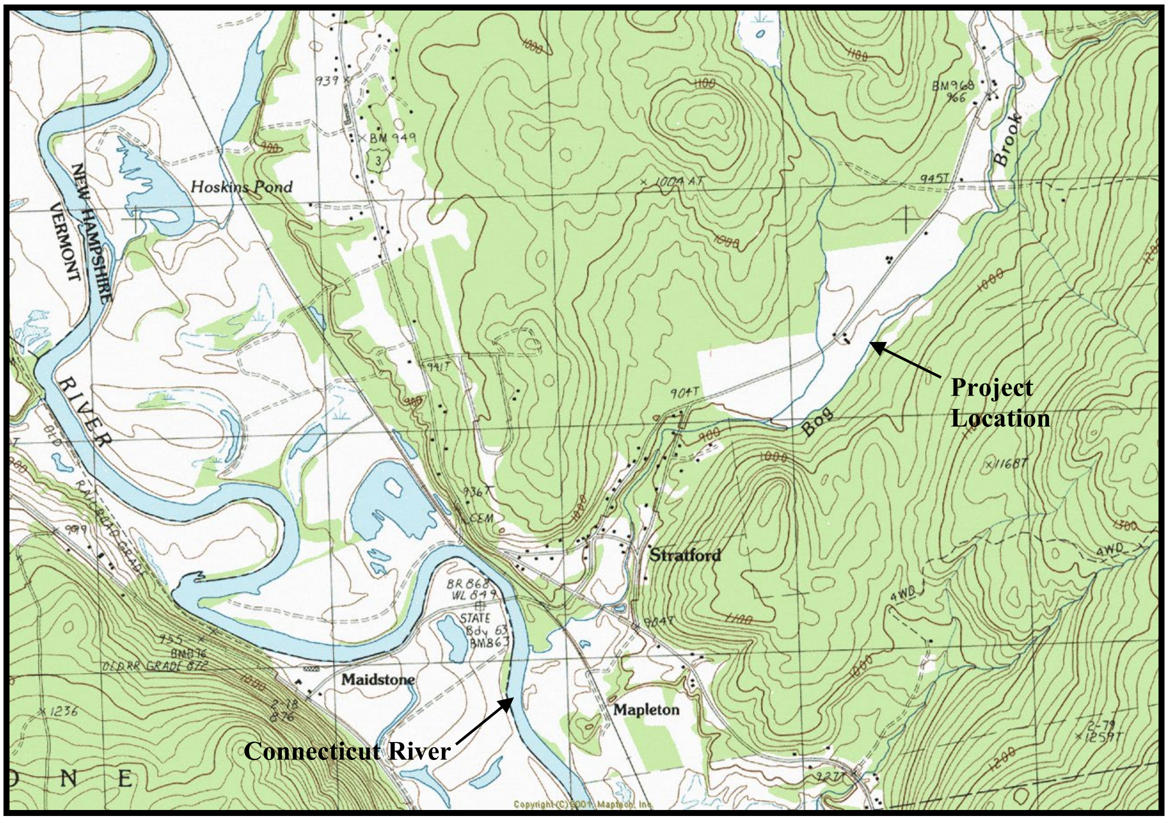
Final Report for

BOG BROOK RESTORATION PROJECT

Stratford, New Hampshire



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<u>APPENDICES</u>

A. INTRODUCTION

In June of 2003 the Town of Stratford, NH was awarded a $14,912 Watershed Restoration Grant from the NHDES Watershed Assistance Section (appropriated through the USEPA under Section 319 of the Clean Water Act) for the Bog Brook Restoration Project. The grant partially funded survey, design, permitting, and construction of the project which stabilized approximately 275 feet of the brook. The total project cost was $24,460. Tom Glidden (landowner) provided $8,748 in matching funds. In-kind professional services for construction supervision, valued at $1,800, made up the remainder of the required non-federal match.

Data collection followed the protocols outlined in the June 2003 Quality Assurance Project Plan (QAPP) for Stream Morphology Data Collection *("Generic Quality Assurance Project Plan for Stream Morphology Data Collection"* , June 17, 2003). Project design relied heavily on that data in conjunction with principles of fluvial geomorphology and natural channel design methods. The project was constructed between May 20th and May 24th, 2004 by Winterset, Inc. under full-time supervision by the project designer, Sean Sweeney (formerly of Provan & Lorber, Inc.).

The project addressed an area of severe bank erosion which threatened an existing barn and septic tank and was a significant sediment source to the brook and the Connecticut River, to which it flows approximately 1½ miles downstream. Based on a comparison of the 2003 channel location to that on a 1999 aerial photo (see Appendix 2), the channel had eroded laterally up to 35 feet and consumed approximately 4,000 square feet of land. Using a mean channel depth of 2.5 feet over that area, approximately 370 cubic yards, or about 480 tons, of sediment has been introduced into the stream as a result of bank erosion over that four year span. That was on average 120 tons, or about 9 ten-wheeler dump truck loads, per year.

It appears the instability resulted from the removal of woody riparian shrubs from the stream banks. This likely occurred decades earlier as a means of increasing arable land. The absence of deep-rooted shrubs made the banks vulnerable to erosion, especially the outside bank of the meander bend upstream of the barn. As this bank eroded, the meander bend became sharper, placing even greater stress on the bank and accelerating the on-going erosion. Had this process been allowed to continue, it appeared likely that the brook would have eventually cut a new channel across the field immediately south of the barn (channel avulsion). Several thousand tons of additional sediment would have been transported to downstream reaches and the Connecticut River if this had happened.

B. PROJECT GOALS

The goals of the project were to:

- Restore of a stable, self-maintaining channel without the use of traditional bank-armoring techniques such as rip-rap;
- Reduce erosion and sediment supply to downstream reaches and the Connecticut River;
- Improve water quality by reducing the volume of fine-grained sediment and associated nutrients introduced to the stream;
- Protect the barn and septic tank;
- Improve aquatic habitat by restoring riparian vegetation for shade and food production; and
- Prevent a future channel avulsion.

C. PROJECT TASKS AND RESULTS

The project included 8 specific tasks. These are presented below along with the results of each specific task.

Task 1. – Prepare Quality Assurance Project Plan (QAPP)
The QAPP was prepared to ensure that this project, and future stream restoration projects based on fluvial geomorphic principals, follows a structured procedure for data collection and interpretation. The resulting QAPP, entitled *Generic Quality Assurance Project Plan for Stream Morphology Data Collection*, dated June 17, 2003, was approved by EPA on July 15, 2003.

Task 2. - Collection of Available Information
This task included collecting historic and recent aerial photography, determining the drainage area at the project site, and estimating the bankfull discharge and channel dimensions.

Aerial photography from 1954 and 1999 were obtained from the UNH Cooperative Extension field office in Lancaster, NH. Comparing these two photos showed that there had been significant lateral channel migration to the north over that 45 year period. The 1954 photo showed woody riparian vegetation along the outside bank of the meander bend, whereas in the 1999 photograph that vegetation was absent. The meander bend was also much tighter (smaller radius) in the 1999 photograph as compared to that shown in the 1954 photo. These comparisons provided strong evidence that removal of stream-side vegetation was the initial cause of erosion and general instability.

The drainage area at the project site was determined to be 23.6 square miles (see Watershed Map in Appendix 1). Using this drainage area and the NH Regional

Hydraulic Geometry Curves (also in Appendix 1), the bankfull discharge and channel dimensions were estimated as follows:

- NH Bankfull Discharge ~ 850 cfs
- NH Bankfull Cross-Sectional Area ~ 184 sq. ft.
- NH Bankfull Width ~ 59 ft.
- NH Bankfull Mean Depth ~ 3.1 ft.

Bankfull discharge and channel dimensions were also predicted using the Vermont Regional Hydraulic Geometry Curves (see Appendix 1) with the following results:

- VT Bankfull Discharge ~ 520 cfs
- VT Bankfull Cross-Sectional Area ~ 131 sq. ft.
- VT Bankfull Width ~ 49 ft.
- VT Bankfull Mean Depth ~ 2.7 ft.

<u>Task 3. – Field Survey/Data Collection</u>

This task included:

- Seven cross-sections of the brook and adjacent flood plain;
- Longitudinal profile along approximately 1,050 feet of the brook;
- Transit survey to develop a site plan of the project area and measure plan view characteristics of the brook;
- Pebble count and sub-pavement sample to be used for sediment transport calculations; and
- Wetland delineation for state and federal environmental permitting.

Results of the pre-construction surveys, pebble count, sub-pavement sample, and sediment transport calculations are included in Appendix 2 and discussed below.

Cross-Section Surveys

Seven cross-sections, numbered 5 through 11, were surveyed in July 2003 using a fiberglass tape and laser level. Cross-Section 5 is located downstream of the relocated reach in an area which, due to the dense riparian shrubs along the banks, is experiencing little active bank erosion. Sections 6 and 7 span the relocated reach and portion of the former channel which was experiencing severe bank erosion. Sections 8 through 11 are located upstream of the relocated reach where there is an adequate riparian buffer and comparably little erosion. Cross-sections 10 and 11 appeared particularly stable. All cross-sections, with the exception of number 6, were located at riffle bed features. Cross-section 6 was at a pool.

Iron rods (5/8" rebar with yellow plastic caps) were set near the endpoints of each section so they could be located for future monitoring surveys. The rebar monuments also serve as local elevation benchmarks. The horizontal locations of the rebars set at cross-sections 5 through 9 were captured while performing the transit survey. The locations of these sections are shown on the Existing Conditions (pre-construction) Site Plan in Appendix 2. Note that cross-sections 10 and 11 are well upstream of the relocated reach and were not located as part of the transit survey.

This reach of Bog Brook is split, or bifurcated, as shown on the aerial photo in Appendix 1 and the Existing Conditions (pre-construction) Site Plan in Appendix 2. The significance of this condition, and its influence on the restoration design, is discussed under Task 4. The area of severe bank erosion was located along the main northerly branch (right channel looking downstream). Cross-section 9 is located across the channel split. Cross-section 10 and 11 are located upstream of the split and provided reference cross-sectional geometry data for a single-thread channel. Sections 5 through 8 are located across the northerly branch. Several width measurements made along the length of the southerly branch indicated that it is less than half the width of the northerly branch.

The following table summarizes the cross-sectional geometry characteristics surveyed prior to construction.

Cross-Section	Bankfull Cross-Sectional Area (sq. ft.)	Bankfull Width (ft.)	Bankfull Mean Depth (ft.)	Max. Bankfull Depth (ft.)	Width/Depth Ratio
5*	63	39	1.6	3.0	24
6*	98	44	2.2	5.4 (pool)	20
7*	58	36	1.6	3.0	23
8*	50	43	1.2	2.0	36
9**	98	80	1.2	2.3	67
10**	103	40	2.6	3.6	15
11**	107	39	2.7	3.3	14

* cross-section spans northerly branch only
** cross-section across single-thread portion of channel

As shown, the cross-sectional areas at riffles within the north branch are about 60% of the cross-sectional areas upstream of the split; however, the bankfull widths are nearly identical. As a result, mean bankfull depths in the north branch are significantly less and width-to-depth ratios are considerably higher than those upstream of the split. These comparatively low depths and high width-to-depth ratios are an indication that shear stress and the brook's ability to transport bedload may be insufficient.

Profile Survey
The longitudinal profile was surveyed along approximately 1,050 feet of the channel from 250 feet upstream of cross-section 9 to about 100 feet below cross-section 5. Downstream of cross-section 9 the profile followed the north branch. A plot of the surveyed profile is included in Appendix 2.

The average water surface slope measured along the entire length of the profile was 0.68%. The average water surface slope in the north branch (downstream of cross-section 9) was determined to be 0.81%. Pools were spaced between 125 feet and 225 feet apart with an average spacing of 180 feet (~4.5 bankfull widths). The lowest bank corresponded to the bankfull stage in all areas along the profile. This indicated that the channel was connected to its flood plain and not incised.

Maximum bankfull depths at riffles were consistently measured between about 2.3 and 2.8 feet - similar to the maximum depth measurements at the riffle cross-sections across the north branch, but less than the maximum depth measurements at the cross-sections in the single-thread reach upstream of the split. This shows that the north branch is shallower than the single-thread reach and is another indication that the sediment transport competence in the north branch may be insufficient.

Transit Survey/Plan View Geometry
A digital transit was used to survey the project area on July 21, 2003. Enough information was collected to locate the brook, barn, edge of woody vegetation, bank erosion areas, and the cross-sections as shown on the Existing Conditions (pre-construction) Site Plan in Appendix 2. The site plan allowed basic plan view measurements to be made and was used to assess the impact areas for wetlands permitting.

Using the site plan it was determined that the meander radius at the area of severe bank erosion was 40 feet, or about one bankfull width. This was a very small radius, (sharp meander bend) which placed extreme stress on the outside bank. This radical bend combined with the lack of any deep-rooted woody vegetation to counteract the resulting stress was the primary cause of bank erosion. Stable meander radii for alluvial, gravel bed streams are typically between 2 and 3 bankfull widths (80 to 120 feet for this reach of Bog Brook).

The valley length between cross-section 9 and the downstream end of the profile is about 530 feet. The stream length along the north branch between those two points was approximately 750 feet. Using these values the sinuosity of the north branch was determined to be 1.42 (750 ft/530 ft).

Pebble Count and Sub-pavement Sample
The pebble count and sub-pavement sample were both taken from the active bed of the riffle between cross-sections 6 and 7. Results are included in Appendix 2. The median particle size from the riffle pebble count was 70 mm (small cobble). The sub-pavement sample is a collection of representative channel materials which are subject to movement as bedload. The total weight was about 215 pounds. Sieve analysis of this sample indicated that the median particle size was 50 mm. The largest sub-pavement particle was 140 mm.

A separate pebble count for stream classification purposes was not performed. The median particle size from the active bed of a riffle will always be greater than for the entire channel. Because the median riffle bed particle size was 70 mm and the cutoff between gravel and cobble is 64 mm, it can be reasonably assumed that the mean particle size for the entire channel is below 64 mm and therefore this reach of Bog Brook is a gravel bed stream.

Wetland Delineation
Based on analysis of soils, vegetation, and hydrology, it was determined that the top of bank represented the limit of areas under state and federal jurisdiction. No off-channel wetlands were found within the immediate project vicinity.

<u>Task 4. – Develop Restoration Plans</u>
This first part of this task involved analyzing the survey data and performing sediment transport calculations. The restoration plan was based on the results of these analyses and available funding.

Stream Type
Based on the channel cross-section dimensions, slope, sinuosity, and mean particle size, this reach of Bog Brook is classified as a C4 stream type (Rosgen, 1994). This classification describes a meandering, gravel bed stream with a well developed flood plain. Note that the cross-sections were not extended to capture the entire flood prone area, however, based on visual observation the entrenchment ratio is well in excess of the minimum value required for C-stream types (i.e. broad flood plain).

Channel Dimensions
Both the New Hampshire and Vermont Regional Hydraulic Geometry Curves predict cross-sectional geometry values greater than what was measured in the single-thread reach, with the Vermont curves being the closer of the two. This seems logical as the site is near the Vermont border and the New Hampshire curves include data from many gages in the White Mountains region which generally have greater precipitation and runoff (and therefore larger channels) than areas outside of the mountains (including the project site). The regional curves are intended to predict bankfull channel geometry, but are not intended to supersede measured data. Because the data from cross-sections 10 and 11 were consistent and somewhat similar to that predicted by the Vermont curves, the cross-sectional geometry measured at those sections was used as reference data.

Reference Bankfull Cross-Sectional Geometry (riffle, single-thread channel):

Width = 40 ft.
Cross-Sectional Area = 105 sq. ft.
Mean Depth = 2.6 ft.
Width-to-Depth Ratio = 15
Max. Depth = 3.5 ft.
Estimated Bankfull Discharge = 500 cfs

Plan View Geometry
Using the reference bankfull width and radius-to-width ratio of 2 to 3, appropriate meander radii should be between 80 and 120 feet. Sinuosity for C-stream types is typically 1.2 or greater.

Sediment Transport Calculations
The data collected from the riffle pebble count, sub-pavement sample, and channel profile were used to predict the combination of depth and slope need to move the largest particle available as bedload (140 mm). Results are included in Appendix 2. The calculations indicate that a mean riffle bankfull depth of 2.3 feet is required to move a 140 mm particle at a 0.68% slope. At a slope of 0.81% (average water surface slope of north branch below channel split), the calculation predicts a mean riffle depth of 2.0 feet is needed. Both of these depths are greater than those measured at riffle cross-sections 5, 7, and 8 where the mean depths were 1.6 feet, 1.6 feet, and 1.2 feet respectively. The inadequate depth indicates that bedload deposition (aggradation) is likely to occur. To restore sediment transport competence and channel stability it was determined that the depth and/or slope must increase.

Vegetation
The outside bank of the sharp meander bend was primarily vegetated with grasses (Timothy, Reed-Canary Grass, Kentucky Bluegrass, and Orchard Grass). The rooting depth of these species extended only about 6 inches and did little to resist the stresses present at times of high water. Deep-rooted riparian shrubs whose roots extend several feet below the top of bank were needed for long-term bank stability.

Restoration Plan
The following list highlights the major items needed to restore channel stability and reduce bank erosion and sediment supply.

1. Increase meander radius to create a less radical bend and reduce stress in the near-bank region;
2. Increase mean depth and/or slope to improve sediment transport competence;
3. Restore a buffer of deep-rooted riparian shrubs along the bank.

These items are discussed below in detail along with other components of the restoration plan.

Meander Radius
Using the site plan, it was determined that a meander radius of approximately 92 feet could be created by shifting the channel east by about 70 feet (see Proposed Site Plan in Appendix 3). The resulting radius-to-width ratio would be 2.3 (92 ft/40 ft) and would fall within the range typical of C4 stream types. Approximately 140 feet of the channel would be reconstructed to achieve this meander radius. This alignment departed the existing channel about 40 feet upstream of cross-section 7

and tied back into the channel about 50 feet downstream of cross-section 6. The existing stream length between those departure and tie-back points was approximately 270 feet.

Depth and Slope

The new channel alignment would result in a net loss of approximately 130 feet of stream length. Due to the shorter channel length, the average slope in the north branch would increase to 1.00% (see Proposed Channel Profile in Appendix 3). Due to the increased slope, the sediment transport calculations predicted that a mean riffle bankfull depth of 1.6 feet would be needed to mobilize a 140 mm particle. As a result the proposed cross-sectional geometry within the relocated reach was:

Width = 35 ft.
Cross-Sectional Area = 60 sq. ft.
Mean Depth = 1.7 ft.
Width-to-Depth Ratio = 20
Max. Depth = 2.5 ft.

Note that this geometry is very similar to that measured at cross-sections 5 and 7 where there is a good buffer of riparian shrubs and minimal bank erosion.

In addition to increased slope, the shorter stream length also results in decreased sinuosity. The new stream length between cross-section 9 and the downstream end of the profile would be about 650 feet with a valley length of approximately 530 feet. The resulting sinuosity is 1.23 (650 ft/530 ft). Sinuosity values of C-stream types are typically 1.2 or greater, therefore, even though the channel was shortened, the sinuosity is still within the accepted range.

Vegetation

The new channel alignment would cut across a large gravel point bar, portions of which were vegetated with willows. Those growing within the proposed channel alignment were proposed to be transplanted to the new stream bank on the outside of the reconstructed meander bend.

Bank Stabilization Structures

Two 'j-hook' rock vanes were proposed to protect the new stream bank while the transplanted shrubs became established.

Additional Considerations

Had cost and land ownership not been an issue, it would have been preferable to restore a single-thread channel through the length of the split reach (approximately 1,200 feet). The restored single-thread channel would have had a width, depth, and area similar to that measured at cross-sections 10 and 11. Due to the cost to implement a project of this scope, it was not proposed.

The restoration design did anticipate future morphological changes within the split reach. At some time in the future it can be expected that either the north or south branch will be abandoned and the remaining channel will become the "single-thread". The remaining channel would enlarge until it has cross-sectional geometry similar to that measured at cross-sections 10 and 11.

Should the brook abandon the north branch the potential for future bank erosion in the vicinity of the barn is eliminated. Due to the thick riparian vegetation which borders the south branch, enlargement of this channel would be a slow process. A more likely scenario appears to be continued deposition at the upstream end of the south branch with the north branch become the single-thread. If this occurs, the additional flow would likely widen and deepen the channel to create a cross-sectional area of about 105 square feet. The increased meander radius, bank stabilization structures, and transplanted riparian shrubs should limit bank erosion associated with channel widening. In anticipation of potential channel deepening, the inverts of the two 'j-hook' rock vanes were proposed at a depth of 3.0 feet below the bankfull stage even though the proposed maximum depth in the reconstructed reach was only 2.5 feet. The typical design of these structures calls for the inverts to be set at a depth of nine-tenths (0.9) of the maximum bankfull depth. Therefore setting the inverts at 3.0 feet below bankfull would be appropriate for a channel with a maximum depth of about 3.3 feet (3.0 ft/0.9), which is the maximum depth measured at cross-section 11 in the single-thread reach above the split. In summary, the design of the reconstructed channel would not preclude future channel enlargement.

Task 5. – Wetlands Permitting

An application for a Standard Dredge and Fill Permit was submitted to the NHDES Wetlands Bureau in September 2003. The application fee was $1,300.00. Jeff Blecharczyk of the Wetlands Bureau inspected the site on December 5, 2003. The permit (#2003-02264) was issued on December 17, 2003. A copy of the permit is attached in Appendix 4.

Task 6. – Contractor Selection

The project designer (Sean Sweeney) met on site with Glen Lavoie of Winterset, Inc. to discuss the project and solicit a bid for the work. Winterset had completed a similar project on Bog Brook approximately 1.1 miles upstream in June of 2003. At the time they were also reconstructing the Maidstone Bridge over the Connecticut River approximately 1.3 miles downstream of the project site. As such, they had the needed construction equipment and a stockpile of clean fill material in the area. The proximity of equipment and fill would reduce mobilization and trucking costs. For these reasons Winterset, Inc. was the preferred contractor. They proposed to perform the work at a cost of $18,000.00 and were selected to construct the project.

Task 7. – Construction

The project was constructed over three days between May 20th and May 24th, 2004 by Winterset, Inc. Full-time construction supervision was provided by the project designer. This included stake-out, checking grades, and directing the sequence and methods of work. Construction followed the following sequence:

1. The location and grades of the new outside bank were staked by the project designer;
2. Approximately 20 willows and 2 alder were transplanted from areas within the new channel alignment to the new stream bank;
3. The new channel was roughed-in working from the downstream tie-in point to the upstream tie-in point so that as much work could be performed before stream flows were turned into the new channel;
4. Once excavation reached the upstream tie-in point, stream flows were directed to the new channel and the upstream end of the former channel was filled;
5. The downstream 'j-hook' rock vane was installed first followed by the upstream vane;
6. A small root wad found on the point bar was installed on the outside bank near the downstream tie-in point;
7. Sod mats were transplanted to the face of the new outside bank;
8. Material excavated from the new channel alignment was used to fill the upstream end of the former channel;
9. Additional fill material was imported to fill the downstream end of the former channel;
10. Loam was spread over the filled portion of the former channel;
11. All disturbed areas were seeded and mulched.

One excavator, one small bulldozer, and several dump trucks were used. Several photographs taken during and immediately after construction are included in Appendix 5.

Task 8. – Post-Construction Photographs and Measurements

This task includes taking several photographs after construction and surveying at least two cross-sections after spring runoff in 2005 and 2006 to determine the success of the project. Appendix 5 contains several photographs taken immediately after construction and in July 2004, approximately two months after construction. Appendix 5 also contains a Photo Location Plan showing the locations of the photographs taken in July 2004. These same photo points will be used in subsequent monitoring in 2005 and 2006.

Cross-sections 6 and 7 will be re-surveyed in 2005 and 2006 after spring runoff. The 2005 cross-sections will be superimposed on the design cross-sections to determine the difference between the designed and constructed cross-sectional geometry. Similarly, the 2006 cross-sections will be overlaid on the sections surveyed in 2005 to determine any trends in channel stability. Photo documentation will provide visual evidence of channel trends and will also illustrate the success of restoring riparian vegetation. Appendices 6 and 7 have been provided as a location for subsequent monitoring data.

Site visits in the summer and fall of 2004 suggest that the channel modifications are performing well. No bank erosion was observed and all of the transplanted riparian shrubs and sod mats appeared to have survived and taken root (see July 2004 photos in Appendix 5).

D. CONCLUSIONS

Pending the outcome of future monitoring, the Bog Brook Restoration Project will likely demonstrate that, when possible, streambank stabilization methods should be based on the results of rigorous data collection and analysis to determine causes of instability and appropriate means of restoring stability. Traditional bank stabilization methods have typically specified bank armoring (rip-rap, etc.) which treats the symptom rather than addresses the problem.

To date it appears that the project has been successful. Severe bank erosion has been arrested and the sediment load to the brook has been significantly reduced. Also, the impacts to water quality and channel stability associated with a channel avulsion have been avoided. Subsequent monitoring will include quantitative data collection to validate these initial observations.

E. RECOMMENDATIONS

At the present time the only recommendation is additional riparian shrub plantings within the filled portion of the former channel. The goal would be the creation of a wider riparian buffer to further ensure long-term channel stability. These could be containerized plantings purchased from a nursery or live stakes taken from local sources. The latter option would allow for a large number of plantings to be installed at a relatively low cost.

Although other remedial actions are not anticipated, additional recommendations may arise from future monitoring.