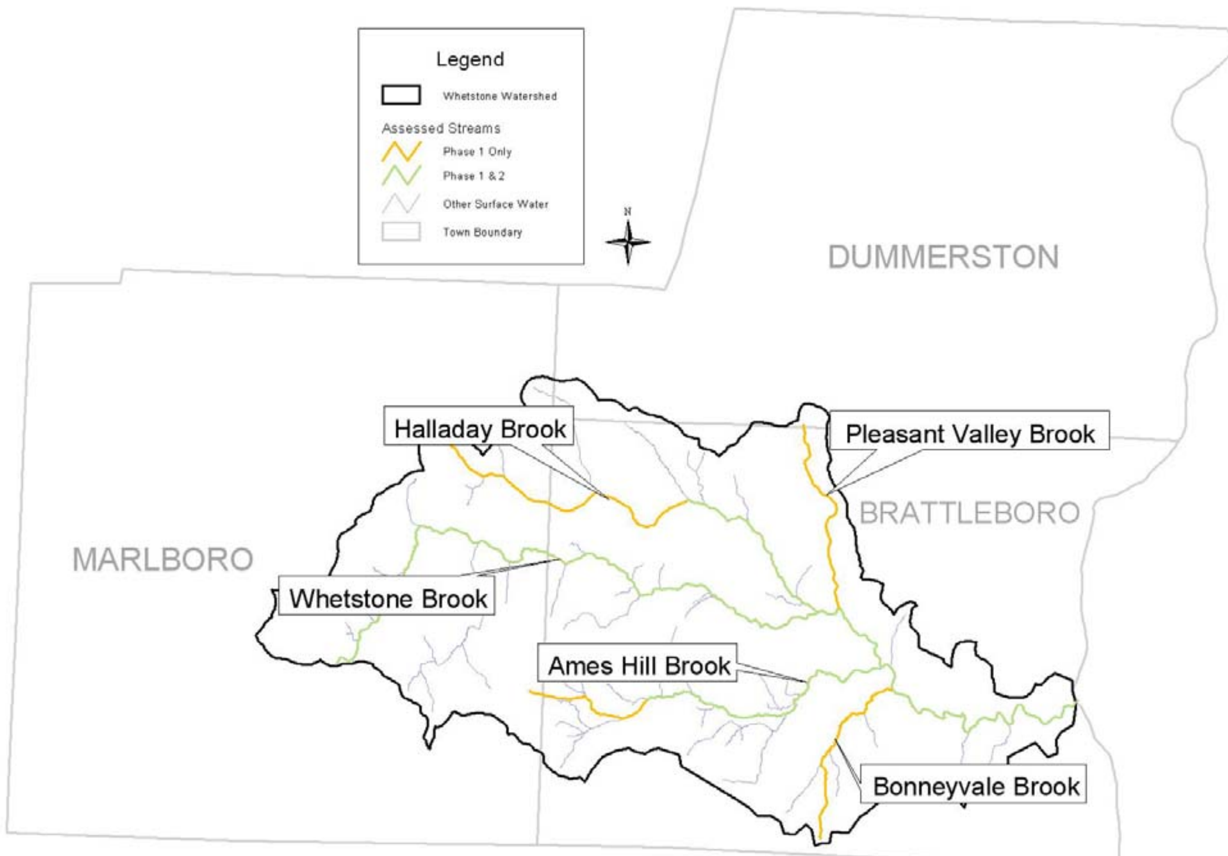
Whetstone Brook Watershed
Stream Geomorphic Assessment
And River Corridor Plan
May, 2008



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1.0 Executive Summary

The Whetstone Brook Watershed is located in Windham County, Vermont, in the towns of Brattleboro and Marlboro with a small portion of the northern watershed in Dummerston. It is part of the Connecticut River Basin and is located in the southeast corner of the State. The watershed is 27.4 square miles or 17,566 acres and the Whetstone Brook is 13 miles long.

A Phase 1 Stream Geomorphic Assessment (SGA) was completed on twenty-five stream reaches in the Whetstone Brook Watershed. These reaches include the entire Whetstone Brook, Bonneyvale Brook, Ames Hill Brook, Pleasant Valley Brook and Halladay Brook. Seventeen of the reaches identified in Phase 1 were selected for the Phase 2 SGA based on Phase 1 Impact scores as well as sensitivity and potential conflicts with infrastructure.

A Phase 1 SGA defines stream reaches based on the physical characteristics of the watershed and stream corridor. Compiling and analyzing existing information on the geology, soils, slope, and watershed size help define the stream reaches and results in “reference stream typing”. The reference stream type offers a description of the physical characteristics of a stream reach in the absence of human impacts. The Phase 1 SGA also includes an inventory of existing human impacts in the watershed that results in an impact rating.

A Phase 2 SGA field checks Phase 1 data and updates it where necessary, providing an understanding of reference conditions, departure from reference and likely causes for departure from reference (disequilibrium). The concept of stream equilibrium is based on the understanding that all streams, left un-managed, will find a width, depth and meander pattern that are self-maintaining and will provide for sediment and flood transport in equilibrium over the long term.

The underlying geology (rocks and dirt) and hydrologic (water) cycle in conjunction with human impacts in the watershed have created the waterways that we know today. The glacial history of the Whetstone Brook Watershed left behind deep pockets of highly erodable, sandy alluvium. At the same time, there are also areas where it is very shallow to bedrock, resulting in numerous, natural grade controls throughout the watershed. These bedrock areas keep the stream from eroding down and help it maintain access to floodplain. Topographically, the main stem and all four of the major tributaries have very steep headwater reaches flowing into valley bottom reaches that are relatively flat, resulting in natural areas of high sediment transport and other areas of high sediment deposition. Another consequence of the sandy soils left behind by the glaciers is that the Whetstone does not have many natural wetland areas (nature’s sponges) to assist with the storage of flood water and sediment. Because of this, when large rain events occur, more of the water enters the streams than in watersheds with abundant wetlands.

The greatest human impacts to the watershed are from urban development and channelization. Urban development watershed-wide is 16% and in the sub-watersheds it ranges from 72% to 5%. A watershed that is more than 10% developed is considered to have an altered hydrologic cycle. Because of the narrow valleys and steep adjacent hills, much of this development has occurred in the flood plain and even in the floodway areas of the stream. It has also resulted in 88 storm water pipes and ditches draining directly into the stream throughout the assessed reaches, bringing storm water even more quickly and in larger volume to the rivers than would occur naturally.

The Whetstone Brook is 40% straightened; Bonneyvale Brook does not appear to have been straightened; Ames Hill Brook is 16% straightened and Halladay Brook is 80% straightened. Channel straightening increases stream power by increasing channel gradient and flow velocity, causing a downcutting in the channel bed (increasing slope) and triggering disequilibrium. Eventually, the stream banks will fail and the stream will over-widen.

River management at the watershed scale seeks to reduce the long-term costs and risks of erosion and flood damage to downstream reaches by identifying restoration activities that will restore the natural pattern of flooding. This plan calls for conservation of the few remaining flood attenuation areas, retrofitting of Low Impact Development techniques to reduce storm water inputs, removal of existing structures from the floodway, and the prevention of further encroachment into the floodway and flood plain through adoption of a Floodplain and Fluvial Erosion Hazard (FEH) Zone by the town of Brattleboro. An FEH zone is identified by using information gathered through Stream Geomorphic Assessments to determine the width of river corridor necessary for re-establishing channel equilibrium. When implemented by towns, it prevents development from occurring in those areas that are most likely to erode over time, reducing future, costly conflicts between property owners and the river and providing the river the room it needs to re-establish equilibrium.

2.0 Project Overview

2.1 Introduction

The Whetstone Brook has a history of severe, unpredictable, and disruptive flooding. The underlying geology, soils and topography, combined with considerable and increasing development in the river corridor and a history of intensive channel management have created numerous and frequent human/river conflicts that are costly to both individuals and to the town of Brattleboro. As a result, the town of Brattleboro, and numerous local, regional, and state agencies have an interest in understanding the on-going physical processes in the watershed, and in using this knowledge to inform how the Whetstone Brook and its corridor can best be restored.

A River Corridor Protection and Restoration Plan, based on Stream Geomorphic Assessments (SGA), identifies management and land use strategies as well as potential conservation and restoration projects that will help avoid and resolve conflicts. With careful planning and management, informed by sound science, Brattleboro residents can redefine their relationship with the Whetstone Brook, turning it from a liability into a community asset.

2.2 Project Partners

The Windham County Natural Resources Conservation District (WCNRCD), with funding from the Vermont Department of Environmental Conservation (DEC) Clean and Clear River Corridor Grant, hired Landslide Natural Resource Planning, Inc. to complete Phase1 and Phase 2 Stream Geomorphic Assessments and River Corridor Planning in the Whetstone Brook Watershed. The Windham Regional Commission was also a partner in this project.

2.3 Past Studies

The Whetstone Brook has been studied numerous times in the past. In 1967 the U.S. Department of Agriculture, as part of the Connecticut River Basin survey and in 1972 the Army Corps of Engineers Flood Plain Information Study both identified that the Town of Brattleboro is vulnerable to flood damage. In the Connecticut River Basin survey, the Whetstone Brook was identified for “early action”. Also in 1972 the Soil Conservation Service, now the Natural Resource Conservation Service, completed a “Watershed Investigation Report” that identified numerous measures to reduce flood damage and future conflicts between the river and the residents of the watershed. These recommendations included developing a series of reservoirs, complemented by dikes (berms), channel modifications (widening) and flood plain management, including implementing zoning, relocating and flood proofing properties and flood insurance. Of these measures, it appears that some berming and channel modifications were done and that flood insurance was made available to residents.

2.4 Goals and Objectives of the Project

Over time and in the present climate, a river left in its natural state will maintain an equilibrium condition. A stream in a state of equilibrium will maintain a relatively stable channel, reducing erosion hazards and flood damages, improving water quality and providing a diverse habitat for aquatic organisms. Historically, humans have sought to control rivers by moving, straightening, hard armoring and dredging them. This has caused major disequilibrium in many locations and creates expensive on-going management concerns.

The goal of river corridor planning is to utilize Stream Geomorphic Assessment (SGA) data to determine the river's current degree of departure from the reference equilibrium state and to identify existing constraints to the river evolving back to equilibrium. The analysis results in a prioritized list of restoration projects that may be implemented over the long-term by individuals and organizations interested in reducing expenses related to flood and erosion hazards, reducing sediment pollution entering the Whetstone Brook and in improving aquatic and terrestrial habitat within the watershed.

This SGA was completed to assist the towns of Brattleboro and Marlboro with planning for and avoiding erosion and flood hazards in the future. The Phase 2 SGA data collected on the Whetstone Brook and its tributaries is necessary for the development of a Fluvial Erosion Hazard Zone (FEH). An FEH zone is a corridor along both sides of the stream channel that is defined by the type of stream, its sensitivity rating and its current adjustment process. This area defines the space the river is likely to erode in the future. Maps of the FEH are available to the towns of Brattleboro and Marlboro to incorporate into their local planning efforts.

2.5 Description of Study Area

A Phase 1 Stream Geomorphic Assessment (SGA) was completed on twenty-five stream reaches in the Whetstone Brook Watershed. These reaches included the entire Whetstone Brook, Bonneyvale Brook, Ames Hill Brook, Pleasant Valley Brook and Halladay Brook. Seventeen of the reaches identified in Phase 1 were selected for a Phase 2 Stream SGA based on Phase 1 Impact scores as well as sensitivity and potential conflicts with infrastructure. A total of 29 stream miles were assessed in the Phase 1 SGA and 19 miles were assessed in Phase 2. The seventeen reaches assessed in the Phase 2 SGA were further divided into 47 segments, five of which were not assessed due to beaver dams, human dams or bedrock gorge features. See Figure 1 in Appendix A and Map 1 in Appendix B for a complete description of the assessed reaches.

3.0 Background Information

3.1 Geographic Setting

The Whetstone Brook Watershed is located in Windham County, Vermont, in the towns of Brattleboro and Marlboro with a small portion of the northern watershed being in Dummerston. It is part of the Connecticut River Basin and is located in the southeast corner of the State. The watershed is 27.4 square miles or 17,566 acres and the Whetstone Brook is 13 miles long. Like most of the rest of Vermont, the watershed was primarily forested prior to European settlement. With the introduction of agriculture (originally sheep farming, now dairy) the area was deforested for pasture and crop production (Albers). By the late 1800's the entire state was 75% denuded of trees. Today, much of this watershed has returned to forest land with increasing amounts of land being converted to residential use. Currently, the watershed is approximately 70% forested, 16% developed (including residential, commercial and roads), 7% agriculture, 6% water and 1% wetland. In 1972 the watershed was 78% forested, 5% urban, 6% crop, 4% pasture and 7% miscellaneous (USDA, 1972).

From 1970 to 2000 the population of Brattleboro has *declined* from 12,239 to12,005 people while the number of housing units has *increased* from 4,299 to 5,686 (2003 Brattleboro Town Plan). Approximately 988 people live in Marlboro.

3.2 Geologic Setting

The Whetstone Brook Watershed is located in the Connecticut River Valley of Vermont in the southernmost area of the Southern Vermont Piedmont bio-physical region. The Southern Vermont Piedmont is defined by the rolling foothills east of the main Green Mountains. Post glaciation, the majority of the igneous and sedimentary rock has been eroded away, leaving bedrock dominated by a "mixture of limestone, schist, and granite" (Johnson, p. 30). The Whetstone Brook has seven bedrock grade controls in the assessed reaches with three segments not being assessed due to bedrock gorge conditions. Ames Hill Brook has 10 bedrock grade controls and Halladay Brook has five.

The lower third of the watershed was inundated by post glacial Connecticut Valley Lake and the middle third of the Whetstone Brook was dammed by glacial ice (Shelburne) during the last glaciation (Doll). Approximately the lower half of the main Whetstone Brook is dominated by Littoral Sediments of sand and gravel with a large area of recent alluvium mapped for commercial purposes (Doll).

The main stem of the Whetstone Brook drops 1600' over 13 miles (2.3% overall channel slope) with 1,220' of that drop occurring in the uppermost 5.6 miles on reaches M09-M12 (4.1% channel slope). The grade flattens out quite dramatically near the horse farm and veterinarian's office on Route 9 at segments M08B and M09A. The main tributaries experience similar changes in grade: Bonnyvale Brook has an overall channel slope of 4.1% with the last reach having a slope of 5.8%; Ames Hill Brook has an overall channel slope of 4.9% with the last reach having a channel slope of 9%; Halladay Brook has an overall channel slope of 2.9% with T2.04 having a slope of 3.9%. These dramatic changes in grade create fluctuations in the streams natural ability to transport and store water and sediment. See Figure 2 in Appendix A.

3.3 Geomorphic Setting and Reference Stream Types

Reference stream types provide a framework for describing streams with similar physical characteristics in the absence of human impacts. Reference stream types are determined by reach valley slope and confinement. Of the 25 reaches assessed, one is a reference stream type A, eight are B, 15 are C and one is an E. A and B stream types occur in steeper, confined valleys typically with bedrock, boulder, cobble or plane bed forms, while C and E stream types occur in unconfined valleys with moderate to gentle slopes and have riffle-pool or dune-ripple bed forms. C and E stream types are also typically warmer and slower moving thus impacting the aquatic species that can live in them (ANR Phase 1 Handbook). A Phase 2 Assessment field checks reference stream types and identifies stream type departures. See Map 2 in Appendix B for Reference stream types.

3.4 Hydrologic Setting

Groundwater inputs are abundant on 14 of the 25 reaches assessed during the Phase 1 study. They are minimal on nine of the reaches leaving only two with no apparent groundwater inputs.

There are 288.5 acres of wetlands identified on the Vermont Significant Wetlands Inventory in the watershed. There are no USGS flow gauges in the vicinity of the Whetstone Brook. In 1973 the Whetstone Brook, along with most of the State of Vermont, experienced a major flood event. After this event, there was extensive dredging, berming and windrowing in an attempt to control channel width and location and reduce future flood impacts, particularly on reach M05 (Cahoon, personal communication). Other flood events occurred in 1869, 1927, 1936, 1955 and 1969 (USDA, 1972). Four historic mill dams sites were identified during the Phase 2 field work and there are currently two run of river dams on reach M12 and one on the Pleasant Valley Brook for the reservoir. There were only two beaver dams found during the field work and they were both on reach M12.

As long ago as 1893, the waters of Hidden Lake were dammed and diverted from flowing exclusively into the Rock River watershed to the north of the Whetstone Brook watershed to primarily flowing into the Whetstone Brook with the human controlled option of diverting flow into the Rock River. Hidden Lake was created for recreational purposes. Also, the southerly headwaters of Stickney Brook and Sunset Lake Reservoir to the north of the Whetstone Brook Watershed, have been diverted into the Pleasant Valley Reservoir (Hubbard, personal communication). This area is a surface water source protection area and owned by the Town Of Brattleboro. There are two groundwater source protection areas identified in the watershed on small tributaries west of reach M12.

3.5 Ecological Setting

From reach M08 and Pleasant Valley Brook westward, areas defined as “core habitat” in the Vermont Bio-diversity project dominate the watershed. Numerous large deer wintering areas have been identified in the center of the watershed. Approximately 2,776 acres or nearly 16% of land in the watershed has been conserved, primarily through conservation easements on working farmlands, although there are a few large properties owned by the Town of Brattleboro to protect the water supply.

At the heart of the watershed, the Vermont Biodiversity Project (VBP) has identified an almost 1,000 acre “Complimentary Landscape”, an area where a unique combination of elevation, bedrock and surficial geology and topography combine to create a uniquely diverse and as yet unprotected, type of the Vermont landscape (Thompson, p. 27). In particular, this site was selected due to its mostly calcareous gravel and sand derived deposits.

4.0 Methods

4.1 Phase 1 Protocol

The State of Vermont has developed a three phase geomorphic based assessment protocol for watershed assessment. Phase 1 is the “remote sensing” level which evaluates geology, soils, slope, and watershed size to establish a provisional reference stream type for each reach. The Stream Geomorphic Assessment Tool Version 4.59 (SGAT), an ArcView extension, was used to facilitate the collection of data (Davis). The Phase 1 study also quantifies human impacts in the watershed and assigns a provisional impact rating to each reach based on the parameters listed in Figure 3 in Appendix A. The Phase 1 information helps set the stage for understanding what the major watershed impacts are and can assist in identifying areas to focus additional assessment resources. All Phase 1 data is located in Appendix C.

4.2 Phase 2 and Habitat Assessment Protocols

The Phase 2 Assessment includes the collection of field measurements and observations to check against the Phase 1 reference stream types and impact ratings. This information can be used to identify Fluvial Erosion Hazard (FEH) zones as well as for identification of areas for different types of restoration activities. A list of Phase 2 parameters may be found in Figure 4 of Appendix A. Phase 3 assessments involve detailed surveys and are only completed on those reaches that will benefit from active stream restoration activities. All Phase 2 data is located in Appendix D.

4.3 Rapid Geomorphic Assessment (RGA)

The RGA is useful in evaluating current stream processes, departures from a reference condition, and stages of channel evolution for a given reach. Three separate RGA forms are used in the Phase II Assessment, one for unconfined streams, one for confined streams, and one for naturally occurring Plane-Bed streams. Parameters evaluated in the RGA are summarized as follows:

- Degree of channel degradation or incision;
- Degree of channel aggradation;
- Degree of channel widening; and
- Change in channel planform.

Refer to the VT ANR Protocols for more on the RGA (VTANR, May 2007).

Once the RGA is completed and the current "condition" is rated, a stage of channel evolution is identified. One of two channel evolution models is used: either the F-stage model or the D-stage model.

In the F-stage model, a channel loses floodplain access by undergoing degradation due to a disturbance (Stage II). This degradation is typically followed by channel widening (Stage III), then aggradation and planform adjustments (Stage IV), before then regaining stability with regard to its water and sediment loads (Stage V).

In the D-stage model, aggradation, widening, and planform changes are the main adjustment processes, with degradation being limited by resistant bed material or grade controls. The D-stage process can include moderate entrenchment and loss of bed features (Stage IIb), channel widening (Stage IIc), bed aggradation, bar formation (Stage IId), and regaining a balance similar to reference condition (Stage III). Please refer to the VT ANR Protocol Appendix C for more information on channel evolution models (VTANR, May 2007).

Parameters for the RGA as well as a Rapid Habitat Assessment were scored and assigned to the correlating "condition" category describing departure from a reference condition and degree of adjustment (VTANR, May 2007) as follows:

- Reference – Reaches in dynamic equilibrium, having stream geomorphic processes and habitats found in mostly undisturbed streams.
- Good – Reaches having stream geomorphology or habitat that is slightly impacted by human or natural disturbance, showing signs of minor adjustment, but functioning for the most part.

- Fair – Reaches in moderate adjustment, having major changes in channel form, process or habitat.
- Poor – Reaches experiencing extreme adjustment or departure from their reference stream type or habitat condition.

In some cases, where a score lies at one end limit of a category, the condition category that best described the reach can be selected.

A Stream Sensitivity Rating is then generated for each reach or segment according to stream type and geomorphic condition. The range of sensitivity ratings includes: very low, low, moderate, high, very high and extreme. These indicate the sensitivity of a reach or segment to ongoing disturbance or stressors.

4.4 River Corridor Planning

River corridor planning and project development is an opportunity to apply field science to watershed management with the goal of managing toward, protecting, and restoring the equilibrium condition. Corridor Planning is the bridge between the collection of assessment data and actual on the ground project completion. River Corridor Planning involves technical data analysis and mapping, project identification, public outreach and education, preliminary project development and thorough documentation of the progress achieved toward project development. All of the above activities are overseen by an active and engaged steering committee. The protocols for river corridor planning are described in detail in the *"Vermont Agency of Natural Resources River Corridor Planning Guide to Identify and Develop River Corridor Protection and Restoration Projects"* (VT ANR, 2007).

4.5 QA/QC Summary Report

To assure a high level of confidence in this Phase1 and 2 Stream Geomorphic Assessment and River Corridor Plan, strict quality assurance and quality controls were followed. These procedures included both manual and automated reviews of all data by Landslide Natural Resource Planning as well as by the Department of Environmental Conservation River Management Program. A copy of the QA/QC report is in Appendix F at the end of this document.

5.0 Reach and Segment Summaries by Sub-watershed

5.1 Whetstone Brook

M01C

M01 – The first reach on the Whetstone Brook is in the heart of downtown Brattleboro at the confluence with the Connecticut River. It was historically straightened (80%), hard armored (23%) and channelized and the adjacent valley was filled. The sub-watershed is 72% developed and there are 17 storm water inputs throughout the reach. There was an old Mill Pond where the current Food Coop is located that was filled in order for development to occur on the site. The reach is in a broad valley and is a C3 stream type by reference. The reach was segmented four times: segment A is in a rock gorge and was not assessed; segments B and D are incised and entrenched, though it is difficult to distinguish between active downcutting versus filling of the adjacent floodplain. Both of these segments are currently F3 type streams. Segment C is a C4 stream type with access to a floodplain forest along the right bank.

There is interest by the Brattleboro Food Coop to restore riparian vegetation and public access on their four acre site during re-construction of their building. The floodplain forest on segment C is a good candidate for conservation and segment D has potential for floodplain restoration with berm removal.

M02

M02 – This reach is located in a semi-confined valley and is a B Plane Bed by reference but is narrowly confined due to a human caused change in confinement from an abutting road. The reach is 29% straightened and 17% hard armored and the sub-watershed is 60% developed. The dominant corridor land use is urban but the dominant watershed land use is forest. The stream is entrenched and incised in this reach but it remains a B Plane Bed stream type. There are three bridges on M02 (one is a double on Interstate 91) all of which are floodplain constrictions but not channel constrictions. Both the habitat and geomorphic conditions are rated “fair” and the dominant adjustment process is widening.

Due to the narrow and deep valley and constraints from the road, there is limited conservation or restoration potential for this reach.

M03

M03 – This reach is located in a very broad valley type and is a C Riffle Pool type by reference. It was segmented three times due to the presence of a series of bedrock grade control in the middle of the reach that form a bedrock gorge that was not assessed. At the top of this segment is a former mill pond/dam site. It is 46% straightened with eight percent hard armoring. The sub-watershed is currently 70% forested and 13% urban and the corridor is 40% urban.

Segments A and C are currently F type streams due to entrenchment. They are over-widened, straightened, and eroding. The reference channel width is 55' and the current channel width is 61'and 15% of the right bank is currently eroding.   The habitat condition is good and the geomorphic condition is fair with widening being the dominant adjustment process.

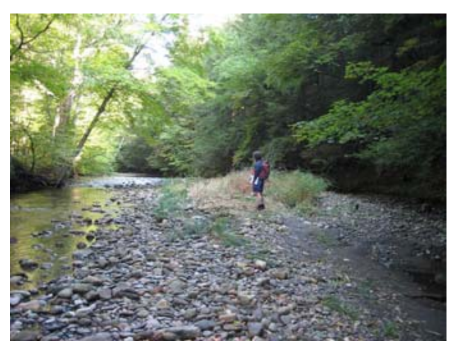
M04

M04 – This reach is located in a very broad valley and is a C Riffle Pool stream type by reference but it is currently entrenched and incised, making it an F Riffle Pool. The valley type changed to narrowly confined due to the presence of Route 9.   The soils are mapped alluvium and the channel is 100% straightened with 764 feet of eroding banks and 880' of revetments on the left bank. The geomorphic condition is Fair and the habitat condition is Fair.

There are two bridges in this reach. The covered bridge at the down stream end is a floodplain constriction and a newer concrete bridge in the middle of the reach that is a channel constriction with deposition above it.

There is potential for conservation and restoration on this reach. The Farmer's Market site along the left bank floods, though it has some small berms. It has potential for floodplain restoration while at the same time continuing use as a seasonal market. Up stream on the right bank, there is a coniferous flood plain forest with restoration and conservation potential.

M05A



M05B

M05 – This reach is located in a very broad valley and is a C Riffle Pool stream type by reference. The slope is one third of reach M06 making it a natural deposition area. It was segmented twice due to channel dimension. Highly erodable alluvium is the dominant geologic material. The valley confinement has been altered by Route 9 and is presently narrowly confined. Bonneyvale Brook enters near the middle of the reach. Urban development is in the corridor is 54% and the dominant buffer width is 0 to 25 on both banks. There are seven storm water inputs along the reach and it was extensively dredged after the 1973 flood (Cahoon, interview). Both segments are incised and entrenched with Segment A currently being an F3 Riffle Pool and segment B being a B3 stream type. Segment A has two undersized bridges that are channel constrictions with deposition above and below them.

Segment A will likely remain actively managed in the near future. There is potential for floodplain restoration/conservation in segment B.

M06 – This reach is a C Riffle Pool stream type by reference and is located in a very broad valley. It was segmented three times for channel dimension. The soil is highly erodable alluvium. Segments A and C are F3 Riffle Pool stream type and segment B is a C3 Riffle Pool with access to floodplain in a meadow that is owned by the Vermont Land Trust and does not have a riparian buffer. The reach is currently 71% straightened, extensively bermed on the right bank, has eight storm water inputs, and seven meander migrations noted. The river corridor is 58% urban development, the watershed is 44% urban development and there are nine storm water inputs along the reach. There is a bridge on Segment C that has deposition above and below it but is not undersized. Segment A has an 11 acre wetland that was lost to development.

M06C – straightened section of river.

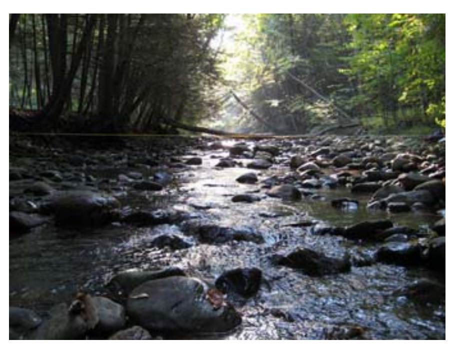
The dominant adjustment for Segments A and C is widening and planform. Segment B is planform. Habitat condition is Fair for all three segments.

There is potential for floodplain conservation/restoration on segment B where the Vermont Land Trust owns a field that floods regularly.

M07 – This reach is a Cb Riffle Pool by reference, located in a very broad valley type. It is currently a B4 with aggradation, widening and planform adjustments on-going. There is human caused change in the valley confinement to semi-confined due to Route 9.   There are two bridges on the reach, both of which have deposition above and one of which has deposition below and is skewed to the stream, though not undersized. The other structure is both a channel and floodplain constriction. Geomorphic and habitat condition are both fair and there are six large point bars in the reach. The dominant soil type is highly erodable alluvium and the reach is 92% straightened. This reach is 47% developed with residential development being extensive in the river corridor.

M07 – Aggradation u/s of first bridge.

Addressing the undersized and misaligned structures in this reach would allow for increased sediment transport. There is an eroding bank heading toward a private resident that needs to be stabilized. Otherwise, no additional development should be allowed to occur within the river corridor on this reach.



M08A

M08 – This reach is a Cb Plane Bed in a Broad valley type by reference. It was segmented twice due to planform and slope. Segment A is currently a Cb Plane Bed and Segment B is a C Riffle Pool. Segment B is the downstream end of major planform adjustment that is occurring on Reach M09 due to historic straightening upstream and a dramatic change in channel slope. There are multiple flood chutes and meander migrations in the segment. Segment A is located on highly erodable alluvium though the right bank has extensive ledge along it and there is a natural constriction in the valley type. Both habitat and geomorphic condition are good for Segment A. Geomorphic condition is Fair for Segment B and habitat is Good. There are no storm water inputs on this reach!

M08B

This entire reach is a candidate for corridor conservation due to the notable lack of encroachments in the corridor.

M09 – This reach is a Cb Plane Bed stream by reference, located in a very broad valley setting. Segment B is a B Plane Bed by reference. The dominant geologic material is highly erodable alluvium, the left riparian buffers are intact and the right buffer is 0-25’ and though the corridor has 30% urban development. Groundwater inputs are abundant and the channel is 51% straightened. The reach was segmented in two during the Phase 2 Assessment due

M09A

to planform and slope, channel dimension, substrate size and depositional features. Both segments have a human caused change to valley width, from very broad to narrow for segment A and to semi-confined for segment B, due to Route 9. Segment A is currently a C4 Riffle Pool stream type with very active planform adjustment, aggradation and widening occurring. There is one private bridge that is both a channel and floodplain constriction with deposition above and below it. There are multiple bar features and eight flood chutes in this segment and there are three mass failures on the right bank totaling 403’ in length. There is recent windrowing and dredging at the upstream end of the segment. Both habitat and geomorphic condition are fair.

M09B

Segment B is currently a B3 Plane Bed stream type. There is one private bridge at the downstream end of this segment that is a floodplain constriction with deposition below it. 26% of the left bank is actively eroding and 11% of it is hard armored. There are numerous gravel bars, five flood chutes, two steep riffles and one headcut. Both habitat and geomorphic condition are fair with widening and planform being the dominant adjustment processes.

M10 – This 2.1 mile long reach is located in a semi-confined valley type, it is a B2 step pool by reference. The dominant geologic material is till with alluvium being sub-dominant. Both of these are highly erodable materials. It was segmented two times due to corridor encroachment, bed and bank and valley width.
Segment A is incised and entrenched, making it currently an F3 step pool stream type. There is significant erosion on both banks: 29% on the left bank and 24% on the right bank. Route 9 causes a change in the valley width, though this segment is very broad. There is one undersized bridge at the downstream end that is both a floodplain and channel constriction with deposition above and below. There are multiple gravel bars and seven flood chutes and an old mill dam site with extensive berming and channelization toward the upstream end of the segment.

M10B

Segment B has multiple flood chutes, steep riffles, stormwater inputs, four mass failures, and significant encroachment from Rt 9. There are numerous point, side and mid channel bars, however, it remains a B stream type with sedimented riffles. It is in channel evolution stage III, widening, most likely due to increased flows from multiple stormwater inputs.
Conservation of the right bank is critical for this reach.

M11A

M11 – This reach is 1.2 miles long and located in a narrowly confined valley. It is Cb Cobble by reference and it has a small run of river dam at the head of it. The dominant geologic material is highly erodable till. It was segmented five times due to channel dimension, grade controls, planform and slope, valley width and bedrock gorge (not evaluated). The riparian buffer is >100' on both banks and groundwater inputs are abundant.

M11B

Segment A is semi-confined due to a human caused change in the valley width (Rt. 9). It is incised and entrenched, causing a stream type departure from Cb to Fb. There is one undersized bridge with deposition above and below it. It is nearly 100% straightened. The habitat is in good condition and it is in fair geomorphic condition.

Segment B was historically straightened and bermed, though it has grade control at the downstream end and ledge along the left bank, preventing bed and bank erosion. It is broadly confined and is entrenched from a C to a B stream type. Both the habitat and geomorphic

M11C

conditions are good.

Segment C is a sub-reach with reference stream type E. It is currently an E stream type in a very broad valley with abundant wetlands adjacent on the left bank. There is one undersized double culvert at the down stream end with deposition below it. There are multiple flood chutes, though both habitat and geomorphic condition are good.


M11D

Segment D is semi-confined and is downstream of a rock gorge and run of river dam. There is significant ledge along both of the very steep valley walls with eight flood chutes, multiple stormwater inputs and two gullies. It is a B stream type by reference and currently.

M12 – This reach is a narrowly confined, E riffle pool stream type by reference. It is 2.3 miles long and it has a small run or river dam at the head of it. It was segmented four times due to the ponding from the run of river dam on M11 (not assessed), bedrock grade control, banks and buffers and an upstream impoundment. Both watershed and stream corridor land cover is predominantly forest with buffer widths on both banks being greater than 100'. Groundwater inputs and wetlands are abundant.


M12B

Segment B is a B riffle pool stream type by reference and currently due to the channel bed being dominated by bedrock grade controls – there are seven. It has one channel constricting culvert at the downstream end with deposition above and below. Both the habitat and geomorphic conditions are good.


M12C

Segment C is an E riffle pool by reference and currently.

This is a meandering E type stream that travels through wooded and shrubby forests with one beaver pond in the middle and a ROR dam at the u/s end. The VHD stream theme is very inaccurate for this segment. Both the habitat and geomorphic conditions are good.

5.2 Ames Hill Brook

T1.01 – This is a B riffle pool stream type by reference. It is located in a semi-confined valley and is 1.3 miles long. The dominant geologic material is highly erodable alluvium. The dominant riparian buffer width on both banks is >100'and groundwater inputs are minimal. The


T1.01A

reach is 15% straightened and there is 1,600' of eroding banks. The reach was segmented four times for planform and slope and grade controls.

T1.01B

Segment A is a narrowly confined B riffle pool by reference and currently. There are few corridor encroachments, lots of large woody debris, five stormwater inputs and one channel constricting bridge. There are numerous mid, point, side and diagonal bars. The segment is historically incised, currently over-widened and entrenched. There is an un-improved path along the left bank. The dominant adjustment processes are widening with planform. There are multiple flood chutes and significant erosion. There is evidence of past channel management. Habitat condition is good while geomorphic condition is fair.

T1.01C

Segment B has incised to cause a stream type departure from B to F. There are four channel spanning grade controls and an old mill dam near the upstream end of the segment. The segment is over-widened and has eroded to bedrock likely due to both increased and concentrated flows caused by the constriction at the old dam site and straightening upstream of there.

T1.02A

Segment C is a sub-reach with a reference stream type C riffle pool. It is currently departed to an F riffle pool stream type. It has 0-25' of riparian buffer on the right bank and 26-50 on the left bank. There is one channel constricting bridge with deposition above and below and the segment is nearly 100% straightened. This segment is historically degraded and incised but the channel width is quite close to the reference (26' current, 25.9' Phase 1 reference). It is remarkably stable given the channelized straight planform. Both habitat and geomorphic condition are fair.

T1.02 – This reach is a C riffle pool by reference. It is in a very broad valley and is approximately one mile long. The dominant geologic material is alluvium and the soils are potentially highly erodable. The dominant riparian buffer width is 26-50' on both banks. Groundwater inputs are abundant and the channel is 56% straightened. The reach was segmented three times due to channel dimension, grade controls and planform and slope.

T1.02B

Segment A is entrenched and incised with sedimented riffles. It is currently in stream type departure from C to F. There is one channel constricting bridge with deposition above and below it. There are multiple point, side and diagonal bars present. The segment is straightened, bermed and eroding. Both habitat and geomorphic condition are fair. It is currently undergoing planform and widening.

Segment B was segmented for channel spanning grade control. It is a C riffle pool stream type by reference and currently. It is a short segment that stands out due to the existence of floodplain access.   There is one channel constricting bridge with deposition above and below it. Both habitat and geomorphic conditions are fair with minor widening and planform adjustment.


T1.02C

Segment C is departed to an F step pool. It is almost 100% straightened and bermed and lacks riparian buffers. There is an old meander scar on the left terrace. Both habitat and geomorphic conditions are fair.

T1.03 – This reach is a Cb riffle pool stream type located in a semi-confined valley. The dominant geologic material is alluvium and the soils are highly to potentially highly erodable. The dominant buffers are 51-100’ on the left and >100’ on the right and groundwater inputs are abundant. The impact from road encroachments is high. The reach was segmented in two for grade control and planform and slope.


T1.03A

Segment A has four channel spanning grade controls. There is one floodplain constricting bridge with deposition below. The segment is 93% straightened and 20% bermed along the left bank causing a stream type departure from Cb to B. Both habitat and geomorphic conditions are fair.


T1.03B

Segment B is not straightened, has few encroachments and has intact buffers. It is in reference regime as a Cb riffle pool stream type undergoing major planform adjustment with widening. This segment has multiple flood chutes and mass failures that may have been triggered in Oct. 2005 during the "Alstead, NH" storm. Habitat condition is good and geomorphic condition is fair.

5.3 Halladay Brook


T2.01A

T2.01 – This reach is a C riffle pool by reference and is located in a very broad valley type. The dominant geologic material is alluviuml and the soils are highly to potentially highly erodable. The dominant buffer width for both the left and right banks is 0-25'. The channel is 99% straightened. Impact for watershed land cover, corridor land cover and buffer widths are all high. Impacts from encroachments, development and meander widths are all high. This reach was segmented in two for channel dimension.

Segment A is historically straightened, bermed along the right bank and hard armored for half of its length. It is currently a C riffle pool stream type. There is one bridge that is a floodplain constriction with deposition below. The habitat condition is fair and the geomorphic condition is good.

T2.01B

Segment B is historically straightened, currently over-widened and has good flood plain access along the right bank. This segment is not incised or entrenched, it is over widened and currently under-going planform adjustment.

Habitat condition is fair and geomorphic condition is good.

T2.02C

T2.02 – This reach is a Cb riffle pool stream type located in a semi-confined valley. The dominant geologic material is alluvium and the soils are highly to potentially highly erodable. Impacts for watershed land cover and corridor land cover are both high and groundwater inputs are abundant. It is 68% straightened and impacts from encroachments are high. The reach was segmented six times for channel dimension.

Segments A, C and F are currently Cb riffle pool stream type. They were historically straightened and bermed and are not incised with good access to floodplain. Habitat condition is good and geomorphic condition is fair. The dominant adjustment process is minor aggradation and widening with moderate planform adjustment. They are in channel evolution model F stage IV. Segment A has an old mill pond on it.

T2.02B

Segments B and D are sub-reaches with reference stream type B riffle pool and they are currently in B riffle pool stream types. Both segments are historically degraded and re-building floodplain with "hard armor" on the left bank from the road bed. Habitat condition is good and geomorphic condition is fair. They are in channel evolution model F stage II.

T2.02E

Segment E is also a sub-reach with reference stream type B step pool. It is currently a B step pool stream type with two channel spanning grade controls. The dominant left buffer width is 51-100' and the sub-dominant is 0-25'. There is one channel constricting bridge with deposition below it. There were percolation tests being done on the top of the right bank during the field survey. Bedrock grade control and road bed hard armoring the left bank keep this segment stable. There is floodplain access on the right bank. Both habitat and geomorphic conditions are good. This segment is in channel evolution model F stage I.

6.0 Analyzing River Processes

A stream in "equilibrium condition" will maintain a relatively stable pattern (sinuosity), dimension (width and depth) and profile (gradient). These forms are created by inputs of water, sediment and debris. Changes to the watershed inputs at the watershed or reach scale will result in a disruption of equilibrium conditions until the channel has time to adjust its pattern, dimension and profile accordingly. Human changes to the landscape create stress on the existing planform and can push the stream into disequilibrium.

The Stream Geomorphic Assessments completed on the Whetstone Brook and its tributaries provide an inventory of the human induced stressors that are causing disequilibrium. In the following section, watershed and reach scale stressors have been mapped, organized and analyzed to develop a "watershed story" that describes the current geomorphic condition of the watershed and individual reaches. This information is used in Section 7 to identify and prioritize the restoration activities that will be most effective in re-establishing watershed equilibrium and thus reducing flood and erosion hazards, reducing sediment and nutrient loading and improving habitat.

6.1 Watershed Scale Stressors

6.1.1 Hydrologic Alterations

The volume and rate that water, sediment and debris flow through a stream system, combined with the resistance of the bed and bank material, work together to form the channel over the long-term. Increases or decreases to the natural hydrologic regime (the volume and rate of water entering the stream) can push a stream into disequilibrium, leading to increased flood and erosion hazards. Hydrologic stressors and physical constraints that impact the volume and rate of water and sediment moving through the stream system were analyzed to aid in our understanding of current channel adjustment processes. Hydrologic alterations within a watershed that does not have flow gauges must be evaluated indirectly using data on changes that are known to impact the hydrologic regime. Among the things that can affect the volume and rate of water entering a watershed are deforestation, dams, loss of wetlands, development and related increases in storm water runoff, and ditching related to roads, farm fields and skid ruts (VT ANR RCPG, 2007).

Deforestation affected most of the state of Vermont, with almost complete clearing occurring by the end of the 19th century and re-forestation to 75% forest cover by the end of the 20th century. Trees reduce the volume of water and sediment that flow into the channel. It is likely that the Whetstone Brook is still re-bounding from the loss and gradual re-growth of forest cover, and some of the historic incision and subsequent widening found in the watershed is related to the increased flows and floodplain buildup resulting from the historic loss of trees. Today the Whetstone Watershed is 70% forested, down from 75% thirty years ago.

The presence of dams in the watershed alters the flow of water and sediment upstream and downstream of the structure. There is one run-of-the-river dam on the assessed reaches of the Whetstone Brook, on M12. Run of the river dams do not alter the amount of water in the stream, but they do reduce the amount of sediment entering downstream reaches and can result in downstream bed degradation. The downstream reach, M11 is a bedrock gorge and was not assessed. Two beaver dams were found on M12 upstream of Route 9.

Wetlands provide critical storage of surface water during big storm events. They act as sponges, soaking up and holding water, reducing the volume of water and sediment entering streams at any given time. Wetlands are lost when they are drained and filled for agriculture, for road construction or other human development.   Wetland loss in the Whetstone Watershed is primarily associated with roads and residential development and is relatively minor compared to other watersheds in Vermont. The watershed has 577 acres of wetlands in the Vermont Significant Wetlands Inventory and hydric soils identified or 3.3% of the watershed. One rough estimate of how many wetlands have been lost in the watershed is to subtract mapped wetlands and hydric soils from developed and agricultural lands which yield 65.7 acres of lost wetlands. Overall, the Whetstone Watershed was never a watershed with a lot of water storage capacity in wetlands and 11% of those have been lost to development or agricultural land use.

Urban development alters the natural hydrologic regime by increasing surface water runoff into the streams by removing natural vegetation and creating “impermeable surfaces” (roofs and roads) that no longer allow for the absorption of rainwater into the ground.   Roads are related to development and also considered “urban land” in this analysis. As is typical throughout much of the rest of the state, roads were built along rivers and streams, exacerbating their impacts to water quality and quantity. This both increases impermeable surface area and results in the removal of trees within the corridor which are important for absorbing surface water runoff, stabilizing stream banks and shading waterways to reduce water temperatures for aquatic animals. Developed land permanently alters the hydrology of the watershed, making peak flows greater and low flows lower.

The River Management Program (RMP) considers a watershed with between 5 and 10% “urban” or developed lands to have an altered hydrologic regime. Ten of the 25 reaches assessed in the Phase 1 SGA have greater than 20% developed land (reaches M01-M07, T2.01 and T2.03) and nine of the 25 have between 10 and 20% developed lands. The remaining six watersheds are between 5 and 10% developed. The range of urban development goes from a high of 72% on reach M01 to 5 % on M08 and T2.04. Overall development for the whole watershed is 16%, which is quite high when compared to other watersheds in the State. See Map 4 in Appendix B for Hydrologic Alterations.

Storm water inputs are an impact associated with increased human development. Storm water inputs concentrate flows that would otherwise be spread out over land, causing them to discharge directly into the stream, thus increasing the amount of water the stream carries at a given time. There are 88 storm water inputs in this watershed, with most of them being in the heavily developed areas of the watershed (Brattleboro and West Brattleboro villages) but with a fair number also spread throughout the watershed.   See Figure 7 in Appendix A for storm water inputs.

Based on urban development, storm water inputs and road density, of the 42 assessed segments, 20 segments are rated “extreme” for hydrologic alterations. These are all at the downstream ends of their sub-watersheds; 21 segments are rated “high” for hydrologic alterations; two are rated moderate; and two are rated low. See Table 1 in Appendix E.

6.1.2 Sediment Load Indicators

A stream that is in equilibrium will store fine sediment in the flood plain and transport both fine and coarse sediment in the channel such that channel slope, depth and sinuosity remain stable over time. Human alterations to the landscape can act to increase or decrease the sediment load watershed wide, leading to bed degradation (downcutting) or aggradation (rising) which affects channel slope and depth. The hydrologic alterations discussed above impact the streams ability to store and move sediment. The amount and location of sediment moving through the stream channel impacts flood attenuation (storage of sediment and water), nutrient loading and aquatic habitat. Alterations to the equilibrium sediment load are not directly measured in the Phase 2 SGA, instead, observable features such as steep riffles, mid-channel bars, delta bars, flood chutes, avulsions, braiding, mass failures, gullies and length of eroding banks provide evidence to assist in the identification of stream segments that are in adjustment due to sediment load modifications.

In this analysis, sediment load impact was rated low, moderate, high or extreme based on: the number of steep riffles, mid-channel bars or delta bars; the number of flood chutes, avulsions or braiding; the percent of eroding banks and the number of mass failures and gullies. Of the 42 assessed segments, three are rated extreme; 22 are rated high; ten are rated moderate and six are rated low. See Table 1 in Appendix E and Maps 5 and 6 in Appendix B.

6.2 Reach Scale Stressors

Sediment transport capacity is affected at the reach scale by modifications to the valley, floodplain and channel as well as changes to boundary conditions. These changes alter the way that sediment is transported and sorted, affecting channel stability and in-stream habitat (RCPG, 2007). Reach scale stressors have been organized by whether they increase or decrease sediment transport as a function of slope and depth (energy grade) and boundary conditions. Boundary conditions (resistance to increases in the stream’s power) can be increased or decreased in the bed or on the banks and may be natural or man made. Understanding reach scale stressors and limits assists in putting reaches into the overall watershed context.

6.2.1 Channel Slope and Depth Modifiers

Increases in channel slope and depth will increase the channel’s capacity to transport sediment and water. Conversely, decreases to slope and depth will decrease the channel’s ability to transport sediment and flood waters, increasing water and sediment storage capacity. Sediment transport capacity will be increased by straightening, river corridor development and encroachments (berms and roads) and in specific locations below grade controls or channel constrictions (undersized bridges and culverts), where the stream was dredged and below storm water outfalls. Sediment transport capacity can be decreased upstream of dams, channel and floodplain constrictions and at confluences and other back water areas.

Stressors leading to an increase in stream power in the Whetstone Brook Watershed were found on 21 of the 42 assessed segments; 19 segments were found to have neither an increase nor a decrease in transport capacity and; two segments had stressors indicating a potential decrease in stream power/transport capacity due to ledge and a misaligned bridge on Route 9. See Table 1 in Appendix D and Maps 7 and 8 in Appendix B.

The Whetstone Brook is 40% straightened; Bonneyvale Brook has not been straightened at all; Ames Hill Brook is 16% straightened and Halladay Brook is 80% straightened. See Figure 5 in Appendix A and Map 7 in Appendix B. Channel straightening increases stream power by increasing channel gradient and flow velocity, causing a downcutting the channel bed (increasing slope) and triggering disequilibrium. Eventually, the stream banks will fail and the stream will over-widen.

Development and roads within the river corridor increase the volume of water flowing into the stream, causing bed degradation and an increase in the channel slope. The Whetstone Brook has development on one or both banks on 31% of the channel corridor length. Bonneyvale Brook is 12% developed, Ames Hill Brook is 3%, and Halladay Brook is 5% developed. Roads on one side of the river corridor are found along 30% of the Whetstone Brook, 26% of Ames Hill Brook and 44% of Halladay Brook. An insignificant amount of the watershed has roads on both sides of the river corridor. Fifteen of the 42 assessed segments have channel constrictions, which can increase channel slope down stream by concentrating flows and reducing the amount of sediment available to the stream. See Figures 5 and 6 in Appendix A and Maps 7 & 8 in Appendix B.

6.2.2 Boundary Condition and Riparian Modifiers

Channel bed and bank resistance may be increased or decreased by human alterations. Stressors that decrease bed resistance are: snagging, dredging, and windrowing. Removal of bank vegetation reduces stream bank resistance. Grade control and bed armoring will increase bed resistance to erosion and bank armoring decreases the streams ability to move laterally. See Maps 9 & 10 in Appendix B.

Thirteen segments were found to have increased bank resistance due to hard armoring (rip-rap) or a road bed and nine were found to have increased bed resistance due to the presence of natural grade control. Sixteen segments have decreased boundary resistance due to active bank erosion. Two segments had a decrease in bank resistance due to a loss of riparian vegetation. Six reaches have no increase or decrease in bed and bank boundary resistance. M05A and M09A have decreased bed resistance due to documented dredging. See Table 1 in Appendix E.

6.3 Constraints to Sediment Transport and Attenuation

6.3.1 Reference and Existing Sediment Regimes

Human induced alterations to the watershed hydrologic and sediment regimes and reach based stressors can push a stream reach into disequilibrium. Past restoration efforts have applied spot fixes to erosion hazards, requiring expensive on-going maintenance at best and driving problems downstream at worst. More recently, reach scale considerations have been included in restoration planning, but still with limited success. Watershed based restoration project design includes consideration of changes to the sediment and flood attenuation (storage) and transport capacity of upstream and downstream reaches. The Vermont River Management Program has developed a procedure for organizing hydrologic and sediment regime stressor data into five different sediment regime categories that summarize existing and reference sediment and flood transport and attenuation capacity. This provides the basis for an informed restoration project selection process that accounts for departure from reference condition in upstream reaches.

Streams that are in reference sediment regime generally fall into one of two categories: Transport and Coarse Equilibrium/Fine Deposition. Transport streams are those streams that are high gradient, naturally confined and have bedrock, boulder or cobble substrates. Coarse Equilibrium/Fine Deposition are streams that are in unconfined valleys and naturally provide areas for flood and sediment storage through flood plain access. Streams in disequilibrium or undergoing channel evolution will fall into one of the following three categories: Confined Source and Transport, Unconfined Source and Transport and Fine Source and Transport. See VT ANR RCPG, 2007 for detailed Sediment Regime Descriptions.

In the absence of human impacts, the Whetstone Brook main stem would primarily function as a Coarse Equilibrium/Fine Deposition stream, where water and sediment entering a reach would, over time, be equal to water and sediment leaving it. Floodplain access would be common on 35 of the Phase 2 assessed segments. Only M02, M10 and T1.01 (seven segments total) are naturally Transport type streams. Currently, only 7 segments are in Coarse Equilibrium/Fine Deposition regime and only 5 of the Transport segments are in regime. This means that 28 formerly Coarse Equilibrium/Fine Deposition type streams have been converted to Transport type streams. Streams that have been converted from Coarse Equilibrium/Fine Deposition to Transport reduce sediment and flood attenuation capacity on that reach as well as watershed wide, increasing demand on downstream reaches for flood water and sediment load attenuation. See Maps 11 and 12 for existing and reference sediment regimes.

6.3.2 Departure Analysis

In addition to reference and existing sediment regimes, vertical and lateral constraints were analyzed as well. Vertical constraints are natural grade controls and man-made channel constrictions that act to reduce the slope of the stream and prevent it from down-cutting. Culverts are the best example of human caused vertical constraints. Constraints to lateral migration of the stream include existing rip-rap, roads, houses, development and berms. Identifying these features assists in the identification of river segments where there are few constraints to lateral migration and therefore the possibility of restoring flood and sediment storage areas may exist (see Table 2 in Appendix E).

Attenuation assets are those segments that provide for flood and sediment storage during and between major flood events. As mentioned earlier, natural transport streams do exist in the watershed. These are areas where, even in reference condition, not much flood or sediment storage occurs. However, much of the watershed would naturally function to provide flood and sediment storage. An analysis of reference and current transport and attenuation capacity was completed to identify segments that are currently or will evolve on their own, into attenuation assets. Ten segments are currently providing flood and sediment storage and are listed in Table 2 of Appendix E. Those reaches that have few lateral constraints and are currently attenuation assets are considered a high priority for watershed scale restoration and protection of equilibrium condition.

6.3.3 Stream Sensitivity and Current Adjustment

The Vermont DEC River Management Section has developed a five level sensitivity rating for streams based on current stream type and adjustment. Sensitivity ratings attempt to predict how rapidly a given stream type is expected to adjust (move laterally or horizontally) given its current geomorphic condition. The rating scale is low, moderate, high, very high, and extreme. See Map 13 in Appendix B for a map of sensitivity and current vertical adjustment.

Sensitivity ratings were used to assist in restoration project prioritization by identifying segments where rapid channel planform adjustment may occur in the presence of valuable human-built infrastructure. Table 3 in Appendix E prioritizes reaches for restoration based on sensitivity, current adjustment and potential threats to infrastructure. The results were incorporated into project identification tables discussed in the Section 7.

7.0 Preliminary Project Identification and Prioritization

An understanding of the human impacts at work throughout the Whetstone Brook watershed is necessary to prioritize restoration efforts. Spot fixes that do not take larger scale sediment and flow into account have historically proven expensive and un-sustainable. Managing a stream toward long-term geomorphic equilibrium can be accomplished when attenuation of up-stream increases in flow and sediment are accommodated. Restoration activities that seek only to address local or reach scale stressors may transfer energy and therefore, the problem, down stream.

The Vermont DEC River Management Program has developed a step wise procedure for identifying and prioritizing restoration projects. The categories of projects are: 1. Protect River Corridors; 2. Plant Stream Buffers; 3. Stabilize Stream Banks; 4. Arrest Head Cuts; 5. Remove Berms; 6. Remove or Replace Structures; 7. Restore Incised Reaches; and 8. Restore Aggraded Reaches. The first six restoration alternatives may be implemented without an extensive alternatives analysis, making them economically and technically more feasible. The final two, restoring incised reaches and aggraded reaches may require increased time and resources in the form of channel management practices and corridor land use changes

The projects identified in Tables 4 and 5 of Appendix E provide a foundation for continued planning and restoration efforts. Table 4 identifies potential projects by reach and prioritizes them (highest priority in yellow). Table 5 examines the highest priority reaches in more detail, describing stressors and constraints and technical feasibility of the projects.

7.1 Protect River Corridors

River segments that are in equilibrium or are evolving toward equilibrium on their own provide critical sediment and flood attenuation functions on the Whetstone Brook watershed. The Whetstone Brook, Ames Hill Brook and Halladay Brook, have experienced dramatic urban development, widespread historic channel straightening, many floodway, floodplain and corridor encroachments, and consequently, numerous segments have been converted from Coarse Equilibrium to Transport type streams. Because much of the watershed has been converted to transport type streams and there is significant urban development throughout the watershed, those reaches that are providing flood and sediment attenuation are extremely rare and critical to restoring equilibrium throughout the watershed.

Segments that are in or close to equilibrium will provide “release valves” for the rest of the watershed, making corridor conservation along these segments the highest priority. There are a few parcels along the Whetstone that are potential areas for floodplain restoration. Because most of the stream has incised significantly due to alterations to the hydrology and historic channel straightening, most of these areas would likely require restoration of the incised streambed to make floodplain access feasible. There is a significant amount of aggradation occurring in the watershed, so further analysis may reveal that over time, if the floodplain is protected and any berms are removed, the stream may re-establish equilibrium on its own. Areas identified for corridor conservation that provide flood and sediment attenuation exist along the following reaches: M01D, M04, M05B, M06B, M08B, M09A, M11C, M12A, M12C, T1.02A, and T2.01B.

7.2 Plant Stream Buffers

Forested riparian corridors are one of the most cost effective means of providing erosion hazard protection, reducing sediment and nutrient inputs into the stream and improving habitat. Tree roots provide stability to stream banks, slowing erosion and holding onto sediment. Trees also provide shade for the stream corridor during the warmest months of the year, keeping water temperatures lower, which is important to cold water fisheries. Finally, when trees fall into the stream, they provide much needed in-stream habitat diversity by creating deep pools.

Because much of the Whetstone Brook and its tributaries are either deeply incised, making tree planting in-effective until the stream is able to move toward equilibrium) currently forested or adjacent to roads, opportunities for tree planting are limited. Engaging the community in tree planting projects can be an effective means of educating citizens about watershed based restoration efforts, which raises the priority of the few stream planting projects identified. Buffer planting projects were identified on the following segments: M01B & C, M04, M05A, M06B, M06C, M11A, M11B, M12C, T1.01C, T1.02A, and T2.02A, B & D.

7.3 Stabilize Stream Banks

Stream bank stabilization can be effective in arresting eroding banks when the stream is at or near equilibrium and the eroding banks are causing significant increased sedimentation to highly sensitive reaches or they have the potential to erode important human built infrastructure. There are very few places in the Whetstone Brook Watershed where the stream is at or near equilibrium and the banks are eroding. M08A has minor erosion occurring but bank stabilization is not a priority due to the undeveloped nature of the sub-watershed.

7.4 Arrest Head Cuts

Head cuts can result in the rapid degradation of the stream bed, removing floodplain access and transporting significant amounts of sediment to downstream reaches. T1.03B has a head cut on a flood chute and the whole segment is undergoing major planform adjustment. M09A and B also have head cuts that have been identified as potential restoration projects.

7.5 Remove Berms

Berms are used to keep flood waters contained in the channel. They increase channel depth, concentrating flows and lead to bed degradation, as seen throughout the Whetstone Brook Watershed. Removing historic berms that are no longer protecting homes or roads can be a cost effective way to re-establish floodplain access to incised streams. Berms have been identified for potential removal (along with other management practices) on segments M01D, M05B, T2.01A (if trailers are moved), and T2.01B, T2.02A, C & E.

7.6 Remove/Replace Structures

Bridges and culverts with openings that are narrower than the bankfull channel width can cause deposition upstream and scour downstream and trigger disequilibrium. The concentrated flows may also scour around upstream abutments and erode banks downstream, resulting in structure failure. In instances where the road crossing is blocking the floodplain, the upstream ponding and downstream scour may be exacerbated. Additional floodplain culverts may be necessary in these circumstances.

There are numerous undersized structures on the Whetstone Brook that have been recommended for replacement. These structures need to be assessed to determine if the deposition above them is creating a constriction that is actually moving the stream toward equilibrium more quickly by re-creating gravel bars and increasing sediment and flood attenuation. In cases where the undersized structure is impeding the flow of water and sediment, leading to disequilibrium, the structure should be prioritized for replacement. A higher priority has been placed on structures that are derelict, however, there are some old abutments that may be historically significant, requiring another level of social consideration before their removal. Nine structures have been recommended for removal or replacement in the long term. These are located on the following segments: M07 (realignment), M10A, M11A, M12B, T1.01A & C, T1.02A and T2.02A.

7.7 Restore Incised Reach

Incised reaches have cut down through channel bed material, reducing access to floodplain and concentrating flows. This increased flow transports sediment through the reach, disrupting channel equilibrium and depositing it at the next bend or channel constriction or when floodplain access is encountered downstream. Often habitat heterogeneity is destroyed by the scouring activity as the bed becomes dominated by larger particles that are resistant to the increased energy. Much of the Whetstone Brook is incised and entrenched and many reaches have eroded to a coarse bed material. Some of these segments are destined to remain converted to transport, due to their relationship to roads, buildings and valley walls. However, some of the incised reaches may be restored, providing the river room to re-establish equilibrium and re-connecting the channel to its floodplain.

Floodplain access may be accomplished by lowering the height of the existing floodplain to allow the channel to access it as widening and aggradation progress. Floodplain access may also be accomplished by raising the channel bed through construction of a weir or by the creation of debris jams. Debris jams can be encouraged by dropping large woody debris into the channel.

Many reaches along the Whetstone Brook have been converted to transport type streams, which results in an un-even distribution of energy along the channel length, increasing the chances for flood and erosion hazards. Restoring incised reaches by re-establishing floodplain access and by protecting areas that still have floodplain access will provide attenuation assets that are distributed throughout the watershed, ameliorating the impacts of watershed development. Incised segments recommended for restoration: M01D, M04, M05B, M06B, and T1.02A & C.

7.8 Restore Aggraded Reach

There are numerous areas throughout the watershed that are experiencing an increase in bed and bar features, though only four segments have aggradation as the dominant adjustment process. These are: M05A, M07, M08B and M09A. In all cases, this bed aggradation is assisting in moving the stream toward equilibrium and therefore there are no segments recommended for restoration for aggradation.

7.9 Coordinate Restoration at the Watershed Scale

Re-establishing equilibrium at the watershed scale will reduce property damage related to flood and erosion hazards, reduce sediment and nutrient pollution and improve habitat. The allocation of resources available for river corridor restoration and flood and erosion hazard mitigation will be optimized by addressing instabilities at the reach scale that can affect improvements watershed wide. These projects have received the highest priority ranking in this plan (see Table 4 in Appendix E). In a watershed as developed as the Whetstone, a holistic approach to watershed restoration is necessary to reduce flood related expenses, improve habitat and move the stream toward equilibrium.

8.0 Conclusions

Watershed scale restoration represents a significant change from conventional river management. In the past, spot fixing eroding banks with rip-rap, berming and channel widening were all used as river management techniques thought to reduce potential conflicts. Today we know that a river system given adequate space and proper storm water management can maintain equilibrium on its own. Educating landowners, town officials and others who work with the river will take time and effort but is necessary for restoration success. Inclusion of these interested citizens will assist with further restoration prioritization.

The towns of Brattleboro and Marlboro can do a lot to assist with the effort to restore the Whetstone Brook to equilibrium by establishing Fluvial Erosion Hazard zones and adopting enhanced flood plain regulations. An FEH zone is an area identified using SGA data that defines the extent of a river corridor that will accommodate the equilibrium condition and minimize erosion over time. FEH zones may be adopted by communities to reduce future conflicts (and costs related to those conflicts) between the river and development. Enhanced flood plain regulations would improve on the minimum which allow for filling and developing within the flood plain. Additionally, town road crews can use the information in this plan to assist with the sizing of new and replacement bridges and culverts. As old structures are replaced, properly sizing them will be a big step toward providing for flood and sediment passage and reduce costs of structure maintenance.

Past and present alternations to the natural hydrologic and sediment regimes on the Whetstone Brook have led to a frequently incised and entrenched channel with limited access to floodplain. The restoration of channel equilibrium depends on the even distribution and flow of energy throughout the system that is currently disrupted by increased flows from significant urban development, bank armoring, channel straightening and berming. As dispersed and concentrated development continues to expand, impacts to the watershed and those developments in the floodway and flood plain will increase with the potential for costly remediation measures increasing commensurately.

The restoration and conservation of flood and sediment attenuation assets will result in a more even distribution of flow and sediment throughout the watershed where sediment can be stored and flow energy dissipated, reducing sediment loading and erosion hazards downstream.

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Whetstone Brook
River Corridor Plan

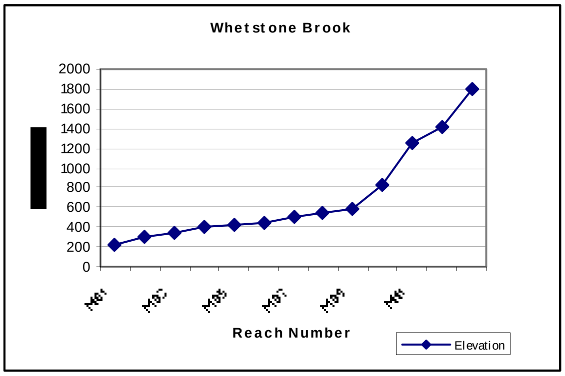
Appendix A Charts and Tables

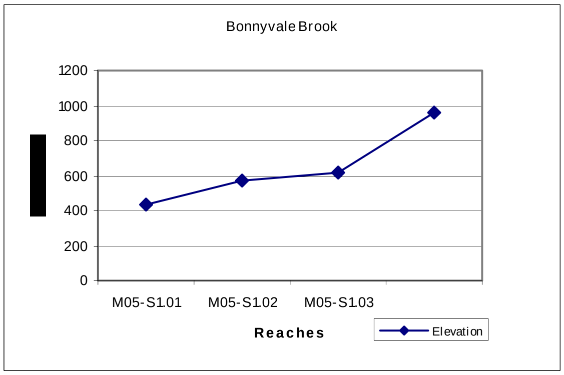
Figure 1. Phase 1 and Phase 2 SGA Assessment Area

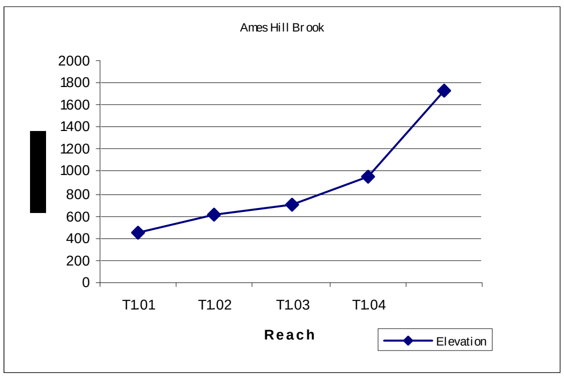
Stream Name	Length in (miles)	Phase 1 Assessed Reaches	Phase 2 Assessed Reaches
Whetstone Brook	13.1	12	All reaches
Bonnyvale Brook	2.4	3	First 2 reaches
Pleasant Valley Brook	2.5	1	None
Ames Hill Brook	5.1	4	First 3 reaches
Halladay Brook	6.0	5	First 2 reaches

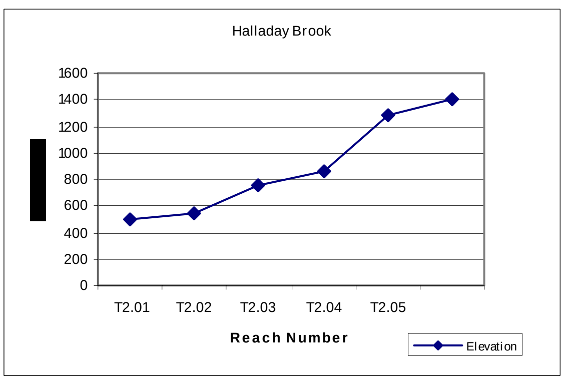
Figure 2. Elevation and Slope of Assessed Reaches

Elevation

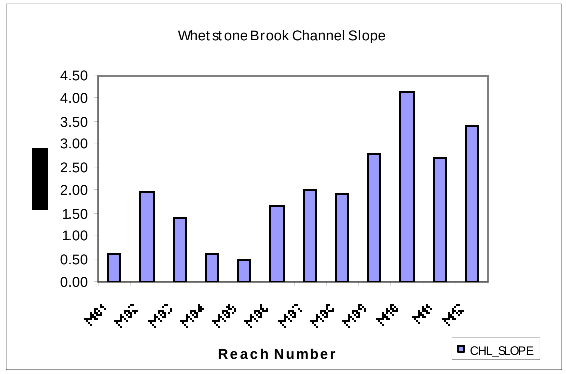


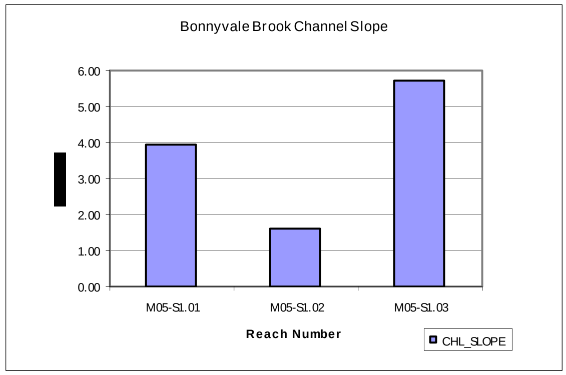


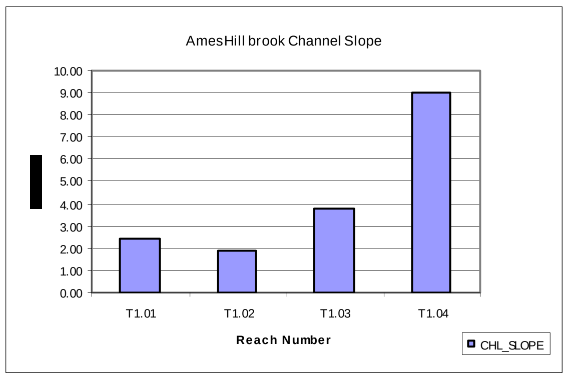




Slope







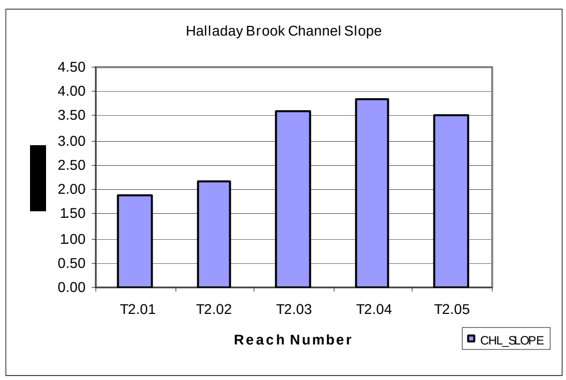


Figure 3. Phase 1 Parameters

Phase 1 Parameters	
Step Number	**Parameter**
4.1	Watershed Land Cover/Land Use
4.2	Corridor Land Cover/Land Use
4.3	Riparian Buffer Width
4.4	Groundwater and Small Tributary Inputs
5.1	Flow Regulations and Water Withdrawls
5.2	Bridges and Culverts
5.3	Bank Armoring or Revetments
5.4	Channel Straightening
5.5	Dredging and Gravel Mining History
6.1	Berms and Roads
6.2	River Corridor Development
6.3	Depositional Features
6.4	Meander Migration / Channel Avulsion
6.5	Meander Width Ratio
6.6	Wavelength Ratio
7.1	Dominant Bedform / Material
7.2	Bank Erosion – Relative Magitude
7.3	Debris and Ice Jam Potential

Figure 4. Phase 2 Parameters

Phase 2 Parameters	
Step Number	**Parameter**
1.2	Alluvial Fan
1.3	Development
1.3	Encroachment
1.6	Grade Control
3.1	Bank Armoring or Revetment
3.1	Erosion
3.3	Gully
3.3	Mass Failure
4.4	Debris Jam
4.6	Storm Water Input
4.9	Beaver Dam
5.2	Migration
5.3	Steep Riffle or Head Cut
5.4	Stream Crossing
5.5	Dredging
5.5	Channel Straightening

Figure 5. Summary of Slope and Depth Modifiers

Brook	% Straightened	% Developed	Roads
Whetstone	40	31	30
Bonneyvale	0	12	N/A
Ames Hill	16	3	26
Halladay	8	5	44

Figure 6. Channel Constrictions

Segment ID	Constriction Type	Structure Width	Reference Channel Width	Existing Channel Width
M04-	Bridge	42	55	52
M07-	Bridge	26	36	52
M09A	Bridge	26	36	49
M10A	Bridge	29	33	41
M11A	Bridge	16	27	32
M11C	Culvert	10	27	16
M12B	Culvert	8	20	18
T1.01A	Bridge	22	26	29
T1.01B	Old Abutment	22	26	37
T1.01C	Bridge	21	26	26
T1.02A	Bridge	22	25	28
T2.02A	Bridge	22	25	27
T2.02E	Bridge	23	28	29

Figure 7. Storm Water Inputs

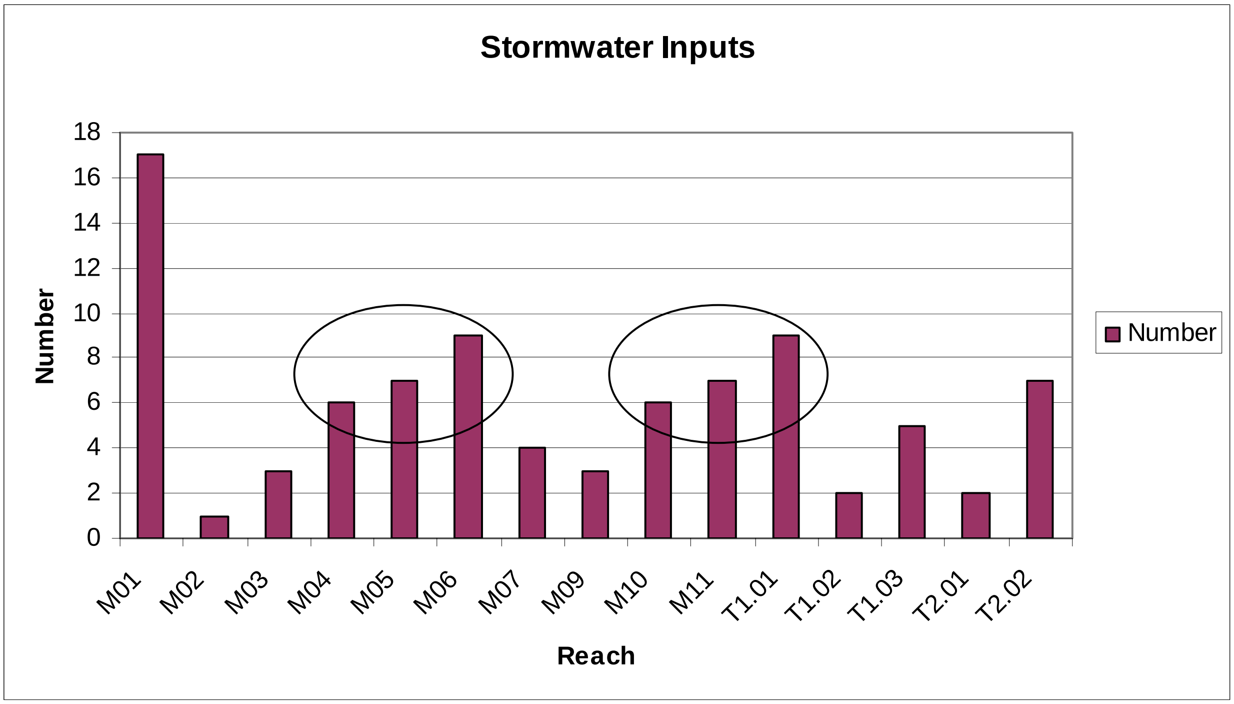
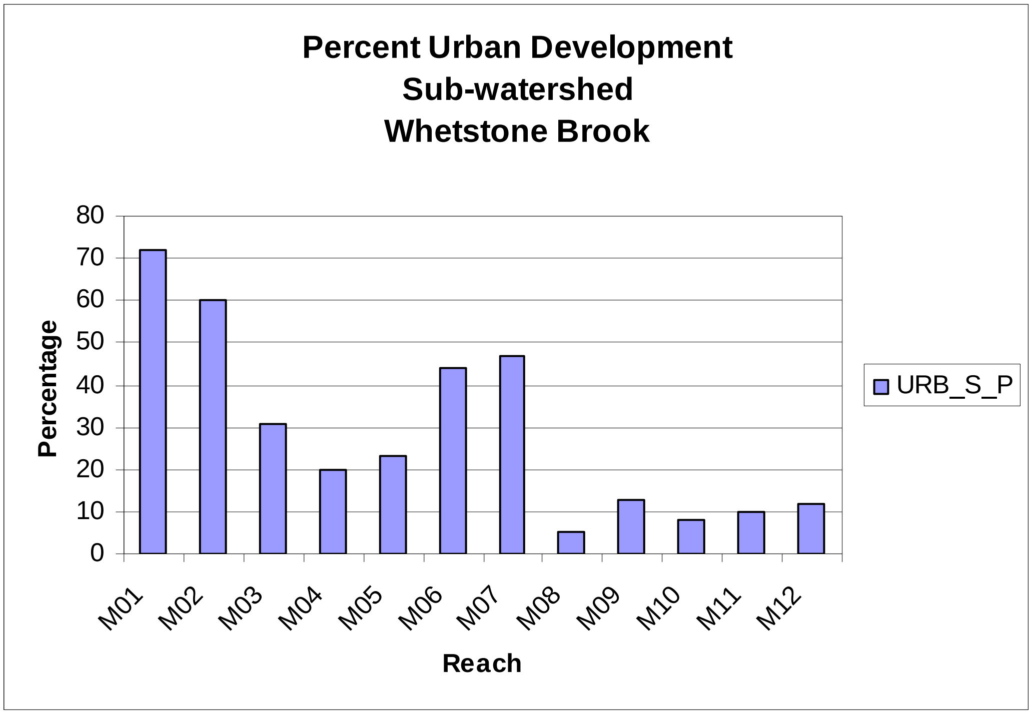
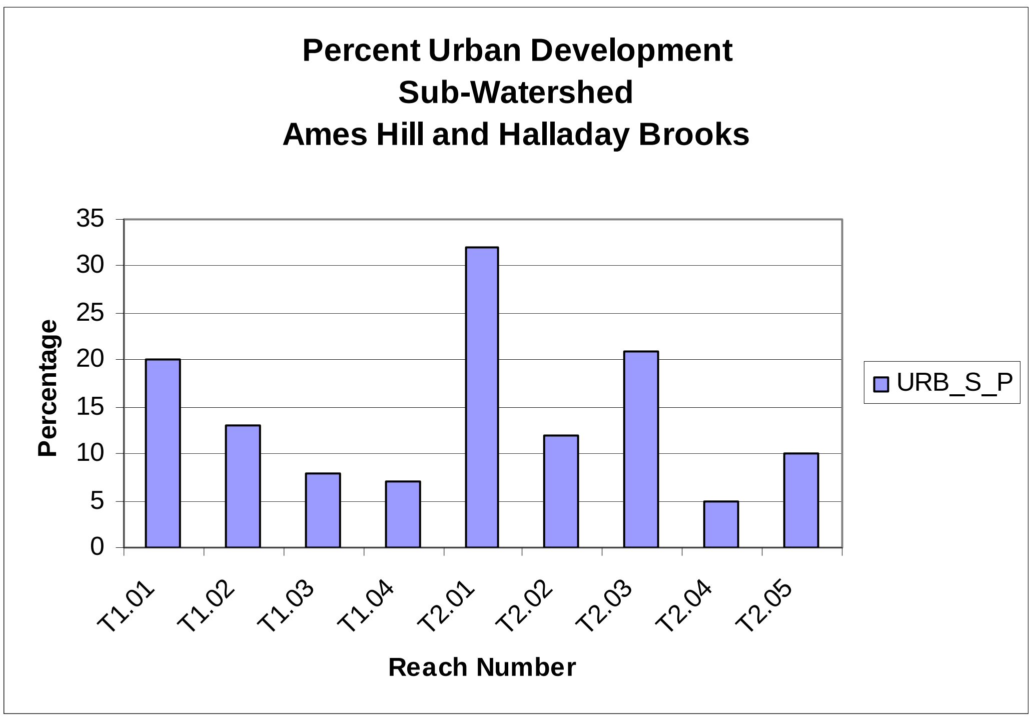


Figure 8. Urban Development by Watershed





	Constraints		Transport		Attenuation		
River Segment	Vertical	Lateral	Natural	Converted	Natural	Increased	Asset
M01A	Natural	Human	X				
M01B	None	Human		X			
M01C	None	Human (1)		X			
M01D	None	Human		X	X		X
M02-	None	Human (1)	X				
M03A	None	Human (1)		X			X
M03B	Natural	None	X				
M03C	None	Human					
M04-	None	Human (1)		X	X		X
M05A	None	Human		X	X		
M05B	None	Human (1)		X	X		X
M06A	None	Human		X	X		X
M06B	None	None		X	X		X
M06C	None	Human*		X	X		X
M07-	None	Human		X	X	X	X
M08A	None	Natural		X			
M08B	None	None		X	X	X	X
M09A	None	Minimal		X	X	X	X
M09B	None	Human (1)		X			
M10A	None	Human (1)	X				
M10B	None	Human (1)	X				
M11A	None	Human		X			
M11B	Natural	Natural		X			
M11C	None	Human (1)		X	X		X
M11D	None	None		X			
M11E	Natural	None		X			
M12A	N/A	Minimal	N/A				
M12B	Natural	None	X				
M12C	Human (t)	None			X		X
M12D	N/A	None					
T1.01A	None	None	X				
T1.01B	Natural	None	X				
T1.01C	None	None	X				
T1.01D	None	Human (1)	X				
T1.02A	None	Minimal		X	X		X
T1.02B	Natural	Human (1)		X	X		
T1.02C	Natural	Human (1)		X	X		
T1.03A	Natural	Human (1)		X			
T1.03B	None	Minimal		X	X		X
T2.01A	None	Human (1)			X		
T2.01B	None	None			X		X
T2.02A	Natural	Minimal			X		X
T2.02B	None	Human (1)		X	X		
T2.02C	None	Human (1)			X		
T2.02D	None	Human (1)		X	X		
T2.02E	Natural	Human (1)		X			
T2.02F	Natural	Human (1)					

(t) = temporary culvert for vertical constraint
(1)= one side

(o) = old abutment
(*)=some unconstrained areas exist
Vertical: Culverts constricting flow; Ledge
Lateral: Encroachments; hard armoring; berming; development
Transport: Reference transport
Converted: Confined, unconfined & fine source and transport = incised, straighted, armored.
Attenuation: Alluvial Fan/delta bar; Increased = aggradation adj. process; Asset = reference coarse