.

Excess nutrients are also a primary water quality concern, and vegetated buffers can play an important role in preventing their entry into a stream. Nutrients like phosphorus and nitrogen are essential for plant growth, and are found in limited amounts in freshwater systems. Found naturally in the soil or put there with the application of fertilizers, excess nutrients may make their way to a water body adhered to sediment or may even dissolve in rainwater. Vegetated buffers can be effective at removing excess nutrients by slowing the flow, settling out sediment, and by providing places for water to soak into the ground.

When the nutrient rich water soaks into the ground, plant roots can absorb the excess nutrients.



Effects of vegetation on rain water and runoff: leaves intercept rain drops, roots hold soil in place and absorb rain water, and groundcover slows and filters runoff



A "good" buffer is comprised of an upper canopy or overstory (trees), a midstory (shrubs), and groundcover (grasses, duff, mulch, flowers). It also stretches the entire length of the parcel with very limited pathways for erosion to enter the stream, shades the stream, and extends 100 feet back away from the stream.

Overall, characteristics to consider when assessing a vegetated buffer are its composition, complexity and size. A wide buffer that extends far from the water's edge will do a much better job at slowing flow and absorbing water than a narrow buffer. Likewise, a buffer that extends the entire length of a property will be more effective than a buffer with large gaps or direct pathways for water to flow to the stream. The composition and complexity refers to the variety and spacing of vegetation that makes up the buffer.

Along Beaver Brook, and considering the three aspects of a buffer: width, integrity and continuity, the narrowing of the buffer width is the most common factor that has been impacted historically as the city continued to develop adjacent to the riparian corridor.

The presence of non-native and/or invasive plants in the buffer is also an important consideration, more so as a habitat concern. Some invasive plants may still be quite effective for pollution control and soil stabilization. However, there are other species that out-compete more effective plant community assemblages in regards to their ability to stabilize soils, maintain stream bank integrity, and mitigate of NPS pollution sources from the upland.

Some invasive plants associated with a riparian corridor have the added ability to expand their habitat by dispersing their seeds though downstream water movement. Similarly, some plants may also spread by fragmentation. If the bank where the plants are growing is destabilized, invasive plant parts and root stock can be transported to new establishment sites through erosion.

Stream Aeration

Reorganizing the raw data in the table below, we can see that besides the imperviousness and buffer being a common land-use that negatively affects the water quality of Beaver Brook, the loss of stream aeration is observed.

Parcels - IMPACTED		Roads - IMPACTED	
Category	***Impacted***	***Category***	***Impacted***
Buffer Width	30	Buffer Width	14
Impervious	27	Impervious	14
Buffer Integrity	24	Buffer Integrity	13
Stream Aeration	24	Buffer Continuity	10
Buffer Continuity	19	Stream Aeration	7
Permeability	19	Slope	3
Slope	6	Ditches/Drains	3
Yard Waste	4	Bridges	2
Hazardous Waste	3	Paved Roads	0
Driveway	2	Bank Condition	0
Pipe Outfall	2	Pipe Outfall	0
Ditches/Drains	1	Yard Waste	0

In streams, there is a dynamic between oxygen addition through stream aeration and oxygen depletion, primarily through decomposition of organic based materials.[23] The ecological concern is the loss of habitat to oxygen sensitive species.

Stretches of riffles, where the water surface is broken up by turbulence adds oxygen to waters. This can occur normally in shallower reaches of a stream characterized by small hydraulic jump over rough bed of material causing small ripples, waves, and eddies. Flowing water will also have more oxygen mixing capacity than still water so that oxygen that diffuses into the surface waters is continually mixed to the lower levels of the water column.

These areas of oxygen recharge also are mechanisms for releasing heat from water. Ecologically, this is important since cooler waters have greater capacity to hold oxygen. Thus, in areas where there are high impervious surfaces, degraded buffers and loss of shading, aeration maintenance is one of the natural mechanisms to help mitigate thermal pollution and increase the water oxygen content.

Along Beaver Brook, channel structure has been historically altered. This becomes obvious when comparing the current condition of the brook channel with streams in the watershed that are in similar topographic settings but have experienced less development pressure.

More specifically, a number of obstructions were observed along the brook, which has constrained flow of water or have been sources of materials that can consume oxygen as they decompose. Some of the obstruction to stream flow is the result of deposition of various materials in the stream, which included trash and yard waste.

Parcel 98g

Parcel 21b

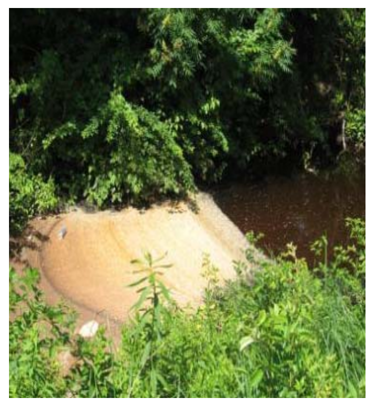
[23] *This dynamic of oxygen consumption is termed biological demand, and correspondingly, the materials are often designated as BOD materials. These can include, yard waste, manures and other organic materials.*

These organic materials negatively affect the water quality in that the waste material can become lodged along the water course creating a dammed area, pooling water and reducing aeration and increasing water temperature, all which negatively impact water oxygen content. In addition, those wastes that are organic, consume oxygen during decomposition, which contributes to a degradation of habitat for oxygen sensitive aquatic species.

Another set of land-use activities observed which can impact water oxygen content, directly or indirectly are observed access points to the stream from adjacent landowners. These paths to the stream provide an opportunity for bank erosion and potential flow of BOD materials and other non-point source pollutants into the stream. In addition, by compromising the integrity of the streambank, such stream access points can exacerbate bank erosion. The erosion can contribute to nutrient loading into the aquatic habitat, as well as depositional damming and ponding further down stream.

Parcel 121

Parcel 98b



An additional dynamic observed , which impacts stream flow and aeration, is associated with road-crossing with Beaver Brook. One aspect of this dynamic is the fact that the street storm-drain system empties into the brook at, and adjacent to, the road crossings.

At the outfall of the storm drain pipes (Exhibit 27), there was significant build-up of sediment that has created sediment dams and allow water to pool upstream. This condition is called shoaling, and in some cases appears to be exacerbated by other obstructions in the stream.

Marlboro Bridge Crossing

An additional contribution of sediment to the shoaling of waters along the brook could be occurring due to deterioration of road and bridge shoulders that cross, or run parallel to, the stream. Depending on the bank vegetation structure and soil type, such diversion of road-water over a bank can quickly begin to cut and erode the material.

Upper Knight Street

Parcel 44B

The build-up of sediment shoals result in ponded water, which in turns reduces stream aeration. In addition, during summer months, as the water crosses these shoals the flow is quite shallow. This shallow water, if not shaded, will quickly heat, thus reducing its ability to hold oxygen. Also such shallow flows can limit movement of aquatic species along the brook.

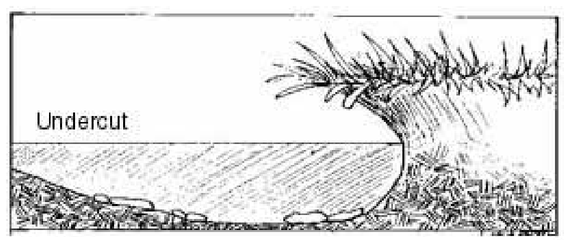
Baker Street Crossing

Stream Bank Condition
Somewhat related to the presence of a vegetated buffer, the condition of the streambank and its stability may play a role water quality. An eroding streambank is a likely source of sediment and nutrients bonded to soil particles.

Most phosphorus pollution is associated with soil erosion, due to the adsorption of phosphorus to clay and organic particles. The secondary impact of phosphorus enrichment in streams is the potential for expansive blooms of algae. As this algae decomposes, it depletes dissolved oxygen within water column.[24]

Soil also presents physical threats to the stream ecosystem. Soil moving into streams can bury or smother non-mobile species and impact filter feeding aquatic organisms. Further, soil suspended in the water column can inhibit light penetration which limits benthonic photosynthesis and replenishment of oxygen in deeper layers of the water column.

A stable, vegetated streambank may help slow the deposition of other pollutants into the stream, as it is part of the vegetated buffer. Conversely, a stable, *un*vegetated bank (one that has been artificially stabilized with rip-rap, concrete or other material) may permit easier deposition of pollutants in the stream. Artificial stabilizers also carry the potential for adding warm water to a stream, as mentioned in the section about



Undercut streambank, bank material has eroded below the root zone of streambank vegetation. *Graphic credit: Environmental Protection Agency.*

[24] *This dynamic of phosphorus loading in freshwater systems, and the subsequent cycle of algae bloom and oxygen depletion are typical characteristics of a eutrophic water body.*

Impervious Surfaces
Stream bank condition is assessed based on its stability, how it is stabilized and signs of erosion and undercutting.

From the raw data the following four (4) are considered those that are most ***impacted*** based upon the criteria of stream bank condition (Exhibit 24). For this particular criteria 'impacted' denotes a bank that is unstable and undercut or slumping, bare soil, little to no vegetation OR bank is not natural and is not stable.

PARCEL
43
316
340
27

The following table shows stream bank conditions ***at risk*** (Exhibit 24). For this particular criteria, 'at risk' denotes a bank that is unstable and shows signs of erosion, bare soil, exposed roots but not undercut, some vegetation OR majority of bank is artificially stabilized (rip-rap, concrete, etc).

PARCEL
DPW Concord Rd & Old Concord Rd
21
191
89
322
289
92
338
DPW Griffin St & May St
0
58
146
DPW George St
177
184
44
3
187
210
215
306
DPW Beaver St
2
35
59
64
72
76
121
138
151
154
179
186
188
190
195
198
207
232
241

279	DPW Harrison St
283	DPW Roxbury St
286	DPW Spring St
298	DPW Water St
299	143
308	303
310	233, 66, 161
323	DPW Baker St
344	DPW Marlboro St
6, 7, 8	166
DPW Church St	194

These sites listed in the previous two tables have the potential for restoration activities and may be the focus of a more in-depth prioritization and subsequent planning and design effort.

Recommendations

Stream Morphology and Wildlife Habitat

There are several constraints to the complete restoration of the Beaver Brook corridor. These limitations are physical and contractual and have been used as guidelines in making recommendations for the improvement of the aquatic and riparian habitats of Beaver Brook. These recommendations were designed in a manner which is compatible with the geomorphic setting and promotes channel stability while enhancing wildlife habitats. Recommended methods to improve aquatic and riparian habitats are presented below for each stream segment and are shown in Exhibit 28. These recommendations have taken into consideration the following constraints for physical modifications to the channel and adjacent areas.

- *Streamside Development*
  Residential and commercial development borders the brook in many areas. Building foundations form the streambanks in some places and the Kingsbury Corporation building spans the channel in two locations. Modifications to or demolition of buildings, parking lots, and other developed areas, though desirable from a stream restoration/habitat improvement perspective, have not been considered feasible options.

- *Streambank Revetments*
  Many sections of the brook have been armored with concrete, stone masonry walls, gabion baskets, stone rip-rap, and similar revetments. Although restoration of natural, vegetated streambanks would be desirable from a stream restoration/habitat improvement perspective, removal of these armaments has not been considered a feasible option.

- *National Flood Insurance Program Regulations*
  The City of Keene participates in the National Flood Insurance Program (NFIP), which enables property owners in the community to purchase federally-subsidized flood insurance. Participation in the NFIP is contingent upon the town adopting and enforcing a floodplain management ordinance that meets or exceeds minimum NFIP requirements as set forth in the Code of Federal Regulations (CFR) Title 44, Chapter I, Subchapter B.

  A regulatory floodway has been designated along the brook through the entire length of the study area. Minimum NFIP requirements for flood plain management regulations in flood-prone areas where floodways have been designated 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 any 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 if a Conditional Letter of Map Revision (CLOMR) is applied for and issued by FEMA; however, it is our opinion that a CLOMR would not likely be issued for a habitat improvement project.

In light of the NFIP requirements, the only recommendations that have been made which may increase flood stages include the structures to assist fish passage at four locations as described below.

- *Beaver Brook Local Protection Project*
  Modifications to the brook between Marlboro and Water Streets were completed between October 1985 and June 1987 and included channel widening, bank grading, and streambank revetments. This project was funded by the federal government under the direction of the U.S. Army Corps of Engineers. Thus, various limitations to restoration within this area exist, and in return for federal funding of the project, the State of New Hampshire under contractual agreement shall, among other items[25]:

  - Prevent future encroachment which might interfere with proper functioning of the project; encroachments refer to the deposition of waste materials, building of unauthorized structures, or other features that may adversely affect or exacerbate flood conditions;

  - Maintain the channel improvements as needed to obtain the maximum benefits; this effort includes maintaining the brook in a way that it is clear of debris, weeds, wild growth, and shoals (sediment dams) in a manner that promotes free flow of floodwaters; and

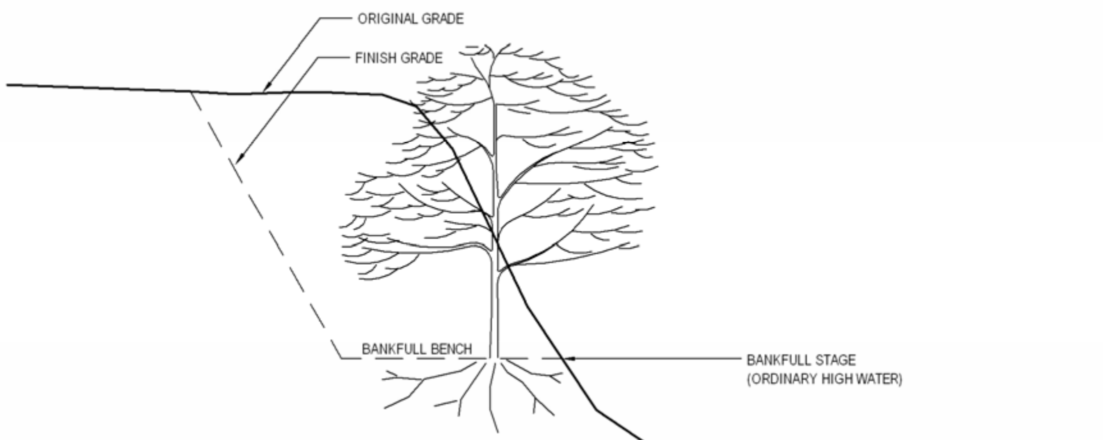
  - Prohibit any excavation, construction, or modifications within the limits of the project without approval of the Corps of Engineers; any change associated with the brook and its banks must be approved prior to any construction of improvements.

Implementation of any habitat improvements must comply with these constraints and all other local, state, and federal regulations. Landowner permissions shall also be obtained. Detailed engineering and stream restoration designs must be completed for improvements that involve relocation of the brook, installation of in-stream structures, or other earthwork. The recommendations presented below are conceptual in nature and are compatible with the geomorphic setting and promote channel stability while enhancing wildlife habitat. Refer to Exhibit 28 – Conceptual Stream Restoration and Habitat Improvement Recommendations for specific locations of stream segments, as well as Exhibit 10 - Bank Erosion Hazard Index and Exhibit 12 - Bridge and Fish Passage Barrier Plan.

[25] U.S. Army Corps of Engineers New England Division. June 1990. *Operation and Maintenance Manual, Local Protection Project, Beaver Brook, Keene, New Hampshire*

Stream Segment R1S1
This segment, located just above the confluence with The Branch, appears to be the only segment in reach 1 which has not been straightened. The channel is sinuous with alternating riffle-pool bed features. The brook cuts through the higher floodplain of The Branch and riparian areas are, for the most part, well-vegetated and dominated by silver maple, a desirable native species for riparian areas and floodplains. Active erosion is occurring on the outside of the meander bends due to the height of these banks, which are well above the bankfull stage, and the relatively shallow rooting depths. Small active floodplains have formed on the inside of the meander bends, which are desirable features that can help store floodwaters.

Stabilization of bank segment R5, which is vegetated primarily with multiflora rose, is recommended by excavating a bankfull bench (see Conceptual Bankfull Bench Detail below) and planting the bench with native trees, shrubs, and herbs. Bank revetments and/or flow deflectors constructed of logs, root fans, and large stone could also be installed to protect the bank while vegetation becomes established and to provide in-stream structure. The other eroding banks in this segment could be stabilized in a similar manner; however, this would require removing existing trees and understory vegetation which is not recommended.



Conceptual Bankfull Bench Detail

Stream Segment R1S2
This entrenched segment would ideally be converted from a G stream type back to an E stream type; however, development along the banks likely precludes the creation of floodplains needed for this conversion. The exception to this is at bank segment R1, which is vegetated by shallow-rooted switchgrass, actively eroding, and separated from Martell Court by a substantial distance. Stabilization of this bank is recommended by excavating a bankfull bench, planting the bench with native trees, shrubs, and herbs, and installing bank

revetments and/or flow deflectors constructed of logs, root fans, and large stone to protect the bank while vegetation becomes established and to provide in-stream structure.

Bank segment L2 is steep, sparsely vegetated, and is experiencing some active erosion. There is no space to construct a bankfull bench in this area. The most feasible option for stabilizing this bank is to grade the bank, apply topsoil, seed, and erosion control blankets, and install dogwood and willow livestakes or containerized plantings.

When the twin corrugated metal culverts at Route 12 (Main Street) require replacement, a single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

When the concrete bridge at Route 101 requires replacement, a larger, single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

Stream Segment R1S3

This segment, although technically an E stream type, has been straightened and is incised in some areas. Dredge spoils placed along the left (east) bank have increased the bank height and created a berm which limits access to the floodplain on that side of the brook. Due to the relative absence of streamside development, this segment presents one of the best opportunities for habitat improvements.

Removal of the dredge spoil berm and installation of native riparian tree and shrub plantings is recommended; however, flood protection currently provided by the berm must first be evaluated. If this evaluation shows that removal of the berm would increase flood hazards for nearby structures, construction of an offset berm is recommended. Flow deflection structures which add in-stream structure and promote the formation of scour pools should also be considered.

A more aggressive habitat improvement plan would include restoring a meandering channel alignment. This would physically increase the amount of aquatic habitat and promote the formation of a diversity of channel bed features (riffles, runs, pools, and glides). Bank revetments and/or flow deflectors constructed of logs, root fans, and large stone would likely be a component of this plan. It may be possible to convert abandoned portions of the existing channel to oxbow ponds which could be connected to the relocated stream by diversion channels. These ponds could provide refuge during floods and rearing habitat for juvenile fish.

When the concrete bridge at Baker Street requires replacement, a single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

Stream Segment R1S4
This entrenched stream segment includes a portion of the Army Corps Local Protection Project. Ideally the channel and overbank areas would be modified to create active floodplains and convert the stream type from G to E; however, streamside development and requirements of the Local Protection Project would preclude this approach in most areas. One area where this may be possible includes bank segments R1 and L1 which extend about 550 feet upstream from Baker Street. Construction of bankfull benches along both banks, planting the benches with native trees, shrubs, and herbs, and installing bank revetments and/or flow deflectors to protect the banks and provide in-stream structure is recommended. Additionally, the dredge spoil berm along bank segment L1 should be removed if engineering analysis shows that its removal would not increase flood hazards to nearby properties. If removal of the berm would increase flood hazards, relocation of the berm further from the channel (offset berm) should be considered.

When the concrete bridge at Marlboro Street requires replacement, a single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

Opportunities exist to construct bankfull benches along bank segment R6 and the upper portion of bank segment R4; however, these alterations would require Army Corps approval.

Stream Segment R1S5
This E-stream type segment currently supports well vegetated, narrow, active floodplains along one or both banks throughout most of its length and is functioning near potential given the surrounding land use. The rail trail bridge spans both the channel and its floodplain. One opportunity for habitat improvement would be cessation of mowing along bank segment L1 and the addition of riparian trees and shrubs.

Stream Segment R1S6
This entrenched, channelized stream segment encompasses both the Carpenter Field area and the concrete lined section between Spring and Harrison Streets.

For the portion of this segment bordering Carpenter Field, creation of an active floodplain encompassing a restored meandering channel is recommended. All constructed floodplain surfaces, streambanks, and slopes should be vegetated with native trees, shrubs, and herbs and bank revetments and/or flow deflectors constructed of logs, root fans, and large stone should be installed to add in-stream structure and stabilize the banks while vegetation becomes established. If channel relocation is not feasible, construction of bankfull benches along both sides of the brook and installation of log and rock flow deflectors for in-stream structure is recommended.

Construction of bankfull benches along both sides of the brook (space permitting) is recommended for the portion of this segment flowing east between Harrison Street and Carpenter Field. The benches should be vegetated with native trees, shrubs, and herbs and bank revetments and/or flow deflectors are recommended to protect the banks while vegetation becomes established and provide in-stream structure.

To eliminate the fish passage barrier on the downstream side of Harrison Street, a grade control structure is recommended a short distance downstream from the concrete sill which creates the drop. The invert of this structure, which would be constructed of large stone, would set such that the height of the existing drop is cut in half to about four inches. A second four inch (±) drop would occur over the constructed grade control structure. In essence, the existing drop would be split into two smaller drops. Construction of the grade control structure has the potential to raise flood elevations, which may require a Conditional Letter of Map Revision (CLOMR) from FEMA; therefore, detailed hydraulic analyses must be performed to evaluate the effects of the grade control structure on flood stages.

When the concrete bridge at Harrison Street requires replacement, a single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

Opportunities to promote fish passage through the concrete channel between Harrison and Spring Streets are limited to those techniques which would not increase flood stages. Therefore, an approach which increases the cross-sectional area of the channel (i.e. excavation) is recommended. One potential option would involve the creation of a small pilot channel sawcut into the channel bottom. Flow depths would be greater in this pilot channel and baffles or weirs could be installed to create areas of still water. Any weirs or baffles should be removable to allow accumulated sediment to be sluiced.

When the concrete bridge at Church Street requires replacement, the new bridge should have vertical abutments, rather than the existing sloping abutments. The additional cross-sectional area of the waterway opening will increase flow capacity and may decrease flood stages to the point that small grade control structures could be installed in the bottom of the concrete channel above the bridge with a no net increase in flood stages. Detailed hydraulic modeling would be required to determine if this is feasible.

If possible, the concrete encased utility line beneath the Roxbury Street Bridge should be lowered such that it is below the channel bottom. This would eliminate the fish passage barrier, increase the flow capacity of the bridge opening, and possibly reduce flood stages above the bridge. Construction of a series of grade control “steps” below the bridge would not likely comply with minimum NFIP standards.

Stream Segment R1S7

The brook does have access to floodplains along this stream segment; however, the lower portion is incised. This incision appears to be associated with a headcut knickpoint located near the R1/R2 bank segment break. Construction of a grade control structure to stabilize this knickpoint and prevent its further headward advancement is recommended.

Stream Segment R1S8

With the exception of a short section of the left (east) bank upstream from Beaver Street, the banks of this short, entrenched stream segment have been armored with stone masonry walls. The left bank above Beaver Street is bordered by a vegetated bankfull bench and is stable.

The span of the Beaver Street Bridge is only eleven feet – substantially smaller than the natural bankfull channel width. When the bridge requires replacement, a single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

Stream Segment R1S9

This segment has been straightened and is incised in some areas. Dredge spoils placed along the banks in the upper portion of this segment have increased bank heights and created berms which limit floodplain access. These spoil deposition areas have become vegetated with dense stands of Japanese knotweed. Due to the relative absence of streamside development in most areas, this segment presents one of the best opportunities for habitat improvements.

The current practice of mowing to the edge of the brook at bank segments L2 and L4 should be ceased and a riparian buffer of native trees and shrubs should be reestablished.

A corridor of mowed grass is maintained just beyond the top of bank along bank segment L5. This practice of mowing should be ceased and the grass corridor planted with native trees and shrubs to promote bank stability and shade the brook.

Additional native tree and shrub plantings are recommended along approximately 320 feet of the right (west) bank immediately downstream from the cemetery road bridge.

Restoration of a meandering channel alignment is recommended in the portion of this stream segment upstream from the cemetery bridge. This would physically increase the amount of aquatic habitat and promote the formation of a diversity of channel bed features. The opportunity for restoration of the sinuous abandoned section of channel west of the existing channel should be evaluated. Newly created sections of channel should be located through areas of native shrubby vegetation. Bank revetments and/or flow deflectors constructed of logs, root fans, and large stone would likely be a component of this plan. It may be possible to convert abandoned portions of the existing channel to oxbow ponds which could be connected to the relocated stream by diversion channels.

Stream Segment R2S1

Opportunities for stream restoration and habitat improvements in this segment are limited by the proximity of streamside development. Conversion of the current entrenched G stream type to a moderately entrenched B stream type is recommended where space permits.

The span of the George Street Bridge is only 13.5 feet – substantially smaller than the natural bankfull channel width. When the bridge requires replacement, a single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

The addition of large woody debris (LWD) should be considered throughout this segment as a means of adding in-stream structure and creating bed form diversity. The addition of LWD should be done in a manner which does not increase flood stages.

The recommended approach for stabilizing bank segments R1 and L3 includes grading the banks to a flatter slope, applying topsoil, seed, and erosion control blankets, and installing dogwood and willow livestakes or containerized plantings. Flow deflection structures constructed of large stone and/or logs should be installed to protect the bank while vegetation becomes established.

A series of steps and pools should be constructed immediately downstream from the exposed concrete-encased sewer main to eliminate this fish passage barrier. Steps should be constructed of large stone. A six inch maximum water level drop is recommended across each step. These channel improvements have the potential to raise flood elevations over a short section of the channel, which may require a CLOMR from FEMA; therefore, detailed hydraulic analyses must be performed to evaluate the effects of these improvements.

To eliminate the fish passage barrier on the downstream side of Giffin Street, a grade control structure is recommended a short distance downstream from the concrete sill which creates the drop. The invert of this structure, which would be constructed of large stone, would set such that the height of the existing drop is cut in half to about four inches. A second four inch (±) drop would occur over the constructed grade control structure. In essence, the existing drop would be split into two smaller drops. Construction of the grade control structure has the potential to raise flood elevations, which may require a CLOMR from FEMA; therefore, detailed hydraulic analyses must be performed to evaluate the effects of the grade control structure on flood stages.

When the concrete bridge at Giffin Street requires replacement, a single span, open bottom bridge wide enough to accommodate the bankfull channel and active floodplains along both banks is recommended.

Stream Segment R2S2

The brook has access to floodplains and is shaded by forest canopy throughout this stream segment; therefore, the brook is functioning near potential.

The recommended approach for stabilizing bank segment R3 includes grading the bank to a flatter slope, applying topsoil, seed, and erosion control blankets, and installing dogwood and willow livestakes or containerized plantings. Flow deflection structures constructed of large stone and/or logs should be installed to protect the bank while vegetation becomes established.

Restoration of the abandoned meander along the right (west) bank at the upstream end of this segment should be considered as a method of stabilizing bank segment L4 and creating a lateral scour pool.

The addition of large woody debris (LWD) should be considered throughout this segment as a means of adding in-stream structure and creating bed form diversity. The addition of LWD should be done in a manner which does not increase flood stages.

Stream Segment R2S3
Opportunities for stream restoration and habitat improvements in this segment are limited by the proximity of streamside development. Conversion of the current entrenched G stream type to a moderately entrenched B stream type is recommended where space permits.
The recommended approach for stabilizing bank segment R1 includes grading the bank to a flatter slope, applying topsoil, seed, and erosion control blankets, and installing dogwood and willow livestakes or containerized plantings. Flow deflection structures constructed of large stone and/or logs should be installed to protect the bank while vegetation becomes established.

The addition of large woody debris (LWD) should be considered throughout this segment as a means of adding in-stream structure and creating bed form diversity. The addition of LWD should be done in a manner which does not increase flood stages.

Stream Restoration and Habitat Improvement Priorities
The greatest opportunities for stream restoration and habitat improvements are in stream segments R1S3, along Carpenter Field in segment R1S6, and above the cemetery bridge in segment R1S9. The relative absence of streamside development in these areas would allow more aggressive restoration and habitat improvements. Removal of fish passage barriers should be another priority as this would allow migration between areas of suitable habitat. Each of these sites represents the highest priorities for the restoration of Beaver Brook.

Invasive Species Management
As noted above, invasives species are established throughout the streambanks and riparian areas of Beaver Brook. As such, priorities for management should focus within the Woodlawn Cemetery and Carpenter Field areas. These offer the most opportunistic sites to begin management of invasive species. Focal species should include purple loosestrife and Japanese knotweed.

Since invasive species management is a long-term effort, an Integrated Pest Management (IPM) plan should be developed that utilizes a variety of manual, mechanical, and chemical methods to effectively control the noxious invasives. This type of management expands options and provides flexibility in the weed control program. It also affords the opportunity to enlist volunteers in combination with licensed herbicide applicators. To apply an herbicide the City of Keene would need to choose a state-registered commercial applicator and submit an application to the NH Department of Agriculture (NHDA). This application can be filled out by the City or the company conducting the herbicide application. In order to choose a company with the appropriate type of license the City should submit a map to the NHDA showing the specific areas for herbicide application. They can then help you determine which license would be necessary since the sites to be treated are adjacent to an aquatic system. The IPM plan should be implemented prior to riparian plantings since activities could negate a positive response of such plantings.

Exhibit 29 offers a variety of management options that can be integrated into Keene’s overall noxious weed control program for Beaver Brook. These management techniques are broken down by species and include the type of action, description of action, time span required and the advantages and disadvantages of each action.

Woodlawn Cemetery
The two main invasives that should be targeted for management include purple loosestrife and Japanese knotweed. For the latter species, direct management would be best applied to both sides of the brook within the shrub swamp. Management recommendations include:

- Purple Loosestrife
  - Release 15,000-20,000 *Galerucella* beetles to promote species establishment and control of loosestrife;
  - The goal here is to develop a self-supporting population that can then disperse to other sites upstream and downstream;
  - Results should begin to be noticeable in 3-5 years;
  - Since the acquisition of the *Galerucella* beetles have to be approved by the New Hampshire Department of Agriculture email your request to Doug Cygan (Invasive Species Coordinator) at dcygan@agr.state.nh.us. Doug will then email the New Jersey Department of Agriculture and confirm your order. Orders can be prepaid and should arrive in May-June.
  - Periodical newspaper articles in the Environment section of the Keene Sentinel to spotlight these actions and promote community awareness and involvement

- Japanese Knotweed
  - Cut and remove all plant parts in May;
  - Conduct a second cutting in mid-June to July;
  - Hire a licensed herbicide applicator to apply a foliar spray when the plant is going into full flower (usually sometime in August). It is important to note that the timing of the herbicide application is crucial. It should not be applied when the flower is in full bloom but at the point that it is going into bloom. This would require regular site visits to determine the most appropriate time for the foliar application.
  - Periodic newspaper articles in the Environment section of the Keene Sentinel to spotlight these actions and promote community awareness and involvement

Carpenter Field
Japanese knotweed is the target invasive species for management activities. Direct management would be best applied to both sides of the brook from Water Street to Harrison Street. Management recommendations include:

- Japanese Knotweed
  - Cut and remove all plant parts in May;
  - Conduct a second cutting in mid-June to July;
  - Hire a licensed herbicide applicator to apply a foliar spray when the plant is going into full flower (usually sometime in August). It is important to note

that the timing of the herbicide application is crucial. It should not be applied when the flower is in full bloom but at the point that it is going into bloom. This would require regular site visits to determine the most appropriate time for the foliar application.

- Periodic newspaper articles in the Environment section of the Keene Sentinel to spotlight these actions and promote community awareness and involvement

Streambank Mowing Practices

All streambank mowing should be discontinued, where not specified and directed by US Army Corps of Engineers, and allow native vegetation to become re-established. If mowing is mandatory then all parts of invasive plants should be removed and disposed of properly to prevent the spread of the noxious weeds. Where mowing is currently being conducted invasive species, in particular Japanese knotweed, have become established and continued mowings typically promote their spread and increase density due to disturbance of soils, light and temperature alterations, and propagation of vegetative parts. Economically, it makes more sense to have mature trees growing along the stream corridor because they require less maintenance. If a tree or large branches fall in the stream, it can be a lot cheaper to remove them than it is to mow the entire stream corridor every summer and to manage the herbaceous vegetation (particularly the invasives).

Adjacent Land-use and Non-point Source Pollution

There is not a single approach to address the myriad of land-use impacts that have been document. A strategy needs to be developed that includes outreach and education, possible technical assistance to landowners in restoration of specific stretches of the riparian corridor, changes in standard operating procedures by homeowners and city personnel alike, actual reconstruction of degraded boundary areas and possible implementation of low impact development strategies.

More specifically, future planning, design and implementation activities by the City may include:

- Targeted Outreach and Education: Because the analysis was done at the parcel level, there is a good baseline data set of land-use activities by landowner. Thus, for those activities such as: depositing yard waste in the over the stream bank, using high-nitrogen/phosphorus lawn fertilizers or pesticides, cutting away buffer vegetation, limiting pet waste disposal on the property, having potentially hazardous materials situated on properties that allows direct pathways to the stream, etc., an outreach campaign can include targeting these known landowners, but could be expanded to a lesser degree to all the City's residences.
- Changes in Operating Procedures: Considering the existence of significant soil deposition in around storm drain outfalls, the city public works department could increase the frequency of storm basin cleanout, and possibly be more cognizant of the timing of such clean-outs in relation in the early spring periods when sand deposition is at its height after the snow season. In addition, periodic inspection of the streams at road crossings to ascertain the sediment buildup would allow the

development of a schedule to remove any sediment impoundments. An associate practice that needs to be avoided by public works operators is any plowing or dumping of snow into the riparian corridor. This would contribute significant loads of sediment over a winter season. For private snow-removal contractors, education and outreach should be implemented to stem such practices from the private sector. Obviously, this can be coupled with a general educational message to all adjacent landowners to avoid plowing/dumping snow into the riparian corridor

- Outfall Tracking: Based on the outfall map related to storm water run-off provided by the city, there were a number of undocumented straight pipes entering the brook. Some of these were discharging liquid, even during the driest parts of the summer. These outfalls should be investigated so as to determine both the source and quality of the outflow.
- Stream Bank Stabilization: There are a number of locations where one is seeing degradation and undercutting of stream banks. In many incidences, the soil erosion and sediment loading is not of such a significant scope that it would be economically out of the question of addressing these with relatively simple structural intervention, along with associated plantings. As such, parcels identified above should receive priorities for streambank stabilization. Subsequent site designs need to be developed in order to craft a cost analysis for site restoration activities.
- Road Crossing Infrastructure Repair: The Road crossings that are showing deterioration so that pathways for run-off are re-routed for natural buffer attenuation, or of a state that they are actually contributing sediment and associated pollutants to the stream should be assessed by public works. This will allow a prioritization and scheduling of repair and restoration.
- Decreasing Effective Run-off: Although, in a built environment it is difficult to reduce the percentages of impervious surfaces and/or recapture the integrity of a viable riparian buffer once structures have been built, However, there are approaches to reduce the amount of water running of the built watershed, which is directly correlated to reducing sediment load, BOD, nutrients, toxins and mitigating thermal pollution. On public controlled lands, this can include installation of infiltration and evaporation swales, establishment of rain gardens, and reduction of the width of impervious shoulders by replacing it with permeable materials. In the event of any major redesign or reconstruction that involves roadways, parking areas and walkways, considering the use of porous pavement and cements. Obviously associated costs analyses need to be provided but taking into account not only capital construction costs, but the associated maintenance costs often show such low impact development approaches to be cost competitive.
- Storm Drain Revamping: One the largest contributions to sediment, into the riparian corridor, appear to be associated with the storm drain systems at or near road crossings. One can assume these sediment loads are also contributing associated phosphorus and BOD to the stream system. Besides the aforementioned reassessment of the storm drain and outfall deposition inspection and cleanout, the city may consider strategically re-constructing certain storm drains to include cyclonic separators, and possibly filter bag inserts. The former is effective in removing not only course but fine sediments often carried by the street run-off, but it is a capital investment and unless it is cleaned out regularly, it effectiveness

diminishes overtime. The latter is a less expensive in regards to installation, and quite effective in removing finer grained sediment, but requires a much more rigorous maintenance schedule.

- Expand This Analysis: The parcel scale analysis was done specifically for the parcels along the riparian corridor, as well as at the point where roads crossed the stream. A second tier analysis would be to expand this assessment methodology for those parcels that would contribute run-off, and associated sediment and pollutant loads in the catchments contributing to the storm water network with outfall at the Brook. However, in lieu of this, it would be simple enough to include those parcels for any "targeted" outreach/education that is appropriate in regards to homeowner practices.

Conceptual Plans

A variety of conceptual plans have been developed as an aid for understanding some of the various types of restoration planning techniques (Exhibit 30). These plans focus on the three prioritized sites for habitat restoration, as well as illustrating some solutions to stormwater management within various zoning districts, including low density and industrial-high density districts.

Planting Plans

Under the scope of work and through feedback with the project committee, planting plans were developed for the areas of Carpenter Field, Baker Field and the Woodlawn Cemetery (Exhibit 31). These plans were drafted from aerial surveys and a rudimentary site survey.

Typically, planting plans would involve more extensive field work to determine the specific site conditions at a finer scale. The plans submitted serve to give a rough estimate of how many and which variety of plants can be planted at the three locations, as well as the source of nursery stock and their costs. However, it is very important, if the city is going to undertake this work, that the plans are developed further, to more accurately reflect the site specific conditions and/or contract with a landscape professional to oversee the purchasing and installation of plant material. The quantity of plant material is large and it will take some good planning and coordination of resources to get it done properly.

As such, these plans and species selection (native plants from the region) are based on current conditions of Beaver Brook and its riparian areas. If sites change then species selection may not adapt accordingly. As mentioned above, it is highly recommended to treat invasive species within targeted areas prior to plantings. Also, it would be highly advantageous to address the soil berm at the Baker Street site prior to plantings.

Cost Estimates

Invasive Species Management

- 15,000-20,000 *Galerucella* beetles @ $200/1,000 beetles $2,000-3,000

- Cost estimates associated with foliar spaying of Japanese knotweed will need to be coordinated with a licensed herbicide applicator. A site assessment by the licensed applicator will most likely need to be performed in order to determine actual costs. Also, the City will need to file an application with the NH Department of Agriculture to determine if a special license for aquatic systems is applicable. If a licensed aquatic pest control applicator is required then this will significantly reduce the number of companies that can perform this task.

Planting Plans
See Exhibit 32.

Fish Passage Barriers
The approach and cost estimates assume all four barriers (Harrison, Roxbury, and Giffen Streets and the sewer main) would be designed, permitted, and constructed as a single project, which would far and away be the most cost effective way to approach this effort. Dividing the cost by four to estimate a per-site cost would yield an underestimated cost.

State wetland permitting of the fish passage barriers would be needed and a separate US Army Corps of Engineers permit would not likely be needed. Local floodplain permitting may also be an issue to be addressed.

A floodway has been established along the brook and, assuming the City has adopted floodplain management regulations equivalent to FEMA's minimum floodplain management criteria, the following will be required:

> *The community shall* (among other things) *: (3) 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 any increase in flood levels within the community during the occurrence of the base flood discharge;* [see 44 CFR §60.3(d) at http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&rgn=div6&view=text&node=44:1.0.1.2.27.1&idno=44]

At a minimum, hydraulic analyses would need to be performed to evaluate the impact of the channel modifications. If the modifications increase flood stages an application for a Conditional Letter of Map Revision (CLOMR) from FEMA would be required. Assuming the CLOMR is approved, an application for a Letter of Map Revision (LOMR), which is based on as-built conditions, would be needed.

The estimated cost for survey, design, wetland and floodplain permitting (including CLOMR and LOMR applications), and construction for all four sites is attached in Exhibit 33. A meeting with FEMA to verify the need for all this work would be advised.

Community Outreach and Education

- In addition to the above cost estimates for the highest priorities for restoration, it is also highly recommended that the City of Keene commit sufficient funds towards community education and outreach through such activities as sign development associated with stream restoration sites, landowner outreach, and workshop series. Costs associated with community outreach and education will vary, depending upon which actions the City of Keene chooses to implement and to what extent.

Source Documents

Alabaster, J. S. (1959). *The effect of sewage effluent in the distribution of oxygen and fish in streams*. Journal of Animal Ecology. 28, 2: 283-291

Andrews, G., Townsend, L., Orgegon State University. (2001). *Stream*A*Syst - A tool to help you examine stream conditions on your property*. Retrieved from: http://www.wsi.nrcs.usda.gov/products/w2q/strm_rst/docs/Stream-A-Syst_2001.pdf

Arnold, Chester L. Jr. & Gibbons, C. James. (Spring 1996). "Impervious Surface Cover – The emergence of a key environmental indicator." *Journal of the American Planning Association,* 62(2), 243-258.

ASTM (2005). *Standard Practice for Environmental Site Assessments; Phase 1 Environmental Assessment Process. ASTM* Designated Standard E 1527-00, American Society for Testing and Materials; West Conshohocken, PA. 25pp.

Carmel River Watershed Conservancy (2004). *Carmel River Watershed Assessment. Section 5.7.2 Analysis of Macroinvertebrate Functional Groups.* Carmel River Watershed Council and Carmel River Watershed Conservancy, Inc. website. Available online at http://www.carmelriverwatershed.org/WA/5_7_2_a_text.pdf

Center for Watershed Assessment. (2008). "RSAT: The Rapid Stream Assessment Technique" *Watershed Assessment – Tools you can use.* Retrieved from: http://www.stormwatercenter.net/monitoring%20and%20assessment/rsat/smrc%20rsat.pdf

Connecticut River Joint Commissions & New Hampshire Department of Environmental Services (NH DES). (1994). *A Homeowner's Guide to Nonpoint Source Pollution in the Connecticut River Valley*. Retrieved April 18, 2009 from: http://www.crjc.org/pdffiles/homeguide.pdf

Donlon, Andrea, McMillan, Barbara, & NH DES. (January 2004). *Best Management Practices to Control Nonpoint Source Pollution – A guide for citizens and town officials.* Retrieved April 30, 2008 from: http://www.des.state.nh.us/wmb/was/documents/2004_npsBMP.pdf

Elder, J.(1987). *Factors Affecting Wetland Retention of Nutrients, Metals and Organic Materials.* In, J Kunsler (ed.), Wetlands Hydrology: Proceedings of National Wetland Symposium.

Environmental Protection Agency (EPA). (1997). "Chapter 3 – Watershed Survey Methods." *Volunteer Stream Monitoring: A Methods Manual.* Retrieved from: http://www.epa.gov/volunteer/stream/stream.pdf

EPA. (1997). "Chapter 4.1 - Stream Habitat Walk." *Volunteer Stream Monitoring: A Methods Manual.* Retrieved from: http://www.epa.gov/volunteer/stream/stream.pdf

EPA. (2007). *Biological Indicators of Watershed Health: Classification of Macroinvertebrates.* US EPA website. Available online at www.epa.gov/bioindicators/html/invertclass.html

Gergel, S.E., Turner, M.G. , Miller, J.R., Stanley, E.H., & Melack, J.M.. (2002). "Landscape indicators of human impacts to riverine systems." *Aquatic Sciences*, 64, 118-128. Retrieved from: http://www.nceas.ucsb.edu/~gergel/Gergel_etal.2002(Indicators).pdf

Gries, G. 2008. Personal communications. NH Fish and Game Region 4 Office, Keene, NH.

Hardesty, Phoebe and Kuhns, Cynthia. (1998). *The Buffer Handbook – A guide to creating vegetated buffers for lakefront properties* (DEP Publication No. DEPLW0094-A2001). Augusta, ME: Maine Department of Environmental Protection.

Horner, Richard, et al (1994). *Fundamentals of Urban Run-off Management*, Terrene Institute, Washington DC, 308 pp

Industrial Hygenics; 2001. 40-Hour HAZWOPER Training Guide. Williston, VT.

Kaller, M. and Kelso, Wm. (2007). *Association of macroinvertebrate assemblages with dissolved oxygen concentration and wood surface areas in selected subtropical streams in southeastern USA.* Aquatic Ecology. 41,1:95-110

Kennebec County Soil and Water Conservation District & Maine Department of Environmental Protection (July 2007). *Camp Road Maintenance Manual – A Guide for Landowners* (DEP Publication No.DEPLW0837). Retrieved May 30, 2008 from: http://mainegov-images.informe.org/dep/blwq/docwatershed/camproad.pdf

Kimball, J.C. (1996). *Adopt-a-Stream Shoreline Survey Leaders' Manual.* Boston: Massachusetts Riverways Program.

Kondratieff, M.C. and Myrick, C.A. 2006. *How High Can Brook Trout Jump? A Laboratory Evaluation of Brook Trout Jumping Performance,* Transactions of the American Fisheries Society 135:361-370.

Korb, Gary & Watkins, Carol. (1999). "Rethinking Yard Care," *Yard care and the environment: A series of water quality fact sheet for residential areas.* Madison, WI: University of Wisconsin Extension. Retrieved April 30, 2008 from: http://clean-water.uwex.edu/pubs/pdf/home.rethink.pdf

Lake Champlain Basin Program. (2006). "Nonpoint Source Pollution," *Fact Sheet Series, Number 2*. Retrieved April 30, 2008 from: http://www.lcbp.org/factsht/npsfactsheet2006.pdf

Laser, M., 2007. *A Framework for Process-Based Restoration: Riparian Function and Large Woody Debris Dynamics in an Atlantic Salmon River in Maine.* PhD Dissertation. Antioch University New England. Keene, NH.

Laser, M. 2005. *Process-based restoration of riparian function: A theoretical justification.* Submitted for partial fulfillment of the candidacy requirement at Antioch New England Graduate School. Keene, NH. 51 p.

Littleton, J.L. 2004. Natural Resources Inventory of Stream Riparian Buffers: Conservation and Restoration Priority Plan. Keene, NH. Moosewood Ecological LLC.

Maine Department of Environmental Protection and Maine Congress of Lake Associations. (1997). *A citizen's guide to lake watershed surveys: How to conduction a nonpoint source phosphorus survey* (DEP Publication No. DEPLW-41-A97). Augusta ME: Maine Department of Environmental Protection.

Maine DEP. (2008). "Unit 6: Stream Watershed Survey," *(Draft) Stream Survey Manual (Volume 1): A Citizen's Guide to Basic Watershed, Habitat, and Geomorphology Surveys in Stream & River Watersheds.* Retrieved April 30, 2008 from http://www.state.me.us/dep/blwq/docstream/team/stream_survey_manual/vol_1/index.htm

Maine DEP. (2008). "Appendix K: Site Form" *(Draft) Stream Survey Manual (Volume 1): A Citizen's Guide to Basic Watershed, Habitat, and Geomorphology Surveys in Stream & River Watersheds.* Retrieved April 30, 2008 from http://www.state.me.us/dep/blwq/docstream/team/stream_survey_manual/vol_1/index.htm

Maine DEP. (2008). "Appendix J: Stream Corridor Survey (Level 1) Field Sheets and Instructions" *(Draft) Stream Survey Manual (Volume 1): A Citizen's Guide to Basic Watershed, Habitat, and Geomorphology Surveys in Stream & River Watersheds.* Retrieved April 30, 2008 from http://www.state.me.us/dep/blwq/docstream/team/stream_survey_manual/vol_1/index.htm

Maine DEP. (1998). *Issue Profile: Nonpoint Source Pollution.* Retrieved April 30, 2008 from: http://www.state.me.us/dep/blwq/docwatershed/lp-nps1.htm

Marsh-mathews, E. and Mathews, W. (2000). *Geographic,terrestrial and aquatic factors: which most influence the structure of stream fish assemblages in the Midwestern United States.* Ecology of Freshwater Fish. 9: 9-21.

Massachusetts Adopt-A-Stream Program. (Not Dated). *Riparian Area Survey.* Retrieved from: http://www.mass.gov/dfwele/river/volunteer/riparian_area_survey.doc

Massachusetts DEP. (Not dated). *Massachusetts Volunteer Guide for Surveying a Lake Watershed Survey and Preparing an Action Plan.* Retrieved April 30, 2008 from: http://www.mass.gov/dep/public/lwsguide.pdf

Massachusetts DEP. (2001). *Surveying a Lake Watershed Survey Data Collection Forms – Guidance for Community Volunteers in Massachusetts.* Retrieved April 30, 2008 from: http://www.mass.gov/dep/public/lwsforms.doc or http://www.mass.gov/dep/public/volmonit.htm

Massachusetts DEP. (2006). "Chapter 1: Nonpoint source pollution." *Nonpoint Source Pollution Management Manual.* Retrieved April 17, 2009 from: http://projects.geosyntec.com/NPSManual/NPSManual.pdf

Massachusetts DEP. (2006). "Chapter 7: Forestry operations." *Nonpoint Source Pollution Management Manual.* Retrieved April 17, 2009 from: http://projects.geosyntec.com/NPSManual/NPSManual.pdf

Massachusetts DEP. (2006). "Chapter 9: Resource extraction." *Nonpoint Source Pollution Management Manual.* Retrieved April 17, 2009 from: http://projects.geosyntec.com/NPSManual/NPSManual.pdf

Moesswilde, Morten. (2004). *Best management practices for forestry: Protecting Maine's water quality*. Augusta, ME: Maine Department of Conservation Forest Service.

Moore, E. (1932). *Stream pollution and its affects on fish life*. Sewage Works Journal. 4, 1:159-165.

Moore, J.W. (1989). "Chapter 7 – Urban Hydrology." *Balancing the needs of water use.* New York : Springer-Verlag.

New Jersey DEP. (2000). *The Clean Water Book: Choices for Watershed Protection.* Retrieved April 30, 2008 from: http://www.nj.gov/dep/watershedmgt/cleanwaterbook/waterbook_tble.htm

Ocean County Soil Conservation District, Schnabel Engineering Associates, Inc., and USDA Natural Resources Conservation Service (2001). *The Impact of Soil Disturbance During Construction on Bulk Density and Infiltration in Ocean County, New Jersey*.

Omernik, J.M. (1976). *The Influences of Land Use on Stream Nutrient Levels.* US-EPA-600/2-76-014. Washington DC.

Parkhurst, J. and Pomeroy, R. (1972). *Oxygen Adsorption in Streams*. Journal of Sanitary Engineering . 98, 1:101-124.

Pitt, Robert, et al (2002). *Compacted Urban Soils Effects on Infiltration and Bioretention Stormwater Control Designs, 9th International Conference on Urban Drainage*, IAHR, IWA, EWRI, and ASCE, Portland, Oregon, September.

Rehnby, N., ed. (2007). *Fundamentals of Urban Run-off Management: Technical and Institutiona*l Issues, North American Lake Management Society. Madison,WI, 327 pp

Rosgen, D.L. 1994. *A Classification of Natural Rivers*, Catena, Vol 22, 169-199, Elsevier Science, B.C. Amsterdam.

Rosgen, D.L. 1996. *Applied River Morphology*. Wildland Hydrology Books, Pagosa Springs, Colorado.

Simpson, M. (2007) *Preparing for Climate Change: A Small City's Mid-century Culvert Drainage Needs*. Presented at the Maine Water Resource Conference, Augusta Civic Center, Augusta ME March 21, 2007; New Hampshire Water Resource Conference, Grappone Center, Concord, NH April 9, 2007

Smale, M. and Rabeni C. (1995). *Influences of hypoxia and hyperthermia on fish species composition in headwater streams*. Transactions of the American Fisheries Society. 124, 5:711-725.

Stack L., Simpson M., Crosslin T., Spearing W., Hague E. (2007) *A point process model of drainage system capacity under climate change*. Climatic Change (in-review)

Soil Conservation Service. (1989). *Soil Survey of Cheshire County, New Hampshire.* Washington, D.C.: U.S. Department of Agriculture, Soil Conservation Service.

The Nature Conservancy & Delaware Department of Natural Resources and Environmental Control. (2005). "Riparian Corridors." *Blackbird-Millington corridor conservation area plan.* Retrieved from: http://www.dnrec.state.de.us/nhp/information/blackbird.asp

Tong, Susanna T. Y. & Wenli Chen (2002). Modeling the relationship between land use and surface water quality. *Journal of Environmental Management*, 66, 377-393.

U.S. Department of Agriculture (1972). *National Engineering Handbook, Section 4*. Soil Conservation Service. Washington DC.

U.S. Department of Agriculture (1986). Urban *Hydrology for Small Watershed, TR55*. Soil Conservation Service. Washington DC.

U.S. Department of Agriculture (1992). Technical release No. 20. Soil Conservation Service. Washington DC.

U.S. Department of Agriculture. (1998). *Stream Visual Assessment Protocol.* Retrieved from: http://www.nrcs.usda.gov/technical/ECS/aquatic/svapfnl.pdf\

University of Wisconsin – Extension. (1997). *Polluted urban runoff – A source of concern.* Retrieved April 30, 2008 from: http://cleanwater.uwex.edu/pubs/pdf/storm.urban.pdf

Vermont Agency of Natural Resources. (May 2007). “Stabilization Measures for an Eroding Lakeshore,” *Vermont Lake Protection Series*, # 3B. Retrieved April 30, 2008 from: http://www.anr.state.vt.us/dec//waterq/lakes/docs/lpseries/lp_lpseries3b.pdf

Vermont Agency of Natural Resources. (Not Dated). “Preventing Driveway Erosion,” *Vermont Lake Protection Series*, #5. Retrieved April 30, 2008 from: http://www.anr.state.vt.us/dec//waterq/lakes/docs/lpseries/lp_lpseries5.pdf

Vermont Agency of Natural Resources. (2003). *Vermont Stream Geomorphic Assessment Phase 1 Handbook: Watershed Assessment – Using Maps, Existing Data, and Windshield Surveys.* Retrieved from: http://www.vtwaterquality.org/rivers/htm/rv_geoassesspro.htm

Vermont Agency of Natural Resources. (2003). *Vermont Stream Geomorphic Assessment Phase 2 Handbook: Rapid Stream Assessment – Field Protocols.* Retrieved from: http://www.vtwaterquality.org/rivers/htm/rv_geoassesspro.htm

Vermont Agency of Natural Resources. (2003). *Vermont Stream Geomorphic Assessment Phase 3 Handbook: Survey Assessment – Field and Data Analysis Protocols.* Retrieved from: http://www.vtwaterquality.org/rivers/htm/rv_geoassesspro.htm

VT Department of Environmental Conservation. 2004. Macroinvertebrate Sampling, Processing, and Metrics. http://www.vtwaterquality.org/bass/htm/bs_macro.htm
Walker, W.W. (1987). *Phosphorus removal by urban runoff detention basins*. Lake and Reservoir
Management 3: 314-328.

Wanielista, Martin and Yousef A (1993) “Stormwater Management,” John Wiley & Sons, Inc.

Welch, E.B. (1992). “Ecological Effects of Wastewater”. Chapman and Hall, London, UK.

Wildland Hydrology, Inc. April 2003. *River Restoration and Natural Channel Design Field Guide.*

Yetman, K.T. (2001). *Stream Corridor Assessment Survey*. Retrieved from: http://www.dnr.state.md.us/streams/pubs/SurveyProtocols2.pdf

Acronyms and Glossary

BMP – Best Management Practices
BOD – Biological Oxygen Demand
CFR – Code of Federal Regulations
CLOMR – Conditional Letter of Map Revision
FEMA – Federal Emergency Management Agency
NFIP – National Flood Insurance Program
NPS – Nonpoint Source Pollution

Bankfull Discharge – The discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels. [Dunne and Leopold, 1978]. The bankfull discharge is often referred to as the "effective discharge" or the "channel-forming flow". The bankfull discharge does not transport the most sediment at one time, but it is the most effective discharge at transporting sediments over time. On unregulated streams, the bankfull discharge typically has a recurrence interval of about 1.5 years, meaning that it is typically equaled or exceeded 2 out of every 3 years.

Bankfull Stage - the water surface elevation resulting from the bankfull discharge.

Base Flood – the flood having a one percent chance of being equaled or exceeded in any given year. Also referred to as the 100-year flood. [44 CFR §59.1]

Benthic Macroinvertebrate - aquatic organisms, without a backbone, that can be seen with the naked eye and lives on or near the bottom of a body of water such as a stream or pond.

Benthonic – Refers to the plant and animal life whose habitat is the bottom of a sea, lake, river, or stream.

Best Management Practices (BMP) - Structural or nonstructural methods which prevent or reduce the movement of sediment, nutrients, pesticides and other nonpoint source pollutants from the land to surface or ground water. BMP's include but are not limited to vegetated buffers, water bars, porous pavement, wet ponds, and detention and retention ponds.

Biological Oxygen Demand (BOD) – BOD is a laboratory test estimating the amount of oxygen-demanding substances in water samples. Examples of oxygen-demanding substances include naturally occurring organic matter (e.g., leaves, wood, dead aquatic organisms), organic matter discharged from wastewater treatment plants (e.g., sewage, industrial/processing wastes), and ammonia. These substances are usually decomposed or converted to other compounds by bacteria if there is sufficient oxygen present in the water. If the BOD level is high, it might reduce dissolved oxygen concentrations in a stream or river enough to stress aquatic organisms such as fish and macroinvertebrates.

Cascade - An area of high turbulence and coarse substrate with a gradient > 4%. These appears as small waterfalls or a series of small waterfalls cascading over coarse substrate, typically small boulders or bigger.

Concentration – The amount of one substance contained within a certain volume of another substance; often expressed in units such as milligrams/Liter (mg/L), parts per million (ppm), or parts per billion (ppb).

Contributing Catchment – The area of roads and associated parcels that direct water towards and into the stream corridor.

Culvert – Buried pipe that allows water to flow or pass under a road.

Desktop – Indicates that information for ranking was gathered utilizing spatial analysis and already defined data sources that were brought together using orthophoto interpretation and/or GIS analysis. For example, the demarcation for soil type and related factors to any one parcel was based on NRCS soil information on the NH GRANIT data base, which was then viewed with the City's data base regarding individual parcels. The limitations of such a spatial analysis is that the precision of the NRCS soil demarcations has limitations and historical changes to the site through development may alter the related soil factors , such as permeability and erosivity factors, associated with any particular parcel.

Erosion – The wearing away of the land surface by running water, wind, or ice.

Flood Stage – as used in this report, the term flood stage refers to the water surface elevation resulting from a flood discharge with a specified recurrence interval. For example, the 10-year flood stage is the water surface elevation resulting from the 10-year flood discharge.

Floodplain – land area susceptible to being inundated by water from any source. [44 CFR §59.1]. As used in this report, the floodplain is that area subject to flooding from overflow of Beaver Brook and The Branch.

Floodway – see Regulatory Floodway.

Glide - A transitional zone between pools and riffles, a run/glide has swift uniform (laminar) flow without surface agitation or waves. Maximum depth is about 5% or less of the average stream width. Do not confuse glides with the downstream ends of pools.

Hydrologic Soil Group – Soil's ability to intake water when the soils are thoroughly wet and receive water from long duration storms. Hydrologic soil groups are used to estimate how much water will runoff from a storm.

Impaired – Referring stream health, the stream does not meet state or national water quality standards for specific pollutants of concern. Water quality is degraded.

Impervious Surface – Hard surfaces that water cannot soak into such as driveways, roads, roofs, and parking lots.

Intercept – Referring to precipitation and vegetated buffers, leaves change the course of a raindrop falling from a cloud directly to the ground.

Invasive Plants – non-native plant species that, through aggressive life strategies, out compete and displace native vegetation and can disrupt wildlife communities, and alter ecological structure and functions.

Leachate – Liquid that seeps away from a larger source of potential contamination.

Meander – The winding of a stream channel. A series of "S"-shaped curves characterized by curved flow and alternating banks and shoals (unvegetated deposits of gravels and cobbles adjacent to the banks that have a height less than the average water level [e.g., point bars]).

Nonpoint Source Pollution (NPS) – Diffuse pollution, generated from large areas with no particular point of pollutant origin, but rather from many individual places.

Nutrients – Substances that encourage growth in living organisms. Common nutrients of concern in freshwater ecosystems, like streams and lakes, are phosphorus and nitrogen. These nutrients are required for plant growth, but their limited availability controls the amount of plant growth in the ecosystem.

Overbank Area – as used in this report, the term overbank area refers to those areas adjacent to the streambanks which are subject to inundation from flood discharges exceeding the bankfull discharge.

Permeability - The ability of soil to transmit water or the rate at which water flows downward through saturated soil.

Point Source Pollution – Pollution discharged directly from a specific site such as a municipal sewage treatment plant or industrial outfall pipe.

Pool - Aquatic habitat in a stream with a gradient less than 1% that is normally deeper and wider than aquatic habitats immediately above and below it. Depth is usually, but not always, greater than about 2 feet for first order (small) streams and greater than 3.0 feet for second order (or above) streams.

Regulatory Floodway – the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. [44 CFR §59.1].

Riffle – Shallow reaches of a stream (1-4% gradient) characterized by small hydraulic jumps over rough bed material, causing small ripples, waves, and eddies. Generally, the water surface is broken up by turbulence.

Riparian Corridor – An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes streambanks, woodlands, vegetation, and part (or all of) floodplains.

Runoff – The portion of rainfall, melted snow, or irrigation water that flows across the surface or through underground zones and eventually runs into streams.

Scouring – The erosive action of running water in streams, which excavates and carries away material from the bed and banks.

Sedimentation – (1) The combined processes of soil erosion, entrainment, transport, deposition, and consolidation. (2) Deposition of sediment.

Urban Sediment – Debris related to a developed or urban landscape, such as sand from winter road sanding, salt, crumbled pavement, bits of tire debris, and flakes of metal from rusting cars or deteriorating brakes.

Vegetated Buffer – The width of naturally vegetated (or recently planted) land between the streambank and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses.