River Corridor Plan for the Williams River in Rockingham, Chester, and Andover, Vermont

September 29, 2016

Mass Failure on Middle Branch
Reach T5.04 along Rt. 11 in Chester, VT

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Executive Summary

The Williams River is one of the five large basins draining to the Connecticut River in southeastern Vermont. The watershed is bordered by the Black River watershed to the north, the West River watershed to the west, and the Saxtons River watershed to the south. The Village of Chester is located at the confluence of the Middle Branch, South Branch, and Lover's Lane Brook. The mainstem of the Williams River flows through the Towns of Rockingham and Chester. The Middle Branch of the Williams River and the Andover Branch flow through the Towns of Andover. The South Branch of the Williams River is primarily within the Town of Chester and the headwaters are located within the Town of Windham.

Major flooding occurred along the Williams River and tributaries during Tropical Storm Irene (August 2011), causing significant damage to transportation infrastructure, residential and commercial properties, and agricultural areas. A localized summer thunderstorm in July 2014 caused major flooding within portions of the Williams watershed, matching or exceeding damages from Tropical Storm Irene in some areas. Roads and bridges were especially hard hit by these floods and the damage to the transportation network slowed recovery efforts and severed main access roads to dozens of homes within the watershed. In response to the impacts from this flood, and the increasing severity of rainfall and flood events in the past few decades, flooding and erosion hazards are a top concern for residents within the Williams River watershed.

As a result of dealing with severe, repeat flood and erosion damage throughout Vermont during the last two decades, Vermont's river scientists and engineers now understand that hazard mitigation and river restoration projects are most successful when carried out within a context of how reach and watershed-scale stressors influence flood and erosion hazards. In an effort to understand the root causes of stream channel instability and flood/fluvial erosion hazards in the Williams River watershed, the Windham County Natural Resources Conservation District (WCNRCD) and the Vermont Department of Environmental Conservation (VTDEC) has sought to develop a database of Stream Geomorphic Assessment (SGA) data for reaches of significant size in the watershed. This data allows for a much more comprehensive approach to flood and erosion hazard planning, in contrast to the conventional approach of multiple “spot fixes” with limited knowledge of the river system.

Fitzgerald Environmental Associates, LLC (FEA) was hired by WCNRCD to complete a River Corridor Plan, including Phase 1 and Phase 2 SGA for the Williams River watershed. The Phase 1 study was completed in 2013 and the Phase 2 assessments were conducted in 2014 and 2015. This report describes the results of the Phase 1 and Phase 2 studies and the Williams River Corridor Plan. The project objectives are described below:

1) Develop baseline watershed and reach-scale data for the study reaches.
2) Identify river reaches where more detailed field data collection (Phase 2) is needed.
3) Develop a basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
4) Collect the information needed to improve river corridor mapping in the Williams River watershed.

5) Develop a list of preliminary river corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards and improve ecological integrity and water quality.
6) Prioritize river corridor restoration projects for each area in the watershed.
7) Develop five (5) project packets for high priority restoration sites.

Below is a summary of key findings from the Phase 1 and Phase 2 SGA and River Corridor Plan:

<u>Phase 1 Study</u>

- A total of 105 reaches along 106 river miles were delineated during the Phase 1 SGA analysis. Full Phase 1 data and windshield survey data was collected by FEA for the Williams River, Middle Branch, South Branch, Andover Branch, and thirteen (13) additional tributary and sub-tributary watersheds.
- The Phase 1 SGA approach resulted in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), providing a basis for understanding the natural and human-impacted conditions within the watershed. The Phase 1 data also aided in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts, bank armoring, etc.).
- Approximately half of the assessed reaches (53 reaches) are found in a confined valley setting that would normally support sediment and debris transport channels with A or B-type channel geometry. The remaining 52 reaches are found in an unconfined valley setting with meandering, depositional, C-type, D-type, or E-type channel geometry.
- Approximately 90% of the watershed is forested, with agricultural land use representing approximately 8% of the watershed. Developed lands represent 1-2% of the land area and are mainly associated with development corridors along major roads, the Town of Chester, and commercial and residential development along Route 103 and Route 11. Wetlands and other surface waters represent 1% of the land cover within the watershed.
- Impact ratings were developed for each reach using the Phase 1 parameters representing four classes of watershed and reach-scale impacts: 1) Land Cover and Reach Hydrology; 2) Channel Modifications; 3) Floodplain Modifications and Planform Changes; 4) Bed and Bank Conditions. Out of a total possible impact score of 32, the average rating for all reaches was 11.7, with a maximum score of 24 and a minimum score of 0.
- Based on the Phase 1 impact ratings, a total of 44 high-priority reaches in Rockingham, Chester and Andover were recommended for Phase 2 assessment, including reaches on the Williams River, six tributaries (Middle Branch, South Branch, Lover's Lane Brook, Andover Branch, Trebo Brook, and Whitmore Brook), and two sub-tributaries (Potash Brook and Trout Brook) . The selected reaches have a total channel length of approximately 47.7 miles.

<u>Phase 2 Study</u>

- During the Phase 2 field assessments, the 44 reaches were further subdivided into 59 segments based on variability in stream type, channel slope and confinement, and other factors. Three (3) segments were not fully assessed due to either impoundments (one beaver dam and Brockways Mills dam) or property access.

- The 2011 and 2014 floods triggered major channel adjustments in many of the Phase 2 study reaches. The USGS gage on the mainstem of the Williams River in Rockingham indicated the discharge during Tropical Storm Irene exceeded the 500-year flood estimate. Based on the observations that many state highway bridges along the Middle Branch and its tributaries were at or near maximum capacity in the July 2014 flood, this flood was likely near or above the 50-year discharge in this subwatershed. Both floods unleashed an enormous volume of coarse sediment and woody debris into the channel as a result of stream bed and bank erosion and mass failure valley erosion, much of this originating from the steep headwaters zones in the Middle Branch watershed. In some instances, the flood triggered severe channel adjustments even in reaches with limited human impacts in the river corridor.

- The channels of the Williams River and its tributaries are still adjusting their width, depth, and planform to the following historical and ongoing impacts: 1) aggradation of sediment in the valleys due to European settlement and deforestation that occurred during the 1700's and 1800's; 2) channel straightening, dredging, and corridor encroachment associated with adjacent roads, agriculture, and other land uses; 3) significant floods in recent years which have triggered severe valley erosion, sending huge volumes of sediment and woody debris into the lower valleys in Chester.

- Overall Phase 2 geomorphic ratings indicate fair to poor river stability along much of the Williams River mainstem in Chester and Rockingham, with the exception of some more stable reaches in the upper watershed along Smokeshire Road. Many reaches of the Middle Branch also had fair to poor stability, with severe channel adjustments found along the lower reaches in Chester, and near the confluence with Andover Brook. Andover Brook and its tributaries, such as Potash Brook, also experienced severe channel adjustments during both floods. The South Branch had fair to poor stability, with the most severe channel adjustments seen in the upper reaches in the southwestern part of Chester.

- 84 bridges and 11 culverts were assessed for geomorphic compatibility and aquatic organism passage (AOP) as part of the Phase 2 SGA work. Approximately 40% of the bridges had spans less than the reference bankfull channel width, indicating an increased degree of structure vulnerability to flooding and erosion. All of the culverts represented significant bankfull constrictions, and seven (7) of the structures had widths less than 50% of bankfull. Two culverts do not allow for any aquatic organism passage (AOP) and 8 of the remaining 9 culverts have reduced AOP. The summary of structures in this report, including the reference bankfull channel width listed for each one, provides a means for towns to understand the relative flood vulnerability and prioritize structure replacements with these criteria in mind.

<u>River Corridor Planning and Overall Flood Resiliency Recommendations</u>

- Based on the flood damage incurred in the 2011 and the 2014 floods, the Williams River watershed is vulnerable to severe flooding during prolonged rainstorms (i.e., Irene) and flashy summer thunderstorms. The National Flood Insurance Program (NFIP) study for the Williams River does not cover the entire floodplain with a detailed study; therefore inundation hazards may be underestimated in the smaller tributaries such as Trebo and Whitmore Brooks, and the upper reaches of the mainstem, Middle Branch, and South Branch. Given the hydrologic characteristics of the watershed, and the severe flood damage witnessed during recent floods, we recommend that all towns in the watershed consider flood hazard ordinances that prevent encroachment in the entire 100-year floodplain (i.e., floodway and floodplain fringe).

- River corridor protection ordinances should be considered by each town to better map flood and erosion risks for both the safety and protection of their citizens, and the infrastructure controlled by the municipality.
- By implementing at least one of the above-mentioned zoning recommendations (either river corridor protection or no new structures in the FEMA flood hazard area), towns can qualify for increased state aid (from 12.5% to 17.5%) from the Emergency Relief and Assistance Fund (ERAF) to cover future flood damages. Additional ERAF assistance from the State can significantly reduce the financial burden faced by towns during flood recovery; i.e., during a large flood resulting in 2 million dollars in recovery expenses (approximate Irene damages for the Town of Chester), the increased State share of 17.5% would reduce the Town's match to Federal and State funding by $100,000.
- Site level approaches to river corridor restoration were evaluated in detail at the reach scale, and are organized in the report by watershed. The projects were developed based on the Phase 2 results and watershed-scale mapping of stressors on channel stability. The lists of projects is intended to provide a "roadmap" of restoration projects that will reduce future flood hazards and improve ecological conditions in the river corridor. This effort resulted in the identification of 89 restoration project areas, including 24 projects that do not require significant further study (i.e., passive approaches such as buffer plantings and corridor protection), and 34 projects requiring further feasibility study or engineering design (i.e., active restoration approaches such as bridge replacements).
- The severe channel adjustments during T.S. Irene and the 2014 floods and the subsequent sediment and debris transport through the watershed resulted in the identification of an additional set of 31 projects aimed at increasing resiliency of transportation, residential, and utilities infrastructure. Most of these projects require further feasibility study or engineering design (i.e., bank stabilization and utility relocation).
- The projects were prioritized by FEA using our knowledge of the watershed and reach conditions, guidance from VTANR, and our best professional judgment. Following this prioritization, twelve high priority projects were selected and explored in further detail. These projects were identified as having the highest hazard mitigation priority and/or the greatest ecological benefits.
- Project packets were developed for five (5) of the high-priority sites. This process required additional site visits and landowner outreach, mapping, field surveys, and other data collection. The project packets include more detailed information for project implementation, cost estimates, and potential funding partners.

1.0 Project and Watershed Background

1.1 Project Introduction and Study Goals

1.1.1 Project Introduction

In 2013 the Windham County Natural Resources Conservation District (WCNRCD) and the Vermont Department of Environmental Conservation (VTDEC) identified reaches within the Williams River watershed in southeastern Vermont for assessment of fluvial geomorphic conditions. Prior to this project, geomorphic assessment data had been collected for other nearby rivers in Basin 11 draining to the Connecticut River. Major flooding and erosion damage sustained during Tropical Storm Irene in August, 2011 led to the selection of this watershed for further study. The study is part of a larger effort to characterize the physical and biological conditions of the Williams River watershed and to aid in the identification of stressors on channel stability and aquatic biota communities. In addition, the study results will form the basis for future flood mitigation, stream corridor, and erosion hazard planning efforts in the watershed. Fitzgerald Environmental Associates, LLC. (FEA) was retained by WCNRCD in 2013 to complete river assessments on the Williams River, the Middle Branch and South Branch of the Williams river, and an additional 14 tributaries and sub-tributaries following the Phase 1 Stream Geomorphic Assessment (SGA) Protocols (VTDEC, 2009) developed by the VTDEC. The final report for the Phase 1 study for the Williams River watershed was submitted in April of 2014.

Based on the Phase 1 impact ratings, a total of 44 high-priority reaches in Rockingham, Chester, and Andover were recommended for Phase 2 assessment. The selected reaches on the Williams River, Middle Branch, South Branch, Andover Branch, Lover's Lane Brook, Trout Brook, Trebo Brook, and Whitmore Brook totaled 47.7 river miles. FEA completed the Phase 2 field work in 2014 and 2015 for the selected Phase 2 study reaches and developed a River Corridor Plan (RCP). This report summarizes watershed background information, SGA results, and the RCP into one planning document.

1.1.2 Study Goals

Watershed restoration projects are most successful when carried out within a context for understanding how reach and watershed-scale stressors cause channel instability. The VTDEC SGA Protocols and River Corridor Planning Guide provides sound, scientifically-defensible methods for identifying stressors on channel stability and restoration projects that will address them appropriately (VTANR, 2010). The overall goal of the VTDEC Rivers Program is to "manage toward, protect, and restore the fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner," (VTANR, 2010) achieved through:

- Fluvial erosion hazard mitigation;
- Sediment and nutrient load reduction; and
- Aquatic and riparian protection and restoration

The Phase 1 SGA approach results in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), providing a basis for understanding the natural and human-impacted conditions within the watershed. The SGA data also aids in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts). Ultimately, the Phase 1 results help guide planners in selected reaches for more detailed Phase 2 data collection where this information can be valuable for flood vulnerability mapping, identification of river restoration projects, and long-term river corridor planning. The goal of the Phase 2 and RCP effort is to provide:

1) A basis for understanding the overall causes of channel instability and habitat degradation along the river corridors in the watershed.
2) A list of preliminary corridor restoration projects that can be further developed in the future to mitigate flood and erosion hazards.
3) Information needed to map fluvial erosion hazard zones in Rockingham, Chester, and Andover

1.2 Background Watershed Information

1.2.1 Geographic Setting and Land Use History

The Williams River watershed is located in the Upper Connecticut River Basin in southeastern Vermont (Figure 1.1). At the confluence with the Connecticut River in Rockingham, the Williams River drains 117 square miles in Windham and Windsor Counties (Figure 1.1). We divided the watershed into 4 major basins for this report (Figure 1.2). The Lower Williams River drains the southern portion of the watershed from the mouth to the confluence of the Middle Branch (M01-M11). This 38.2 square mile area includes the First Unnamed Tributary, Wright Brook, the Second Unnamed tributary, and Hall Brook (T1 - T4), and drains portions of the Towns of Rockingham, Springfield, Grafton, and Chester. The Upper Williams River drains the northern portion of the watershed from the headwaters in the northwest corner of the watershed to the confluence with the Middle Branch (M12-M26). This 30.7 square mile area includes the Third Unnamed Tributary, Trebo Brook, Whitmore Brook, the Fourth Unnamed Tributary, and Wheaton Brook (T6 - T10), and drains portions of the Towns of Springfield, Chester, Cavendish, Andover, and Ludlow). The Middle Branch of the Williams River drains the center of the watershed from the confluence with the mainstem in Chester to the western watershed boundary (T5.01-T5.11). This 37.2 square mile basin includes Lover's Lane Brook, Lyman Brook, Andover Branch (T5.S2, T5.S3, T5.S4), and two sub-tributaries to Andover Branch; Potash Brook and Trout Brook (T5.S3.a and T5.S3.b). The Middle Branch drains portions of the Towns of Chester, Andover, Weston, and Londonderry. The South Branch (T5.S1) joins the Middle Branch immediately upstream of the confluence with the mainstem and drains 10.9 square miles including portions of the Towns of Chester, Grafton, Londonderry, and Windham.

Land cover data based on imagery from 2006 (NOAA, 2008) are summarized in Table 1.1. The Williams River drains rural watersheds, with forest representing the dominant cover type. Agricultural lands cover 8% of the Williams River watershed ranging from 10% in the Lower Williams basin to 5% in the South Branch basin. Most of the agricultural lands are found within the river valleys along the mainstem, the Middle Branch, and Andover Branch. There is limited developed land within the watersheds ranging from 1 - 2%. Concentrated areas of residential and commercial development are found in the Village of Chester near the confluence of the Middle Branch and Williams River.

Table 1.1: Percent Land Cover for Williams River watershed and tributaries.

Watershed	Drainage Area (mi^2)	Agriculture	Development	Forest	Open Water	Scrub/Shrub	Wetland
Lower Williams*	38.2	10%	2%	85%	1%	1%	2%
Upper Williams*	30.7	7%	2%	89%	0%	1%	1%
Middle Branch*	37.2	9%	2%	88%	0%	1%	0%
South Branch	10.9	5%	1%	92%	0%	1%	1%
Entire Watershed	117.0	8%	2%	87%	0%	1%	1%

*Land cover data for tributaries are included.

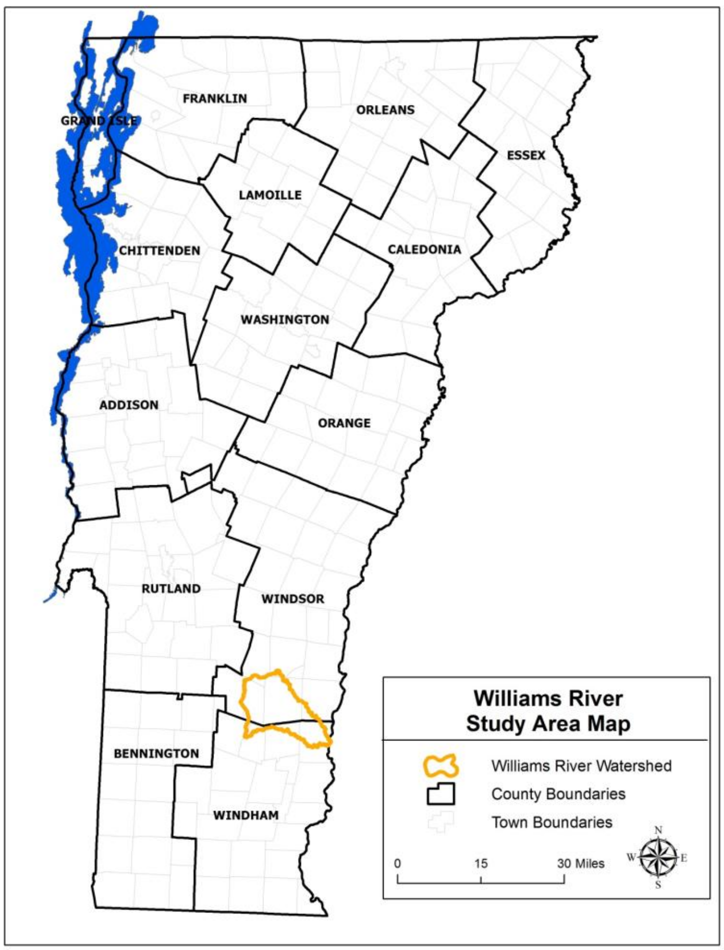


Figure 1.1: Location map for the Williams River watershed.

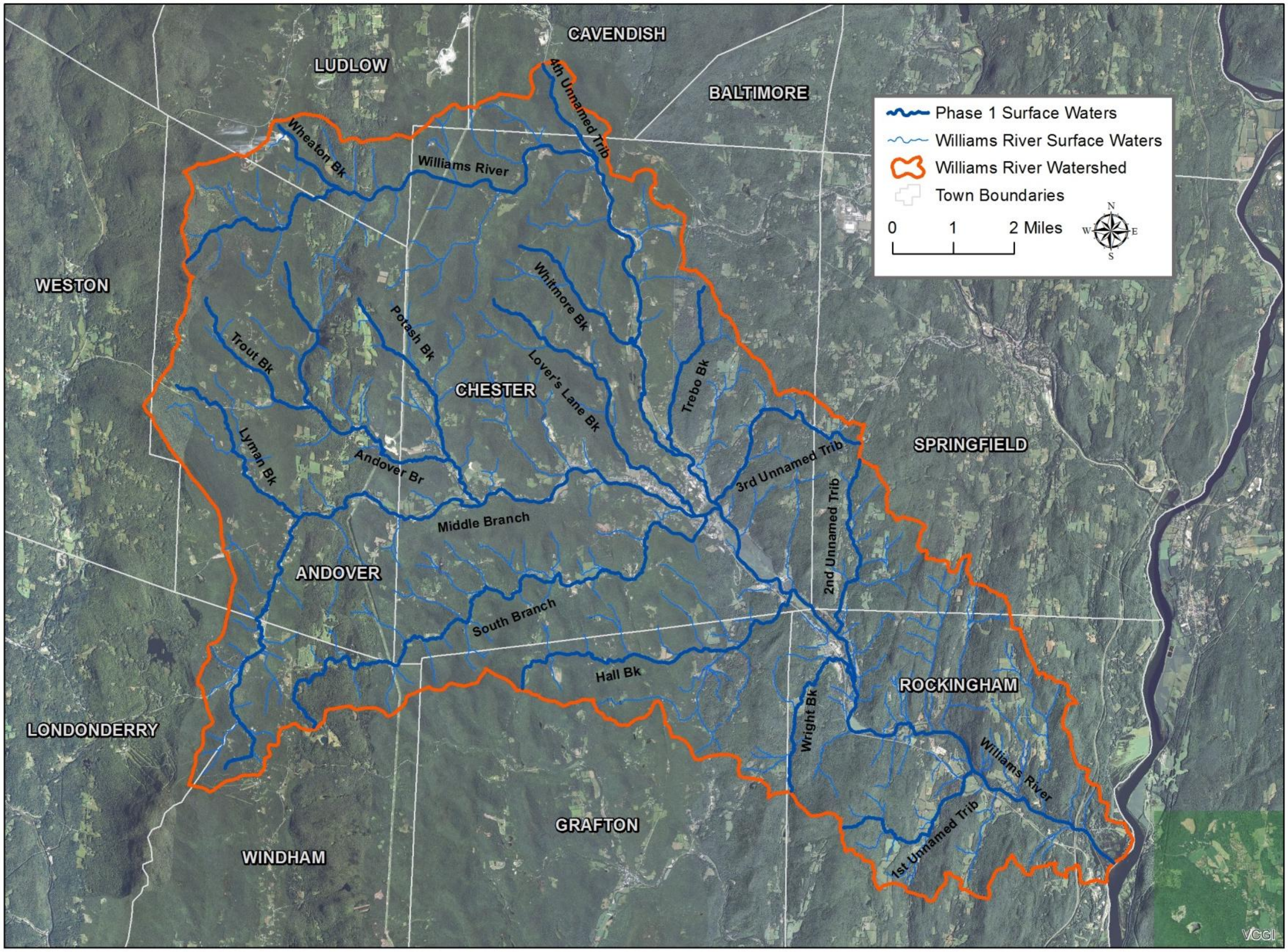


Figure 1.2: Williams River watershed, Phase 1 study reaches, and town boundaries.

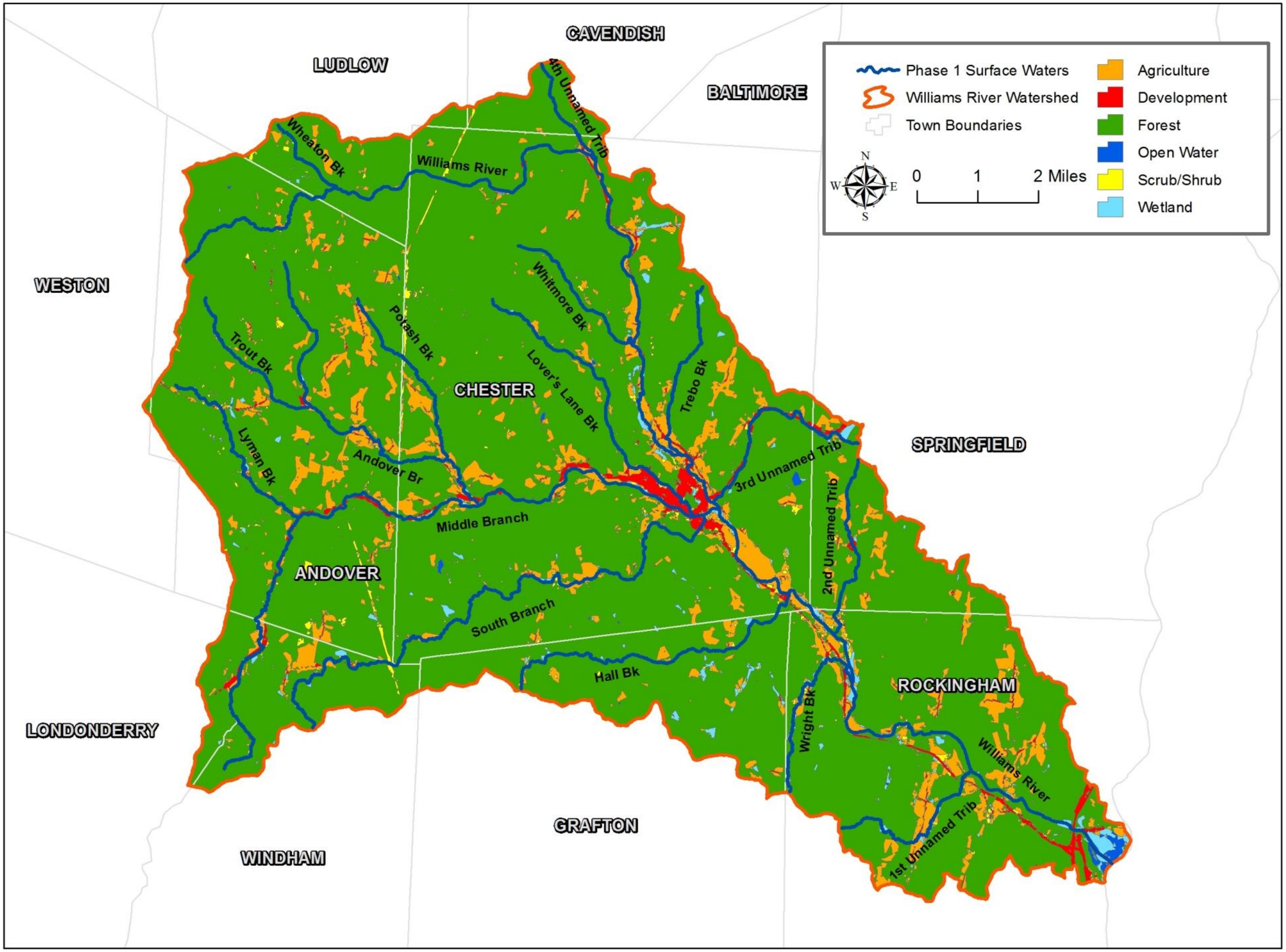


Figure 1.3: Land cover data for the Williams River watershed.

Historical Land Uses

Historically, the impacts of agricultural practices on the Vermont landscape left a lasting legacy on waterways like the Williams River. Prior to the deforestation associated with human settlement, the watershed would have been a mixture of deciduous forest on the valley floors, coniferous forest along the mountain spines, and a mixture of both along the slopes. Deforestation and grazing, largely from sheep farms, likely left over 90 percent of the watershed devoid of trees at one time or another (Albers, 2000). This landscape change had a tremendous impact on waterways like the Williams River. Exposed, highly-erodible soils (e.g. glacial tills) on steep slopes were carried to the valley floors and aggraded on river bottoms; a legacy that still influences the way Vermont's rivers are managed today.

As Vermont's farmers began to move to the Midwest in search of more productive farmland in the mid to late 1800's, the deciduous forests along the mountain slopes began to recover (Albers, 2000). Throughout the early and mid 1900's, as more family farms on marginal lands were given up, the forests continued to recover. Today, almost 90% percent of the Williams River watershed is covered by forest. With the increasing tourism sector in the state, and the need for lumber for second-homes and construction, forestry has replaced agriculture in many of the rural hill slopes of Vermont.

1.2.2 Geologic Setting

The underlying geology of the Williams River watershed is comprised of a range of bedrock types. The lower Williams River basin contains a mixture of carbonate-rich and somewhat carbonate-rich rocks from Precambrian through the Devonian period (Ratcliffe et al., 2011). These rocks are easily weathered and release calcium and other important nutrients. The remainder of the Williams River watershed is primarily non-calcerous schists, phylllites, gneisses, and granofels from Precambrian through the Cambrian period. The Waits River Formation, which contains a mixture of schist and marble, is found in the majority of the Lower Williams watershed. The weathering of calcium carbonate rich (sea bottom) sediments in these formations results in basic soils that typically support communities of rich woods species. Several gneiss formations from the Mount Holly Complex are found in the middle of the watershed (Upper Williams, Middle Branch, South Branch). The upper watershed (Upper Williams and Middle Branch) contains a wide range of bedrock formations, primarily phyllites, schists, granofels, and some ultramafic formations.

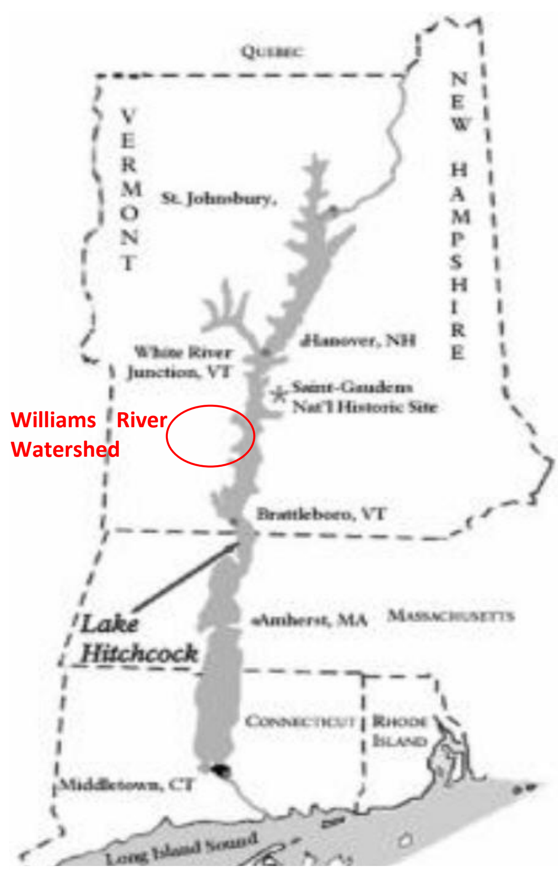


Figure 1.4: Extent of glacial Lake Hitchcock along the Connecticut River valley.

Surficial geologic deposits in the Williams River watershed were governed largely by glacial activity. During the Wisconsin glaciation, glaciers one mile in thickness extended across New England, reaching their maximum extents approximately 20,000 years ago. This glacial event left the Green Mountains with a physical imprint that is clearly evident today. In the Williams River watershed dense till, glacial till, and outwash areas reflect the dynamic nature with which glaciers shaped the landscape (Figure 1.5). Most of the surficial geology of the watershed is dominated by till and the stream corridors are primarily outwash. The resultant soils in the Williams watershed are primarily fine sandy loams, many of which are very stony (Berkshire-Tunbridge, Tunbridge-Lyman, Peru-Skerry-Colonel, Marlow, and Berkshire-Monandnock).

The presence of Glacial Lake Hitchcock also had a significant effect on the surficial geology of the Williams River watershed (Figure 1.4). This lake occupied the Connecticut River Valley from central Connecticut to north of St. Johnsbury during the retreat of the Laurentide ice sheet beginning approximately 18,000 years ago (Ridge and Larson, 1990). The great size of the lake, combined with the erosive forces of the glacier moving over bedrock surfaces allowed for the development of annual layering of fine sediments (e.g., varves) throughout the area affected by the lake.

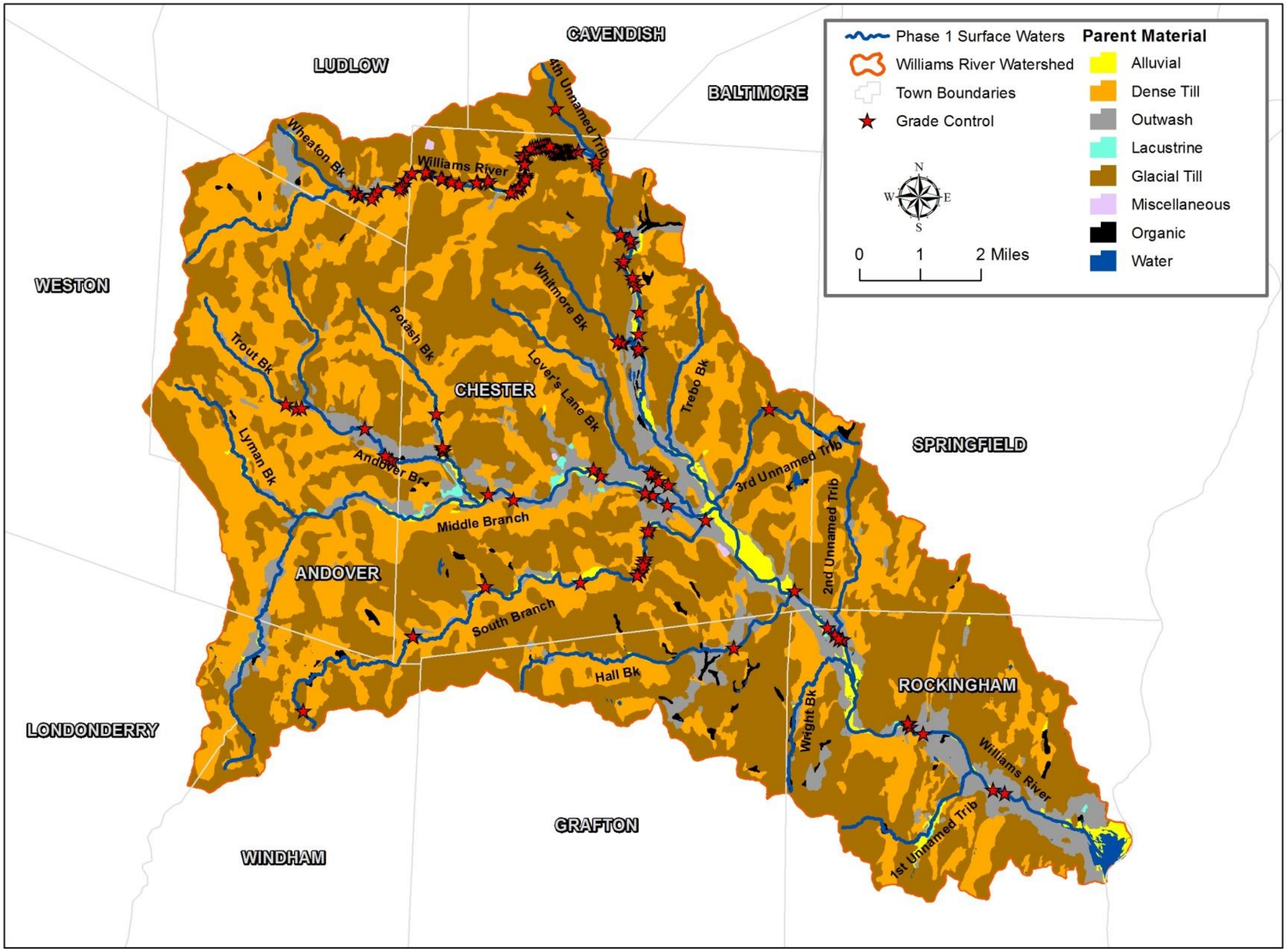


Figure 1.5: Parent surficial materials and grade controls in the Williams River Watershed.

1.2.3 Geomorphic Setting

The Williams River watershed contains two major tributaries (Middle Branch and South Branch) and 14 additional tributaries and sub-tributaries (see reach maps in Appendix C). Average slopes for all of the study reaches are presented in Table 1.2. The study reaches on the Lower Williams flow from the confluence of the Middle Branch to the mouth at the Connecticut River. The first reach braids through a large delta, has very low slope, and is likely backwatered from the Connecticut River throughout. The second reach flows through a broad valley with some braiding and passes through a very narrow man-made valley wall constriction located at the I-91 crossing. Moving upstream, the river enters a naturally confined valley with very steep side slopes tight to both banks for approximately 4 miles. Slope is low through this section except for a large bedrock cascade at the top of M06, ending at the Brockways Mills hydro-electric dam. The valley opens to an unconfined setting from M08 upstream to M11, ending the Lower Williams reaches. Major roads and a railroad share the broad valley through this stretch and through portions of the Upper Williams study reaches. Average slope for the Lower Williams reaches is 0.5% and the valley setting is highly variable (narrowly confined to very broad).

Four tributaries included in the Phase 1 study flow into the Lower Williams. The first unnamed tributary (T1) enters the Williams River in M04 and drains slopes to the southwest. Confinement and slope on this tributary are variable, alternating between steep and confined, and very broad with moderate slope. Wright Brook (T2) joins the Williams River in M08 and drains slopes to the south in a typically unconfined valley with moderate channel slopes (0.75% - 3%). The second reach is steeper and in a semi-confined setting as the stream corridor climbs out of the Williams River valley. The second unnamed tributary (T3) enters the Williams River from the north in M09. This tributary is steeper with an average slope of 4.2% and is primarily located in a semi-confined to narrow valley setting. Hall Brook (T4) joins the Williams River in M10 and drains western slopes through a moderate sloped channel (2% - 3.5%) in a narrow to broad valley setting.

The Upper Williams River study reaches start at the confluence of the Middle Branch and continue upstream to the north and west to the headwaters of the mainstem. The mainstem is consistently lower slope and in an unconfined setting through M18. These mainstem reaches flow south through broad and very broad valleys with slopes less than 1%. M16 is an exception, flowing through a short stretch of narrow valley walls and with increased channel slope (1.4%). Above this stretch, the river turns towards the headwaters in the northwest corner of the watershed. Valley setting remains unconfined but slope increases to 1.7% to 2.5% until the river reaches the headwaters (M23-M26). The headwater reaches have higher slopes (3.4%-11.3%) and are found in confined valleys.

Five tributaries included in the Phase 1 study flow into the Upper Williams. The third unnamed tributary (T6) enters the Williams River from the east, immediately upstream of the Middle Branch confluence. This tributary flows through an unconfined broad to narrow valley setting with moderate channel slopes ranging from 2.3% to 3.1%. Trebo Brook (T7) enters the Williams River in M12 and drains slopes to the north. The first reach is largely within the historic Williams River valley and has lower slope through the very broad setting. Slope (2.5%-4.7%) and confinement increase as Trebo Brook leaves the large river valley and rise up through the headwaters. Whitmore Brook (T8) enters the Williams River in M13 and drains a small area to the northwest. Similar to other small tributaries, the first reach has a lower slope and a very broad valley, primarily within the historic Williams River valley, and slope and confinement increase as the stream leaves the large valley to the headwaters. The fourth unnamed tributary (T9) enters the Williams River in M17 and drains a small area to the northeast corner of the watershed. This tributary also begins with a low slope and very broad valley before climbing to the headwaters through a semi-confined valley with moderate slope. Wheaton Brook (M10) joins the Williams River in M22 at the transition to the headwaters reaches. The stream drains a small watershed to the north and flows through a semi-confined valley with an average channel slope of 4.2%.

The Middle Branch joins the Williams River at Reach M11 and represents more than half of the drainage area at the confluence. The South Branch flows into the Middle Branch immediately upstream of the confluence with the mainstem. The Middle Branch flows through an unconfined valley setting with slopes ranging from 0.8% to 2.1% until the final headwaters reach rises through a semi-confined valley with 8.4% channel slope. Roads occupy a portion of the valley bottom for all the Middle Branch reaches up to the headwaters. The lower half of the Middle Branch is typically lower gradient and situated in a very broad to broad valley setting. The Middle Branch transitions to broad and narrow valley settings with moderate slopes for the upper reaches before reaching the headwaters.

The South Branch is the first tributary to the Middle Branch and joins the Middle Branch in Reach T5.01 immediately upstream of the confluence with the mainstem. The South Branch (T5.S1) gradually rises to the southwest through an unconfined valley with channel slopes ranging from 0.9% to 2.5%. The second to last reach has low slope and multiple large beaver dams as the stream winds through a very broad valley. Above this reach the stream transitions to the headwaters and is steep and confined. Average channel slope on the South Branch is 2.3%. Lover's Lane Brook also joins the Middle Branch in the first reach and flows through a very broad to broad valley before transitioning to the steep and confined headwaters. Andover Branch (T5.S3) joins the Middle Branch at Reach T5.04 and drains slopes to the northwest. Andover Branch flows through a variable but unconfined valley with channel slopes ranging from 1.5% to 1.9% before reaching the headwaters where slope and confinement increase. Two sub-tributaries flow in to Andover Branch: Potash Brook (T5.S3.a) and Trout Brook (T5.S3.b); these sub-tributaries join Andover Branch in the first and fourth reaches respectively. The first reach of Potash Brook is unconfined; the remaining reaches of both streams flow through steeper, confined valleys. Lyman Brook (T5.S4) joins the Middle Branch in Reach T5.04 and drains a small watershed to the northwest. Valley width and channel slope are variable throughout ranging from semi-confined to very broad and having an average slope of 3.1%.

A summary of the average channel slopes for the Williams River, Middle Branch, South Branch, and tributaries is provided below in Table 1.2.

Table 1.2: Average channel slopes for major and sub tributaries.

Channel (SGA Reaches)	Average Slope
Williams River (M1 - M26)	1.6%
Lower Williams River (M1 - M11)	0.5%
Upper Williams River (M12 - M26)	2.4%
1st Unnamed Tributary (T1.01 - T1.05)	5.6%

Table 1.2: Average channel slopes for major and sub tributaries.

Channel (SGA Reaches)	Average Slope
Wright Brook (T2.01 - T2.04)	1.9%
2nd Unnamed Tributary (T3.01 - T3.05)	4.2%
Hall Bk (T4.01 - T4.04)	2.6%
Middle Branch Williams River (T5.01 - T5.11)	2.3%
South Branch Williams River (T5.S1.01 - T5.S1.12)	2.3%
Lover's Land Brook (T5.S2.01 -T5.S2.04)	4.0%
Andover Branch (T5.S3.01 - T5.S3.07)	2.9%
Potash Brook (T5.S3.a.01 - T5.S3.a.03)	5.5%
Trout Brook (T5.S3.b.01 - T5.S3.b.03)	6.9%
Lyman Brook (T5.S4.01 - T5.S4.05)	3.1%
3rd Unnamed Tributary (T6.01 - T6.04)	2.5%
Trebo Brook (T7.01 - T7.04)	2.8%
Whitmore Brook (T8.01 - T8.04)	6.1%
4th Unnamed Tributary (T9.01 - T9.02)	2.3%
Wheaton Brook (T10.01 - T10.02)	4.2%

1.2.4 Hydrology and Flood History

The United States Geological Survey (USGS) currently operates a real-time flow monitoring gage at the Parker Hill bridge in Reach M04 on the Williams River (#1153550). The river has been gaged at this location since 1987. Previously the Williams River was gaged at the Brockways Mills dam (#1153500) in M06 from 1938 to 1984. An additional gaging station was operated on Lover's Lane Brook from 1964 to 1978, with peak flow levels recorded from 1999 to 2015 (#1153300). Long-term flow frequency data from these gages was included in a USGS study to summarize flow-frequency characteristics of Vermont rivers and streams (Olson, 2014). The period of record for the Olson study contains 25 years for the Williams River (M04) and 28 years for Lover's Lane Brook. The recurrence interval flow estimates described in the recent Olson report are significantly higher than those described in the 2002 report which only included 14 years of flow record for the M04 gage (Olson, 2002; Olson, 2014). Flow frequency data for the three stream gages are presented in Table 1.3.

Table 1.3: Frequency and magnitude of flow events in the Williams River watershed based on USGS gage data. Olson results from 2002 are followed by 2014 results in parentheses.

	Discharge (cfs)		
Return Frequency	Williams (M04)	Williams (M06)	Lover's Lane (T5.S2.01)
2 year	6,190 (4,380)	4,380	148 (140)
5 year	8,580 (7,230)	6,440	204 (210)
10 year	10,200 (9,100)	7,910	244 (265)

Table 1.3: Frequency and magnitude of flow events in the Williams River watershed based on USGS gage data. Olson results from 2002 are followed by 2014 results in parentheses.

	Discharge (cfs)		
Return Frequency	Williams (M04)	Williams (M06)	Lover's Lane (T5.S2.01)
25 year	12,300 (11,800)	9,890	298 (345)
50 year	14,000 (14,000)	11,400	342 (414)
100 year	15,700 (16,500)	13,100	387 (490)
500 year	19,700 (23,400)	17,200	505 (705)

The shifts in flood discharges between the two Olson reports show the importance of large floods (e.g., T.S. Irene) in shaping these relationships. The eleven additional years of data collected since the 2002 report contained relatively low peak flows except for T.S. Irene. T.S. Irene flow was measured as 21,300 cfs at the Williams River gage and 602 cfs at the Lover's Lane gage, both well above the previous estimates for a 500-year flood. The inclusion of the new peak flow data shifted the smaller floods downwards and increased estimated flows for the largest floods. The gage at Brockways Mills was operational during the Great Hurricane of 1938 but a discharge for this event was not reported. The water level during this storm was approximately seven feet higher than the next largest storm on record; a 50 year event in 1976 (Figure 1.6). No other major storm events were recorded for the watershed. Figure 1.7 shows the annual peak flow values for the Williams River and the 2, 10, and 100-year flood interval levels using the Olson 2002 data for the historic gage (M06) and the Olson 2014 data for the current gage (M04).

Figure 1.6: Damage from the 1974 flood along the Middle Branch of the Williams River (UVM Landscape, 2011).

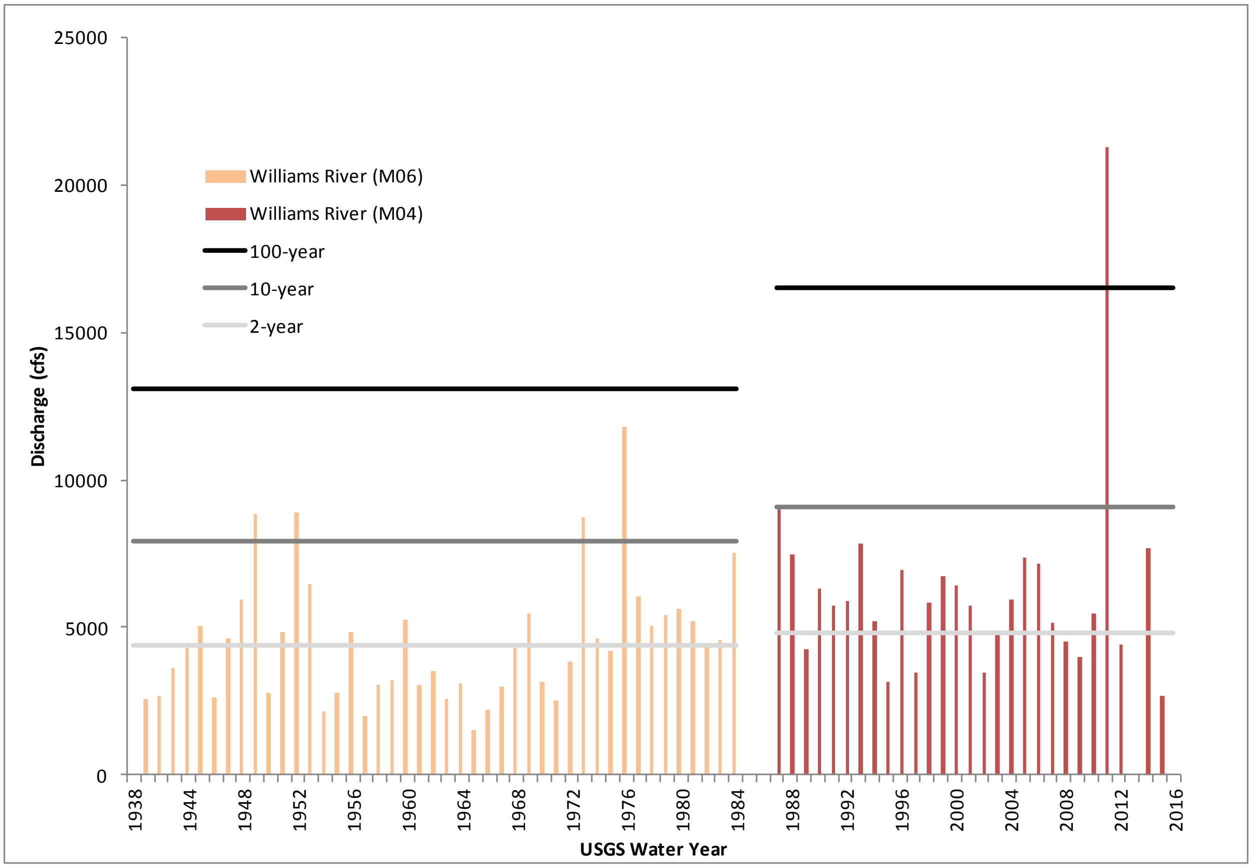


Figure 1.7: Annual peak streamflows from USGS gages on the Williams River.

The 140 year old Bartonsville Covered bridge in Rockingham was washed away during T.S. Irene (Figure 1.8). Pictures and video of this historic bridge washing downstream as the abutments failed were some of the iconic images from this flood that were shown in national media. The bridge was rebuilt and reopened on January 26th, 2013 using funds from taxpayers, donations, insurance, FEMA, and the State of Vermont.

Figure 1.8: Historic photo of the Bartonsville covered bridge (UVM Landscape, 2011).

Imagery obtained by Mansfield Heliflight two weeks after Tropical Storm Irene depict major damage along the Williams River and the South Branch. Both pictures show the massive damage inflicted by floodwaters, and the huge efforts undertaken to restore transportation infrastructure within the river corridor (Figure 1.9). Rivers were temporarily diverted, tall berms were constructed, and huge amounts of soil and rock were moved, dredged, and deposited within the river corridor.

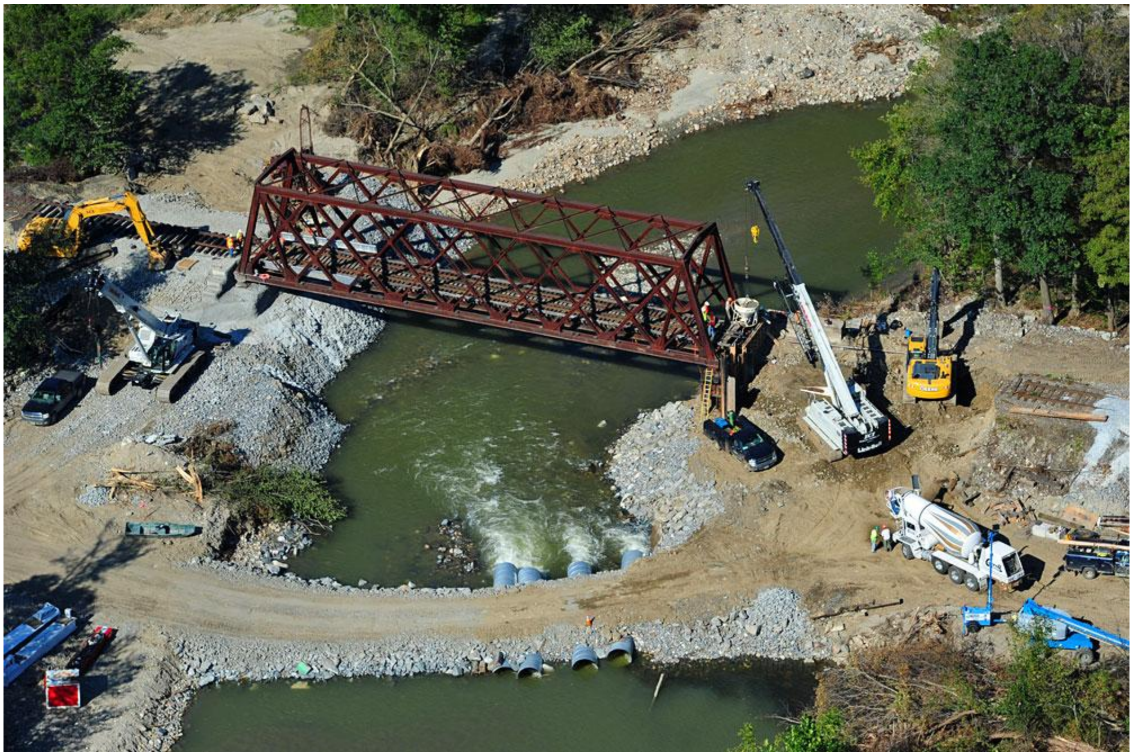


Figure 1.9: Major repairs to a railroad bridge on Reach M10 in Chester. Destroyed house, damage to Route 11, and extensive earth work along the Middle Branch (photos courtesy of Mansfield Heliflight).

An intense summer thunderstorm on July 28th, 2014 caused extensive flooding and severe damage in localized areas of the Williams watershed. The USGS gage on the mainstem recorded a peak flow of 7,680cfs, roughly a 5-year storm, however damage and observed high water marks along the Middle Branch and Andover Branch suggest that this storm may have been as large as a 50-year flood in those watersheds (Figure 1.10).

Figure 1.10: Flooding at the intersection of Route 103 and Route 11 in Chester (top), severe damage to a property along Route 11 on reach T5.07 of the Middle Branch (photos courtesy of S. Cunningham and the Chester Telegraph).

1.2.5 Ecological Setting

The Lower Williams River watershed is located in the Southern Vermont Piedmont (SP) biophysical region, and the remainder of the Williams River watershed is located in the Southern Green Mountains (SM) biophysical region (Thompson and Sorenson, 2000). The SP region is found along the eastern border of Vermont and extends from White River Junction down to Massachusetts. It is characterized by gentle rolling hills and bedrock geology that supports Northern Hardwood Forest communities. Some areas of igneous intrusions (e.g. granitic plutons), such as Ascutney Mountain and Black Mountain to the west of Brattleboro, support rare communities such as the Pitch Pine-Oak-Heath community. Rich soils of loam and silt along the Connecticut River that once supported extensive areas of silver maple (*Acer saccharinum*) and Ostrich Fern (*Matteuccia struthiopteris*) were converted to agricultural use during European settlement in the late 18th century. Post-glacial deposits of sand and gravel are common in the river valleys of the SP region, including the mainstem and tributaries of the lower Williams River watershed. The SM region is found along the spine of the Green Mountains and low foothills to the east in the southern half of Vermont. Temperatures are cooler and precipitation is higher in this region. Bedrock is typically metamorphic, acidic, and non-calcareous. The natural communities in this region tend to be those with northern affinities that are best suited for colder temperatures. Boreal communities are found on the highest peaks where winter conditions are harshest. The slopes grade into the Northern Hardwood forest type at elevations of around 2,500 feet. This forest type dominates most of the Williams River watershed. Deep glacial till deposits cover most of the SM region including the Williams River watershed. Glaciofluvial kame and outwash deposits common in the SM region are found throughout the Williams River valley.

Elevations within the study area range from 289 feet at the confluence of the Williams River with the Connecticut River to over 2,880 feet at the top of Terrible Mountain in the headwaters of the mainstem and at the top of Glebe Mountain in the headwaters of the Middle Branch. A spine of taller peaks, including several over 2,000 feet, run from the western watershed boundary through to the center of the watershed and divide the Upper Williams mainstem from the Middle Branch tributaries.

Macroinvertebrate and fish community assessments have been completed by the VTDEC Biomonitoring Division on the Williams River, South Branch, Andover Branch, and the Second Unnamed Tributary (Tables 1.4 and 1.5). Macroinvertebrate community assessments ranged from "good" to "excellent". Intensive sampling on M11 was conducted to test for impacts from the Chester wastewater treatment plant. The samples from stations 070000000118 and 070000000119 were collected below the plant, 070000000121 and 070000000122 were collected above the plant. Fish community assessments also found communities that were typically "good" to "excellent". The sample collected from M11 in 2012 (post-Irene) had reduced richness, reduced biotic integrity, and a "poor" rating. Comments from the sampling report indicate that heavy sedimentation, likely from T.S. Irene was impacting fish habitat.

Table 1.4: Macroinvertebrate Community Assessment Data

Location	Reach	Date	Station ID	Community Assessment	Total Richness	EPT Richness	Biotic Integrity
Williams River	M04	9/18/92	070000000030	Excellent	47	32.5	3.17
Williams River	M04	9/13/99	070000000030	Excellent	38	24	4.18
Williams River	M11	10/9/08	070000000118	Very Good	61	38	3.96
Williams River	M11	9/21/12	070000000118	Good	71	29	4.83
Williams River	M11	9/12/02	070000000119	Good	57	24	4.50
Williams River	M11	10/9/08	070000000121	Very Good	55	31	3.81
Williams River	M11	10/9/08	070000000122	Excellent - Very good	54	32	3.72
Williams River	M16	9/12/02	070000000187	Excellent	52	27	3.48
South Branch	T5.S1.02	10/13/93	071602000013	Excellent	42	30	2.37
Andover Branch	T5.S3.04	9/2/03	071605000044	Good	55	25	3.95
Andover Branch	T5.S3.04	9/2/03	071605000048	Excellent	54	26	2.96

Table 1.5: Fish Community Assessment Data

Location	Reach	Date	Station ID	Community Assessment	Total Richness	Biotic Integrity
Williams River	M04	10/6/92	070000000030	Very Good	10	37
Williams River	M11	10/14/08	070000000118	Good	8	33
Williams River	M11	9/21/12	070000000118	Poor	5	25
2nd Unnamed Trib	T3.01	7/1/03	71100000004	Excellent	5	45
Andover Branch	T5.S3.04	9/2/03	071605000044	Excellent	4	45
Andover Branch	T5.S3.04	9/2/03	071605000048	Excellent	5	45

Williams River from the Brockways Mills dam to the Connecticut River is listed as juvenile Atlantic salmon nursery and rearing habitat. This stretch of the river is also described as excellent spawning, rearing, and holding habitat for adult salmon. Atlantic salmon fry were stocked annually in the lower Williams River from 1998 to 2012 as part of an effort to restore Atlantic salmon in the Connecticut River. Adult salmon surveys starting in 1998 indicate that adult salmon were successfully migrating to the Atlantic Ocean and some adults were successfully returning to the Williams River to spawn (VTANR, 2008). Unfortunately, the Connecticut River salmon stocking programs were discontinued in 2012 due to low returns of adult salmon and science supporting salmon restoration (USFWS, 2014).

Small areas of wetland are scattered throughout the watershed with a total land cover of approximately 1% of the watershed. Larger significant wetlands are found along the mainstem of the Williams River including a large wetland (Herrick's Cove) at the mouth of the river. The shallow emergent marshland found at Herrick's Cove is listed as a significant natural community, and contains several rare and protected species and uncommon species (VTANR, 2014). Additional small wetlands are found along streams and small tributaries throughout the watershed.

2.0 Study Methods

2.1 Data Collection Methods

The Vermont River Management Program (RMP) has invested many person-years of effort into developing a state-of-the-art system of Stream Geomorphic Assessment (SGA) protocols. The SGA protocols are intended to be used by resource managers, community watershed groups, municipalities and others to identify how changes to land use affect hydro-geomorphic processes at the landscape and reach scale, and how these changes alter the physical structure and biological habitat of streams in Vermont. The SGA protocols have become a key tool in the prioritization of restoration projects that will 1) reduce sediment and nutrient loading to downstream receiving waters such as Lake Champlain and the Connecticut River, 2) reduce the risk of property damage from flooding and erosion, and 3) enhance the quality of in-stream biological habitat. The protocols are based on defensible scientific principles and have been tested widely in many watersheds throughout the state. Data collected for the Williams River watershed using the protocols formed the basis for preliminary project identification carried out during the Phase 2 SGA and River Corridor Planning efforts.

The SGA protocols include three phases (VTDEC, 2009):

- **Phase 1**: The Phase 1 SGA approach utilizes the Stream Geomorphic Assessment Tool (SGAT), a GIS extension developed by RMP for the collection of reach and watershed scale data. In addition to the GIS and remote sensing effort, a cursory field assessment ("windshield survey") is included for the verification of stream and valley forms, significant channel features and the location of man-made infrastructure. The Phase 1 SGA approach results in watershed-scale data about the landscape (e.g., soils and land cover) and the stream channel (e.g., slope and form), which provides a basis for understanding the natural and human-impacted conditions within the watershed. The SGA data also aids in the identification of specific stressors affecting the physical conditions of the stream channels and structures (e.g., bridges and culverts). Table 2.1 summarizes the parameters collected in Phase 1 using the Feature Indexing Tool (FIT), which include those utilized to develop the final impact ratings.

- **Phase 2**: The Phase 2 approach builds upon Phase 1 data through the collection of reach-specific data about the current physical conditions. Characterization of reach conditions utilizes a suite of quantitative (e.g., channel geometry, pebble counts) and qualitative (e.g., pool-riffle habitat) measurements to calculate two indices: Rapid Geomorphic Assessment (RGA) Score; Rapid Habitat Assessment (RHA) score. Using the RGA scores in conjunction with knowledge about the background or "reference" conditions, a sensitivity rating is developed to predict the degree to which the channel will adjust to human and natural impacts in the future.

Table 2.1: Parameters collected with FIT.

Phase 1 Step	Phase 2 Step	Data Type	Impact	Sub-Impact
3.1	**1.2**	Point	Alluvial Fan	NA
3.2	**1.6**	Point	Grade Control	Dam Ledge Waterfall Weir
NA	**3.3**	Point	Mass Failure	NA
5.5	**5.5**	Point	Dredging	Dredging Gravel Mining Commercial Mining
NA	**4.4**	Point	Debris Jam	NA
NA	**4.6**	Point	Stormwater Input	NA
NA	**4.9**	Point	Beaver Dam	NA
NA	**5.2**	Point	Migration	Neck Cut Off Flood chute Avulsion Braiding
NA	**5.3**	Point	Steep Riffle or Head Cut	Head Cut Steep Riffle
NA	**5.4**	Point	Stream Crossing	Stream Ford Animal Crossing
NA	**3.3**	Point	Gully	NA
6.2	**1.3**	Line	Development	NA
6.1	**1.3**	Line	Encroachment	Berm Improved Path Road Railroad
5.3	**3.1**	Line	Bank Armoring or Revetment	Rip-Rap Hard Bank Other
7.2	**3.1**	Line	Erosion	NA
5.4	**5.5**	Line	Straightening	Straightening With Windrowing

- **Phase 3**: Phase 3 surveys involve the collection of detailed, reach-scale survey data to verify or build upon Phase 2 data. These surveys are typically carried out prior to project development for an "active" channel management approach (e.g., floodplain restoration), or for long-term monitoring purposes.

FEA developed a SGAT geodatabase using the SGAT 10.2 toolbar. The subwatersheds, valley walls, and meander centerline themes were created for the study reaches and reviewed by VTDEC staff. The VTANR Data Management System (DMS) database was populated from these themes and reference stream types were assigned. The remaining Phase 1 data was collected remotely by FEA and through windshield surveys for reaches along 106 river miles. All major human impacts and natural features were indexed in a GIS using the FIT.

2.2 Quality Assurance

The VTDEC Quality Assurance (QA) protocols outlined in the SGA protocols (VTDEC, 2009) were followed in order to ensure a complete and accurate dataset. FEA and VTDEC shared responsibility for QA for the SGAT shapefiles and the finalized Phase 1 and Phase 2 datasets. The DMS database for all Phase 1 assessed reaches in the watershed was finalized in November, 2013. The DMS database for all Phase 2 assessed reaches was finalized in June 2016. The QA summaries for Phase 2 are included in Appendix D, there were no outstanding QA requirements for the Phase 1 dataset.

2.3 Bridge and Culvert Assessments

FEA conducted bridge and culvert surveys on all private and public structures within the selected Phase 2 reaches. The Bridge and Culvert Assessment and Survey Protocols specified in Appendix G of the Vermont Stream Geomorphic Assessment Handbook (VTDEC, 2009) were followed. Latitude and Longitude of each structure was recorded in the field with a GPS unit or digitized based on aerial imagery. The assessment included various photographs documenting the condition of each structure.

2.4 Stressor and Departure Analysis

FEA followed the VTDEC methods for developing river corridor plans as outlined in the Vermont River Corridor Planning Guide (VTANR, 2010). This technical guide is directed towards river scientists, planners, and engineers engaged in finding economically and ecologically sustainable solutions to the conflicts between human investments and river dynamics. The guide provides explanations for the following:

- River science and societal benefits of managing streams in a sustainable manner toward equilibrium conditions;
- Methods for assessing and mapping stream geomorphic conditions, and identifying and prioritizing river corridor protection and restoration projects;
- Methods for examining project feasibility and negotiating management alternatives with stakeholders; and
- Information on current programs available to Vermont landowners, towns, and other interested parties to implement river corridor protection and restoration projects.

Included in this approach is an extensive mapping exercise to lay the foundation for understanding stressors on stream channel stability at the watershed and reach scales. These maps are compiled as part of the stressor and departure analysis, and illustrate a gradient of human impacts and stream response across the watershed. The maps provide a basis for identifying projects through a step-wise procedure to screen potential projects for compatibility with long-term equilibrium conditions.

2.4.1 Stressor Analysis

The data collected through the Phase 1 and 2 SGA studies provides the basis for assessing the impacts to the hydrologic and sediment regimes, and the channel riparian and boundary conditions. This data, when combined with other watershed-scale data developed in this study, allows for the assessment of physical departure from reference conditions, and serves to validate watershed-scale patterns and stream conditions observed in the field.

Stressor, departure and sensitivity maps have been prepared to depict the effects of significant physical processes occurring within the Williams River study area. These maps provide an indication of where channel adjustment processes have been altered, at both the watershed-scale and the reach-scale. The analysis of existing and historic departures from equilibrium conditions along a stream network allows for the prediction of future channel adjustments. This is helpful in developing and prioritizing potential river corridor protection and restoration projects.

2.4.2 Departure Analysis

Much research has shown that alluvial river channels in wide valleys will adjust their geometry and planform to accommodate changes in the discharge and sediment loading from the upslope watershed (Dunne and Leopold, 1978). This concept was summarized by Lane (1955) to show that stream power and sediment (size and distribution) will seek a dynamic equilibrium condition in the absence of anthropogenic disturbance or catastrophic natural storm events. Slight changes from one year to another, such as variation in rainfall amounts (and a resulting variation in discharge), may cause subtle changes in channel form. However, the cross-sectional shape and profile of a river is typically stable under reference watershed conditions, and predictable given knowledge about: 1) the geologic conditions of the watershed and river corridor, 2) the topography of the watershed and river corridor, and 3) the regional climate.

Analysis of a watershed's sediment regime is a useful approach for summarizing the reach and watershed-scale stressors affecting the equilibrium conditions of river channels. Sediment regime mapping provides a context for understanding the sediment transport and channel evolution processes (Schumm, 1977) which govern changes in geometry and planform for river channels in a state of disequilibrium. The VTANR River Corridor Planning Guide (VTANR, 2010) outlines a methodology for understanding the reference and altered sediment regimes of reaches according to data collected during the Phase 2 field assessments. The sediment regime types used in this analysis are summarized below in Table 2.2.

Table 2.2: Sediment regime types for corridor planning (VTANR, 2010).

Sediment Regime	Narrative Description
Transport	Steeper bedrock and boulder/cobble cascade and step-pool stream types; typically in more confined valleys, do not supply appreciable quantities of sediments to downstream reaches on an annual basis; little or no mass wasting; storage of fine sediment is negligible due to high transport capacity derived from both the high gradient and/natural entrenchment of the channel.
Confined Source and Transport	Cobble step pool and steep plane bed streams; confining valley walls, comprised of erodible tills, glacial lacustrine, glacial fluvial, or alluvial materials; mass wasting and landslides common and may be triggered by valley rejuvenation processes; storage of coarse or fine sediment is limited due to high transport capacity derived from both the gradient and entrenchment of the channel. Look for streams in narrow valleys where dams, culverts, encroachment (roads, houses, etc.), and subsequent channel management may trigger incision, rejuvenation, and mass wasting processes.
Unconfined Source and Transport	Sand, gravel, or cobble plane bed streams; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to entrenchment or incision and associated bed form changes; these streams are not a significant sediment supply due to boundary resistance such as bank armoring, but may begin to experience erosion and supply both coarse and fine sediment when bank failure lead to channel widening; storage of coarse or fine sediment is negligible due to high transport capacity derived from the deep incision and little or no floodplain access. Look for straightened, incised or entrenched streams in unconfined valleys, which may have been bermed and extensively armored and are in Stage II or early Stage III of channel evolution.

Table 2.2: Sediment regime types for corridor planning (VTANR, 2010).

Sediment Regime	Narrative Description
Fine Source and Transport & Coarse Deposition	Sand, gravel, or cobble streams with variable bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to vertical profile and associated bed form changes; these streams supply both coarse and fine sediments due to little or no boundary resistance; storage of fine sediment is lost or severely limited as a result of channel incision and little or no floodplain access; an increase in coarse sediment storage occurs due to a high coarse sediment load coupled with the lower transport capacity that results from a lower gradient and/or channel depth. Look for historically straightened, incised, or entrenched streams in unconfined valleys, having little or no boundary resistance, increased bank erosion, and large unvegetated bars. These streams are typically in late Stage III and Stage IV of channel evolution.
Coarse Equilibrium (in = out) & Fine Deposition	Sand, gravel, or cobble streams with equilibrium bedforms; at least one side of the channel is unconfined by valley walls; these streams transport and deposit coarse sediment in equilibrium (stream power—produce as a result of channel gradient and hydraulic radius—is balanced by the sediment load, sediment size, and channel boundary resistance); and store a relatively large volume of fine sediment due to the access of high frequency (annual) floods to the floodplain. Look for unconfined streams, which are not incised or entrenched, have boundary resistance (woody buffers), minimal bank erosion, and vegetated bars. These streams are Stage I, late IV, and Stage V.
Deposition	Silt, sand, gravel, or cobble streams with variable and braided bed forms; at least one side of the channel is unconfined by valley walls; may represent a stream type departure due to changes in slope and/or depth resulting in the predominance of transient depositional features; storage of fine and coarse sediment frequently exceeds transport**. Floodplains are accessed during high frequency (annual) floods. Look for unconfined streams, which are not incised or entrenched, have become significantly over-widened, and if high rates of bank erosion are present, it is offset by the vertical growth of unvegetated bars. These regimes may be located at zones of naturally high deposition (e.g., active alluvial fans, deltas, or upstream of bedrock controls), or may exist due to impoundment and other backwater conditions above weirs dams and other constrictions.

** Use of the "Deposition" regime characterization may be rare, but valuable as a planning tool, where the reach is storing far more than it is transporting during some defined planning period. The extreme example would be that of an impounded reach where all of the coarse and a great percentage of the fine sediments are being deposited, rather than transported downstream. This man-made condition may change, thereby changing the sediment regime, but is not likely over the period at which the corridor plan will be used.

Channel evolution models (CEM) also provide a basis for understanding the temporal scale of channel adjustments and departure in the context of SGA Phase 2 results. Both the "D" stage and "F" stage CEMs (VTDEC, 2009) are helpful for explaining the channel adjustment processes underway in the Williams River watershed. The "F" stage CEM is used to understand the process that occurs when a stream degrades (incises) its bed. The more dominant adjustment process for the "D" stage channel evolution is aggradation, widening and planform change. D-stage CEM typically occurs where grade controls prevent severe channel incision and abandonment of the adjacent floodplain. The common stages of both CEMs are depicted in Figure 2.1 below.

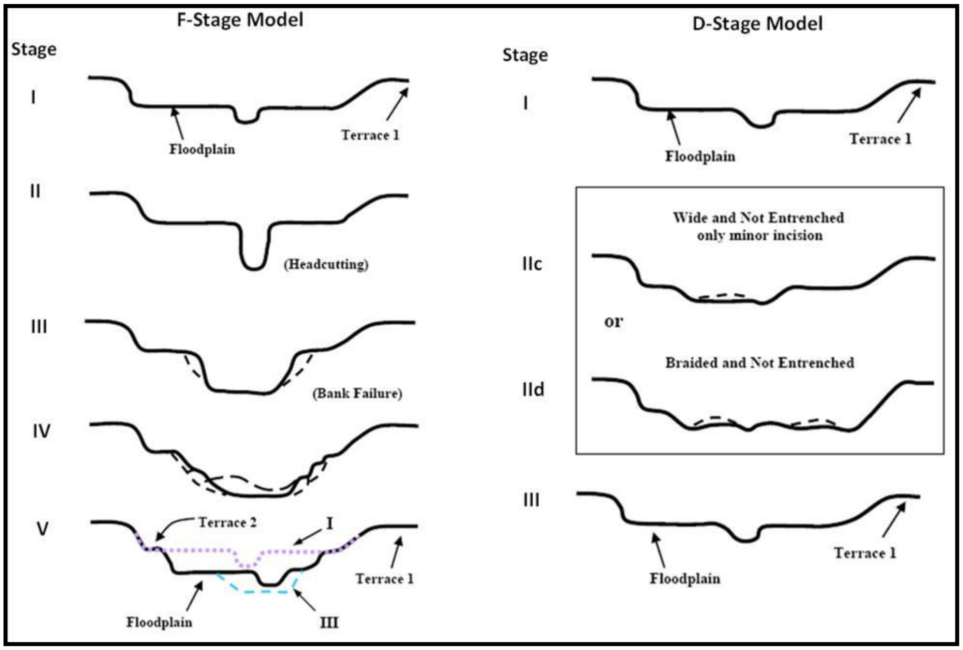


Figure 2.1: Typical channel evolution models for F-stage and D-stage (VTDEC, 2009).

2.4.3 Sensitivity Analysis

The following description of the sensitivity of various stream types to changes in sediment and flow regimes, boundary conditions and channel morphology, is included from the most recent version of the VTANR River Corridor Planning Guide (VTANR, 2010).

> Certain geomorphic stream types are inherently more sensitive than others, responding readily through lateral and/or vertical adjustments to high flow events and/or influxes of sediment. Other geomorphic stream types may undergo far less adjustment in response to the same watershed inputs. In general, streams receiving a large supply of sediment, having a limited capacity to transport that sediment, and flowing through finer-grained, non-cohesive materials are inherently more sensitive to adjustment and likely to experience channel evolution processes more rapidly than streams with a lower sediment supply, higher transport capacity and flowing through cohesive or coarse-grained materials (Montgomery and Buffington, 1997). The geometry and roughness of the stream channel and floodplain (i.e., the width, depth, slope, sediment sizes, and floodplain relations) dictate the velocity of flow, how much erosive power is produced, and whether the stream has the power to transport the sediment delivered from upstream (Leopold, 1994). If the energy produced by the depth and slope of the water is either too little or too great in relation to the sediment available for transport, the stream may be out of equilibrium and channel adjustments are likely to occur, especially during flood conditions (Lane, 1955).

Stream sensitivity maps have been prepared for the Williams River study area. Sensitivity ratings were assigned using the VTDEC Protocols (VTDEC, 2009).

2.5 Project Identification

Site-specific projects were identified using methods outlined by VTANR in Chapter 6 Preliminary Project Identification and Prioritization (VTANR, 2010). This planning guide is intended to aid in the development of projects that protect and restore river equilibrium conditions. The projects identified for the study reaches can be classified under one of the following categories: Active Geomorphic Restoration, Passive Geomorphic Restoration, and Conservation.

Active Geomorphic Restoration implies the management of rivers to a state of geomorphic equilibrium through active, physical alteration of the channel and/or floodplain. Often this approach involves the removal of human constructed constraints or the construction of meanders, floodplains or stable banks. Riparian buffer re-vegetation and long-term protection of a river corridor is essential to this alternative.

Passive Geomorphic Restoration allows rivers to return to a state of geomorphic equilibrium by removing factors adversely impacting the river and subsequently using the river's own energy and watershed inputs to re-establish its meanders, floodplains and equilibrium conditions. In many cases, passive restoration projects may require varying degrees of active measures to achieve ideal results. Riparian buffer re-vegetation and long-term protection of a river corridor (e.g., corridor easements) is essential to this alternative.

Conservation is an option to consider when stream conditions are generally "good" or "reference" and the channel is in a state of dynamic equilibrium. Typically, conservation is applied to minimally disturbed reaches where river structure and function and vegetation associations are relatively intact, and/or where high quality aquatic habitat is found.

3.0 Phase 1 Results

3.1 Reach Delineations

The 106 miles of surface waters within the Williams River watershed were divided into 105 reaches during the SGAT analysis carried out by FEA. Reach divisions were based on changes in valley geometry, channel slope, and the size and influence of tributaries entering the mainstem channel (VTDEC, 2009). The Williams River mainstem, Middle Branch, South Branch, twelve (12) tributaries and two sub-tributaries were included in the SGAT analysis. Table 3.1 summarizes data for the study watersheds.

Table 3.1: Tributary and sub-tributary summary data

DMS ID	Name	Watershed Area (square miles)	Assessed River Length (mi)	Number of Assessed Reaches
M	Williams River	117.0	27.3	26
T1	1st Unnamed Tributary	3.3	3.4	5
T2	Wright Brook	2.5	3.5	4
T3	2nd Unnamed Tributary	3.4	3.3	5
T4	Hall Brook	8.9	6.0	4
T5	Middle Branch	48.1	14.2	11
T5.S1	South Branch	10.9	11.6	12
T5.S2	Lover's Lane Brook	3.6	5.7	4
T5.S3	Andover Branch	12.7	7.0	7
T5.S3.a	Potash Brook	3.8	3.4	3
T5.S3.b	Trout Brook	2.2	2.9	3

Table 3.1: Tributary and sub-tributary summary data

DMS ID	Name	Watershed Area (square miles)	Assessed River Length (mi)	Number of Assessed Reaches
T5.S4	Lyman Brook	4.2	3.7	5
T6	Third Unnamed Tributary	2.6	4.0	4
T7	Trebo Brook	1.8	3.3	4
T8	Whitmore Brook	2.4	2.9	4
T9	Fourth Unnamed Tributary	1.0	2.0	2
T10	Wheaton Brook	1.0	1.6	2

3.2 Reference Stream Types

Windshield survey measurements and observations as well as remotely collected data of valley confinement, channel slope, and sinuosity were used to develop reference stream types for the assessed reaches according to the Rosgen (1994) and Montgomery and Buffington (1997) classification systems. Characterization of reference stream types is based on the channel forms and processes we would expect in a particular geologic and geomorphic setting without human influences. Table 3.2 presents general valley and channel characteristics associated with reference stream types found in the Williams River and tributary watersheds. Table 3.3 describes the reference stream conditions for each study reach.

Table 3.2: Reference stream type characteristics

Stream Type	Valley Confinement	Channel Slope	Sinuosity	Bedform	Number of Study Reaches*
A	Confined	> 4%	Low	Cascade or Step-pool	21 (20%)
B	Confined	2 – 4%	Low	Step-pool or Plane bed	32 (30%)
C	Unconfined	< 2%	Moderate	Riffle Pool	50 (48%)
D	Unconfined	<4%	Variable	Variable	1 (1%)
E	Unconfined	<2%	Highly	Dune Ripple	1 (1%)

* Number of reaches and percentage of total reaches represented by type.

Table 3.3: Reach and watershed characteristics

Surface Water	Reach ID	Watershed Area (Mi^2)	Channel Length (Mi)	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type*	Reference Stream Type†	Bedform‡
Williams River	M01	117.0	0.68	106.5	0.01	1.00	VB	D5	Braided
	M02	116.3	0.54	106.2	0.19	1.00	BD	C4	Riffle-Pool
	M03	115.2	0.77	105.8	0.25	1.01	SC	B4	Riffle-Pool
	M04	111.7	1.55	104.3	0.34	1.02	SC	B4	Riffle-Pool
	M05	106.5	0.92	102.2	1.03	1.06	SC	B4	Riffle-Pool
	M06	102.4	0.20	100.4	3.99	1.05	NC	A1	Cascade
	M07	102.0	0.79	100.2	0.84	1.05	SC	B4	Riffle-Pool
	M08	101.1	1.20	99.9	0.04	1.21	VB	C4	Riffle-Pool
	M09	95.9	0.91	97.5	0.47	1.02	NW	C4	Riffle-Pool
	M10	92.3	1.14	95.9	0.49	1.07	BD	C4	Riffle-Pool
	M11	80.9	2.13	90.5	0.42	1.15	VB	C4	Riffle-Pool
	M12	30.7	1.30	59.1	0.38	1.18	VB	C4	Riffle-Pool
	M13	24.5	2.47	53.5	0.46	1.11	VB	C4	Riffle-Pool
	M14	20.6	1.69	49.6	0.62	1.09	VB	C4	Riffle-Pool
	M15	18.1	0.54	46.9	0.92	1.00	BD	C4	Riffle-Pool
	M16	17.9	0.51	46.6	1.39	1.04	NW	B4	Riffle-Pool
	M17	17.0	0.85	45.6	0.96	1.07	VB	C4	Riffle-Pool
	M18	15.1	0.36	43.2	1.20	1.01	VB	C4	Riffle-Pool
	M19	15.0	1.96	43.1	1.82	1.03	NW	C3	Riffle-Pool
	M20	10.1	1.25	36.2	1.71	1.03	BD	B4	Riffle-Pool
	M21	8.6	1.38	33.8	2.02	1.02	BD	B3	Riffle-Pool
	M22	5.7	0.54	28.2	2.52	1.09	BD	C3	Riffle-Pool
	M23	3.9	1.39	23.9	3.39	1.11	SC	B3	Step-Pool
	M24	2.6	0.27	20.0	4.76	1.07	SC	A3	Step-Pool
	M25	1.8	0.65	17.0	5.40	1.07	SC	A3	Step-Pool
	M26	1.0	1.27	13.0	11.27	1.06	SC	A2	Cascade
1st Unnamed Tributary	T1.01	3.2	0.53	22.0	8.08	1.00	SC	A2	Step-Pool
	T1.02	2.5	1.31	19.6	1.09	1.18	VB	C4	Riffle-Pool
	T1.03	1.1	0.44	13.6	6.93	1.11	SC	A3	Step-Pool
	T1.04	0.9	0.41	12.5	2.43	1.17	VB	C4	Riffle-Pool
	T1.05	0.2	0.70	6.9	13.04	1.03	SC	A1	Cascade
Wright Brook	T2.01	2.5	0.38	19.7	0.75	1.22	SC	B3	Riffle-Pool
	T2.02	2.4	1.02	19.3	3.07	1.17	SC	A3	Riffle-Pool
	T2.03	1.9	0.59	17.4	1.05	1.11	VB	C4	Riffle-Pool
	T2.04	1.3	1.51	14.5	1.68	1.08	NW	B3	Riffle-Pool
2nd Unnamed Tributary	T3.01	3.4	0.54	22.3	3.72	1.07	VB	C4	Step-Pool
	T3.02	3.1	0.62	21.6	2.27	1.04	VB	C4	Riffle-Pool
	T3.03	1.9	0.64	17.6	3.14	1.00	SC	B3	Riffle-Pool
	T3.04	1.2	0.54	14.3	1.69	1.09	SC	B4	Riffle-Pool
	T3.05	0.5	0.99	9.7	7.62	1.04	NW	B3	Step-Pool
Hall Brook	T4.01	8.9	1.39	34.2	2.38	1.04	VB	C4	Riffle-Pool
	T4.02	7.5	1.59	31.7	2.08	1.06	SC	A3	Riffle-Pool
	T4.03	3.3	2.04	22.3	2.84	1.08	NW	B3	Riffle-Pool
	T4.04	0.7	0.94	11.3	3.53	1.08	BD	C4	Step-Pool
Middle Branch Williams River	T5.01	48.1	0.48	72.0	0.79	1.08	BD	C4	Riffle-Pool
	T5.02	33.5	1.59	61.4	0.92	1.01	NW	B3	Riffle-Pool
	T5.03	32.2	1.74	60.4	1.29	1.03	VB	C3	Riffle-Pool
	T5.04	28.3	1.01	57.0	1.30	1.07	VB	C4	Riffle-Pool
	T5.05	14.7	1.30	42.8	1.50	1.09	VB	C4	Riffle-Pool
	T5.06	13.7	1.52	41.5	1.47	1.12	BD	C3	Riffle-Pool

Table 3.3: Reach and watershed characteristics

Surface Water	Reach ID	Watershed Area (Mi^2)	Channel Length (Mi)	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type*	Reference Stream Type†	Bedform‡
South Branch Williams River	T5.07	12.2	0.92	39.3	2.16	1.06	VB	C4	Riffle-Pool
	T5.08	5.7	1.20	28.2	1.89	1.12	VB	C3	Riffle-Pool
	T5.09	4.6	1.00	25.6	1.99	1.17	VB	B4	Riffle-Pool
	T5.10	3.5	1.62	22.7	1.23	1.22	VB	C4	Riffle-Pool
	T5.11	1.5	1.81	15.7	8.40	1.09	BD	B4	Step-Pool
	T5.S1.01	10.9	0.32	37.5	1.50	1.02	VB	C4	Riffle-Pool
	T5.S1.02	10.8	1.43	37.3	2.11	1.07	SC	A3	Riffle-Pool
	T5.S1.03	9.8	0.79	35.7	2.50	1.05	VB	C4	Step-Pool
	T5.S1.04	9.3	0.89	35.0	1.26	1.07	BD	C4	Riffle-Pool
	T5.S1.05	8.7	0.50	33.9	1.68	1.03	NW	B3	Riffle-Pool
	T5.S1.06	8.2	0.67	33.1	1.68	1.14	VB	C4	Riffle-Pool
	T5.S1.07	7.0	1.54	30.9	3.15	1.16	NW	B3	Step-Pool
	T5.S1.08	5.4	0.89	27.5	3.11	1.07	VB	C3	Step-Pool
	T5.S1.09	3.9	0.95	23.8	2.19	1.17	BD	B4	Plane Bed
	T5.S1.10	2.6	0.75	19.9	1.79	1.10	BD	B3	Riffle-Pool
	T5.S1.11	1.8	1.70	17.1	0.91	1.19	VB	C4	Dune-Ripple
	T5.S1.12	0.3	1.15	7.4	4.75	1.07	VB	C3	Step-Pool
Lover's Lane Brook	T5.S2.01	3.6	1.85	23.0	0.79	1.16	VB	E5	Riffle-Pool
	T5.S2.02	3.1	1.64	21.6	2.42	1.03	SC	B3	Riffle-Pool
	T5.S2.03	1.9	1.79	17.5	5.49	1.08	VB	C4	Step-Pool
	T5.S2.04	0.1	0.45	5.7	17.27	1.06	BD	C4	Cascade
Andover Branch	T5.S3.01	12.7	1.08	40.1	1.54	1.18	SC	B3	Riffle-Pool
	T5.S3.02	8.3	1.19	33.3	1.93	1.09	SC	A2	Plane Bed
	T5.S3.03	7.7	1.00	32.1	1.81	1.18	VB	C3	Riffle-Pool
	T5.S3.04	5.9	0.89	28.6	1.59	1.06	BD	B3	Riffle-Pool
	T5.S3.05	2.9	0.80	21.0	1.64	1.05	BD	C4	Riffle-Pool
	T5.S3.06	2.5	0.67	19.5	3.00	1.01	BD	C4	Plane Bed
	T5.S3.07	0.7	1.34	11.2	7.03	1.02	VB	C4	Step-Pool
Potash Brook	T5.S3.a.01	3.8	1.17	23.4	3.62	1.04	SC	B4	Step-Pool
	T5.S3.a.02	1.7	1.21	16.6	5.22	1.00	SC	A3	Step-Pool
	T5.S3.a.03	0.5	0.97	10.0	8.04	1.03	BD	B3	Cascade
Trout Brook	T5.S3.b.01	2.2	0.77	18.5	5.19	1.00	SC	A3	Step-Pool
	T5.S3.b.02	1.6	1.17	16.3	5.00	1.00	SC	A2	Step-Pool
	T5.S3.b.03	0.9	0.94	12.7	10.63	1.04	SC	B3	Step-Pool
Lyman Brook	T5.S4.01	4.2	1.00	24.7	2.73	1.08	SC	A3	Step-Pool
	T5.S4.02	3.3	0.91	22.2	1.88	1.17	SC	A3	Riffle-Pool
	T5.S4.03	0.9	0.84	12.7	4.47	1.11	NW	B3	Step-Pool
	T5.S4.04	0.8	0.68	11.6	1.48	1.18	VB	C4	Riffle-Pool
	T5.S4.05	0.3	0.30	7.8	7.85	1.05	SC	A3	Step-Pool
Third Unnamed Tributary	T6.01	2.6	1.02	19.8	2.34	1.08	VB	C4	Riffle-Pool
	T6.02	1.9	1.08	17.4	2.29	1.04	NW	A3	Riffle-Pool
	T6.03	1.1	0.46	13.9	3.08	1.05	VB	C4	Plane Bed
	T6.04	1.0	1.42	13.2	2.56	1.07	NW	B4	Plane Bed
Trebo Brook	T7.01	1.8	0.78	17.1	1.58	1.12	NW	B3	Riffle-Pool
	T7.02	1.5	1.12	15.8	2.54	1.10	NW	B3	Riffle-Pool
	T7.03	0.9	0.64	12.3	4.74	1.02	VB	C4	Step-Pool
	T7.04	0.4	0.78	8.8	2.69	1.06	NW	B4	Plane Bed
Whitmore Brook	T8.01	2.4	0.38	19.1	1.91	1.24	SC	A3	Riffle-Pool
	T8.02	2.3	0.76	18.8	3.85	1.02	NW	B4	Step-Pool
	T8.03	1.5	0.42	15.8	7.75	1.00	VB	C3	Cascade

Table 3.3: Reach and watershed characteristics

Surface Water	Reach ID	Watershed Area (Mi^2)	Channel Length (Mi)	Channel Width (ft)	Channel Slope (%)	Sinuosity	Valley Type*	Reference Stream Type†	Bedform‡
Fourth Unnamed Tributary	T8.04	1.3	1.34	14.5	8.10	1.03	SC	B3	Cascade
	T9.01	1.0	0.69	13.3	0.66	1.06	SC	A3	Riffle-Pool
	T9.02	0.7	1.33	10.9	3.18	1.04	SC	A2	Riffle-Pool
Wheaton Brook	T10.01	1.0	0.59	13.1	3.31	1.02	VB	C4	Plane Bed
	T10.02	0.8	0.97	11.8	4.76	1.03	SC	B4	Step-Pool

* NC= Narrowly-confined; SC= Semi-confined; NW= Narrow; BD=Broad; VB=Very Broad † per Rosgen, 1994
‡ per Montgomery and Buffington, 1997

Figure 3.1 presents the location of the reference stream types developed for the Williams River watershed. C-type and B-type reaches are most common in the watershed under reference conditions (45% and 33% respectively). C-type streams are typically characterized by a moderately sinuous channel found in a broad, unconfined valley setting with a balance between the upslope sediment supply and the transport capacity. B-type streams are typically characterized by a low to moderately sinuous channel in a confined valley that is dominated by sediment transport processes. Twenty-one (21) reaches were characterized as A-type. These reaches are typically found in the steep headwater areas. One reach (M01) was characterized as D-type, this reach is very wide and braided through a delta at the mouth of the river. One reach (T5.S1.11) was characterized as E-type. E-type reaches are typically found in broad valleys with low slope and depositional environments. Data from the reaches covered in the full Phase 1 analysis are shown in Table 3.3. Outside of the headwater areas; channel slope is relatively consistent through most of the study area, therefore reference stream type is primarily influenced by confinement. C-type reaches typically have broad and very broad confinement, and B-type reaches are typically found in semi-confined or narrow valleys. A-type reaches were found in upper headwater areas on several of the tributaries and the mainstem.

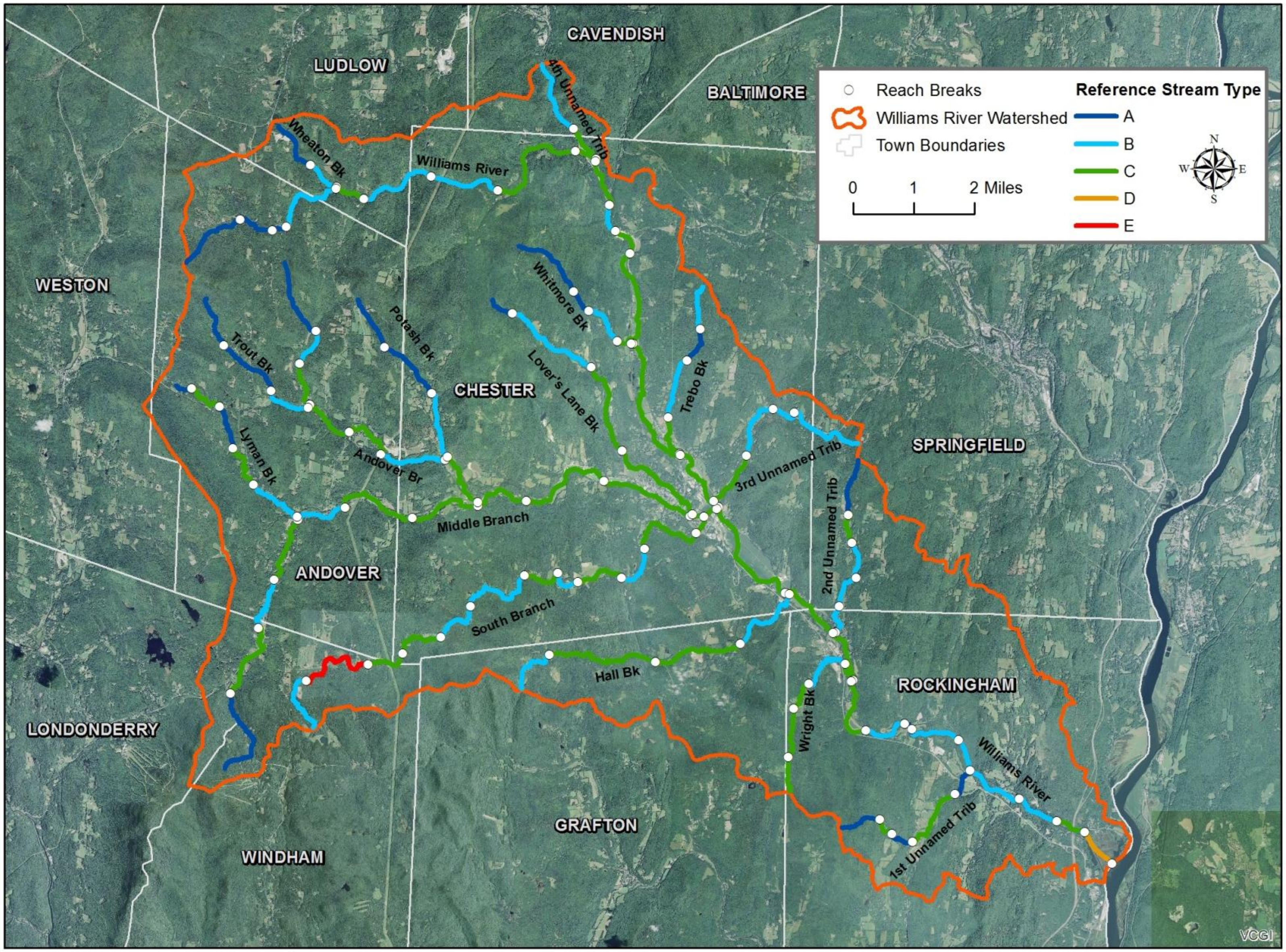


Figure 3.1: Reference stream types per Rosgen (1994) for the Williams River watershed

3.3 Phase 1 Impacts Summary

Based on the Phase 1 impact scores, the DMS also develops predictions for channel adjustment processes (VTDEC, 2009). These predictions are based on the dominant impacts recorded for each reach, and are categorized based on the impacts typically associated with the following four channel adjustment processes: 1) Degradation (e.g., channel incision); 2) Aggradation (e.g., increased sediment deposition); 3) Channel widening (e.g., increased bank erosion); 4) Planform Changes (e.g., irregular meander patterns) (Table 3.4 and Figure 3.2). Using the channel adjustment process ratings, a provisional geomorphic rating is developed for each reach based on the methods outlined in the SGA Phase 1 protocols (VTDEC, 2009). Table 3.5 outlines the four possible geomorphic ratings based on the SGA methods, and Figure 3.5 presents the provisional geomorphic condition for all study reaches.

Table 3.4: Final Impact Score Parameters for Phase 1 Dataset

Phase 1 Step	Phase 1 Parameter	Impact Category
4.1	Local Watershed Land Cover/Land Use	Land Use
4.2	Corridor Watershed Land Cover/Land Use	
4.3	Riparian Buffer Width	
5.1	Flow Regulations	Channel Modifications
5.2	Bridges and Culverts	
5.3	Bank Armoring	
5.4	Channel Straightening	
5.5	Dredging and Gravel Mining	
6.1	River Corridor Encroachments	Floodplain Modifications and Planform Changes
6.2	River Corridor Development	
6.3	Depositional Features	
6.4	Meander Migration	
6.5	Meander Belt Width Departure	
6.6	Meander Wavelength Departure	
7.2	Bank Erosion	Bed and Bank Conditions
7.3	Debris and Ice Jam Potential	

In the Williams River watershed, the most pervasive impacts mapped during Phase 1 assessment were river corridor and floodplain encroachments (Figure 3.3), and riparian buffer degradation (Figure 3.4). These are commonly the most widespread impacts in rural Vermont watersheds due to the presence of roadways along river networks and development and agricultural land uses found along the flat river valleys.

Table 3.5: SGA Reach Condition Ratings.

SGA Rating	Predicted Conditions and Processes
Reference	In Equilibrium – no apparent or significant channel, floodplain, or land cover modifications; channel geometry is likely to be in balance with the flow and sediment produced in its watershed.
Good	In Equilibrium but may be in transition into or out of the range of natural variability – minor erosion or lateral adjustment but adequate floodplain function; any adjustment from historic modifications nearly complete.
Fair	In Adjustment – moderate loss of floodplain function; or moderate to major planform adjustments that could lead to channel avulsions.
Poor	In Adjustment and Stream Type Departure - may have changed to a new stream type or central tendency of fluvial processes – significant channel and floodplain modifications may have altered the channel geometry such that the stream is not in balance with the flow and sediment produced in its watershed.

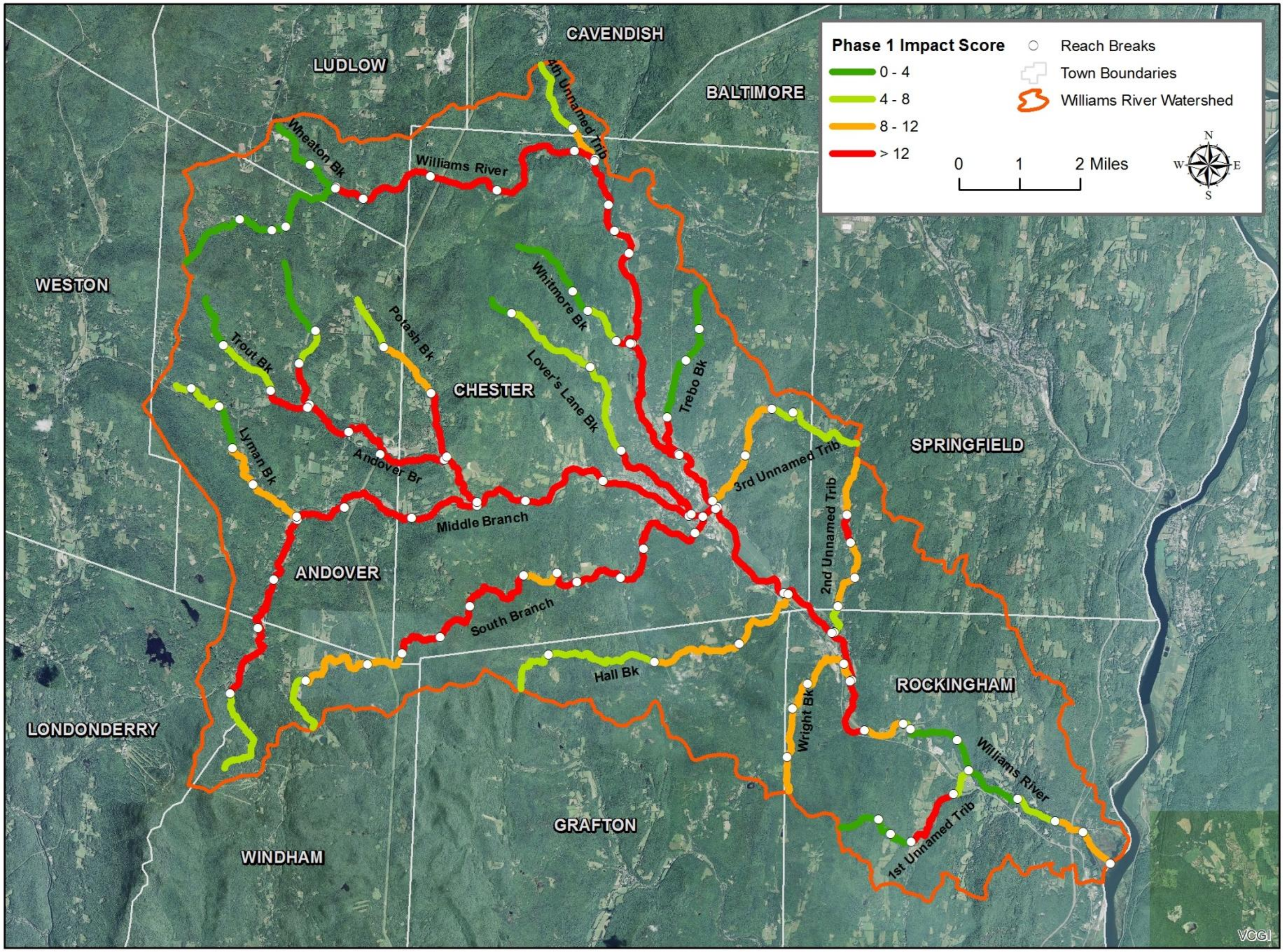


Figure 3.2: Phase 1 impact scores for the Williams River watershed.

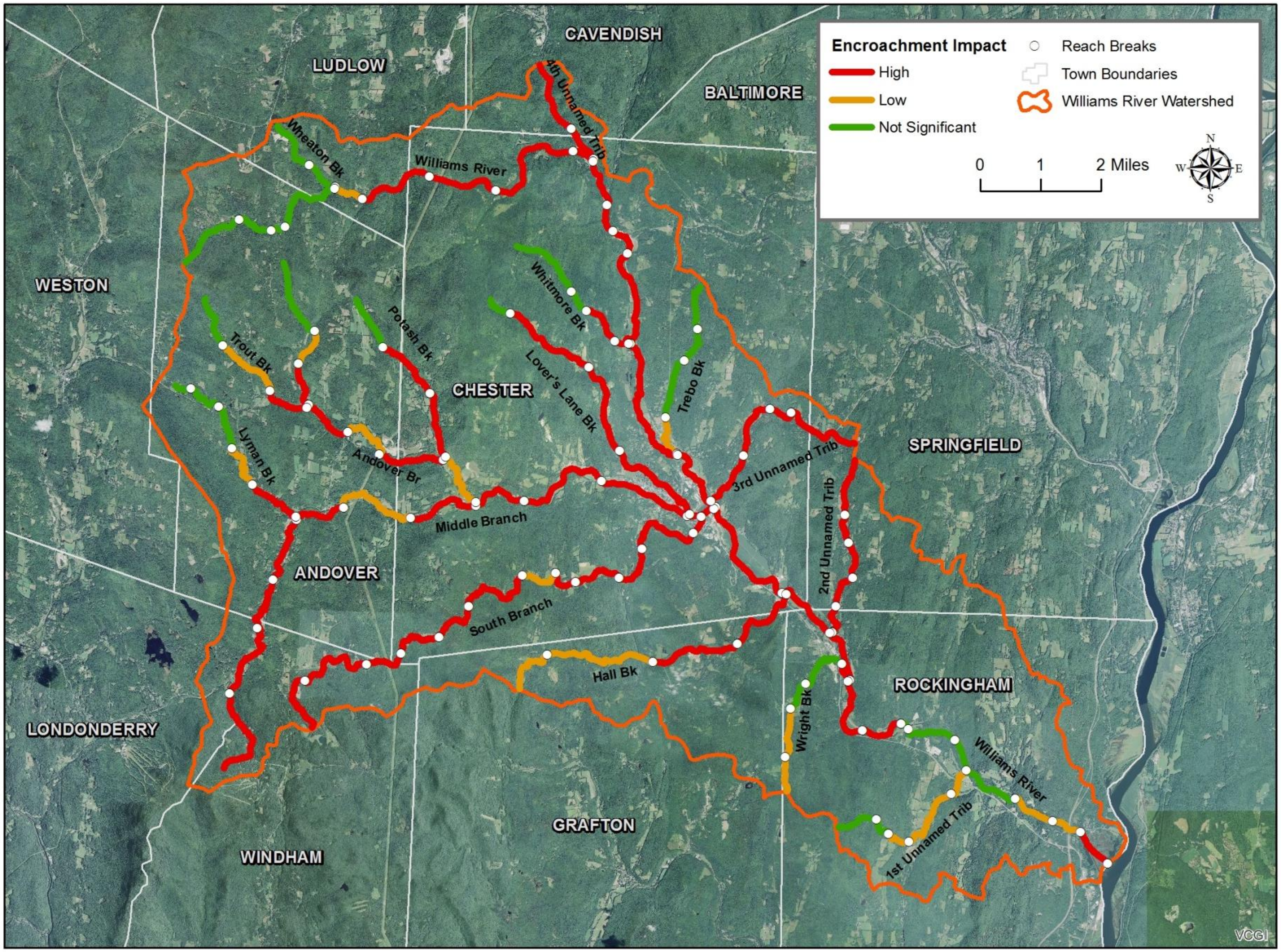


Figure 3.3: Phase 1 encroachment impacts for the WIlliams River watershed.

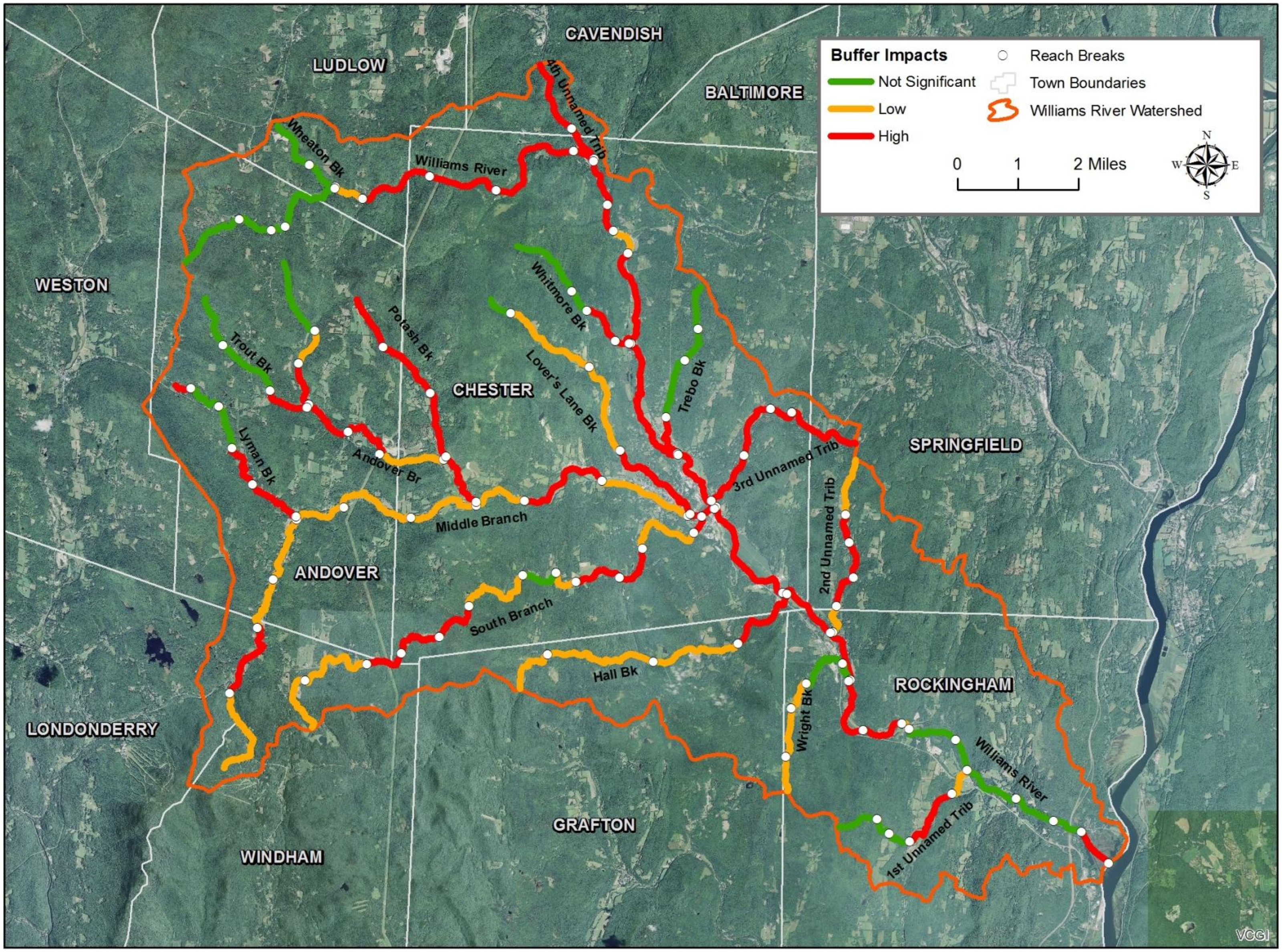


Figure 3.4: Phase 1 buffer impacts for the Williams River watershed.

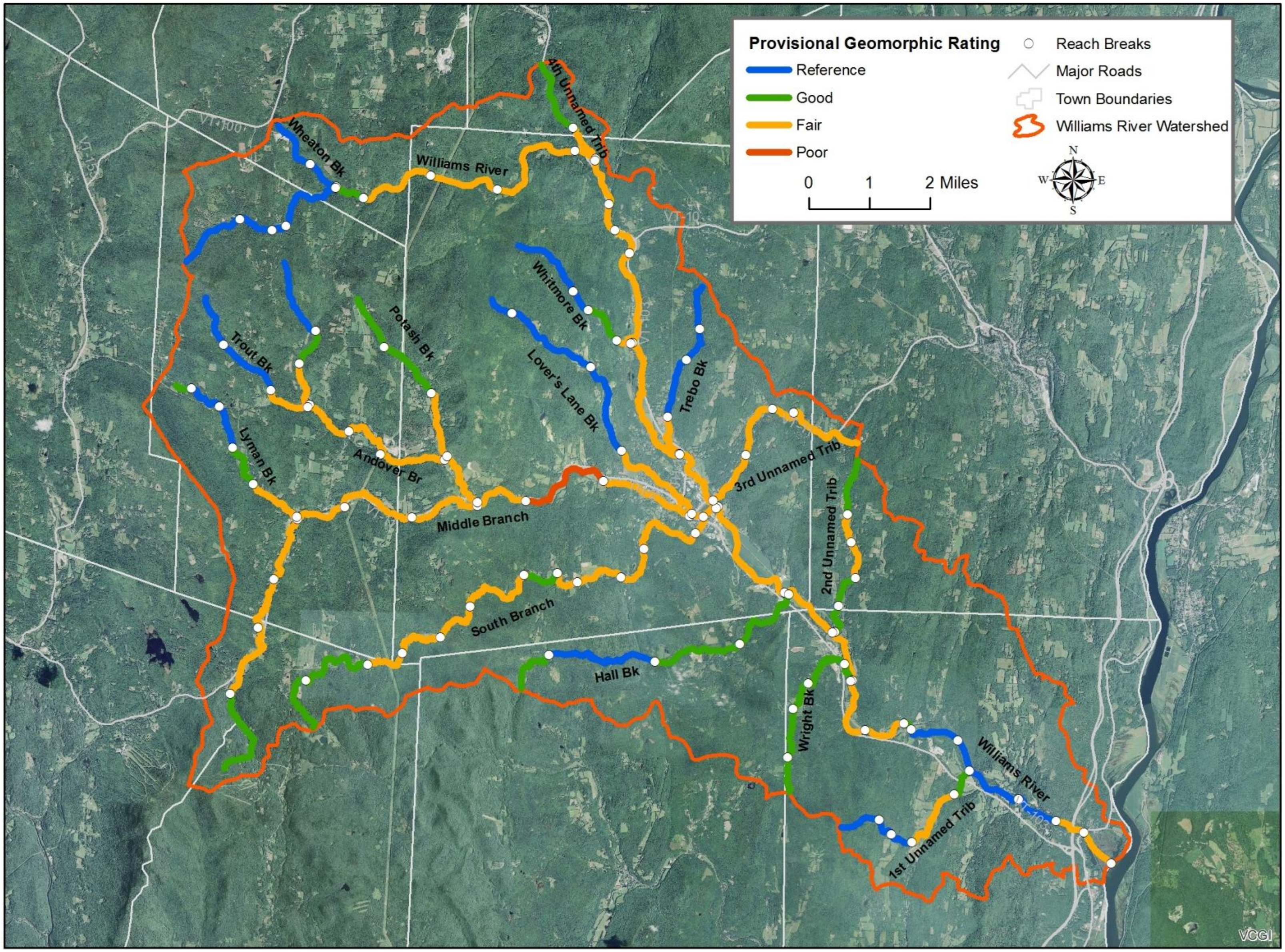


Figure 3.5: Provisional geomorphic ratings for the Williams River watershed.

3.4 Phase 2 Reach Recommendations

Using the Phase 1 Impact Ratings as the primary basis for reach selection, a list of reaches was developed for Phase 2 surveys within the Williams River watershed. Table 3.6 and Figure 3.6 summarize and display the 44 selected reaches covering approximately 47 miles based on watershed location, channel length, channel slope, valley type, and preliminary reference stream type.

Table 3.6: Phase 2 reach selection and Phase 1 impact ratings

Surface Water	Reach ID	Channel Length (Mi)	Channel Slope (%)	Valley Type*	Reference Stream Type†	Bedform‡	Impact Score (Geo Condition)
Williams River	M07	0.79	0.84	SC	B4	Riffle-Pool	12 (Fair)
	M08	1.20	0.04	VB	C4	Riffle-Pool	21 (Fair)
	M09	0.91	0.47	NW	C4	Riffle-Pool	21 (Fair)
	M10	1.14	0.49	BD	C4	Riffle-Pool	22 (Fair)
	M11	2.13	0.42	VB	C4	Riffle-Pool	24 (Fair)
	M12	1.30	0.38	VB	C4	Riffle-Pool	20 (Fair)
	M13	2.47	0.46	VB	C4	Riffle-Pool	18 (Fair)
	M14	1.69	0.62	VB	C4	Riffle-Pool	19 (Fair)
	M15	0.54	0.92	BD	C4	Riffle-Pool	19 (Fair)
	M16	0.51	1.39	NW	B4	Riffle-Pool	18 (Fair)
	M17	0.85	0.96	VB	C4	Riffle-Pool	22 (Fair)
	M18	0.36	1.20	VB	C4	Riffle-Pool	22 (Fair)
	M19	1.96	1.82	NW	C3	Riffle-Pool	17 (Fair)
	M20	1.25	1.71	BD	B4	Riffle-Pool	13 (Fair)
	M21	1.38	2.02	BD	B3	Riffle-Pool	20 (Fair)
	M22	0.54	2.52	BD	C3	Riffle-Pool	14 (Good)
Middle Branch	T5.01	0.48	0.79	BD	C4	Riffle-Pool	21 (Fair)
	T5.02	1.59	0.92	NW	B3	Riffle-Pool	21 (Fair)
	T5.03	1.74	1.29	VB	C3	Riffle-Pool	24 (Poor)
	T5.04	1.01	1.30	VB	C4	Riffle-Pool	17 (Fair)
	T5.05	1.30	1.50	VB	C4	Riffle-Pool	19 (Fair)
	T5.06	1.52	1.47	BD	C3	Riffle-Pool	16 (Fair)
	T5.07	0.92	2.16	VB	C4	Riffle-Pool	18 (Fair)
	T5.08	1.20	1.89	VB	C3	Riffle-Pool	22 (Fair)
	T5.09	1.00	1.99	VB	B4	Riffle-Pool	18 (Fair)
South Branch	T5.S1.01	0.32	1.50	VB	C4	Riffle-Pool	20 (Fair)
	T5.S1.02	1.43	2.11	SC	A3	Riffle-Pool	20 (Fair)
	T5.S1.03	0.79	2.50	VB	C4	Step-Pool	13 (Fair)
	T5.S1.04	0.89	1.26	BD	C4	Riffle-Pool	20 (Fair)
	T5.S1.05	0.50	1.68	NW	B3	Riffle-Pool	19 (Fair)
	T5.S1.06	0.67	1.68	VB	C4	Riffle-Pool	12 (Good)
	T5.S1.07	1.54	3.15	NW	B3	Step-Pool	17 (Fair)
	T5.S1.08	0.89	3.11	VB	C3	Step-Pool	17 (Fair)

Table 3.6: Phase 2 reach selection and Phase 1 impact ratings

Surface Water	Reach ID	Channel Length (Mi)	Channel Slope (%)	Valley Type*	Reference Stream Type†	Bedform‡	Impact Score (Geo Condition)
	T5.S1.09	0.95	2.19	BD	B4	Plane Bed	16 (Fair)
Lover's Lane Bk	T5.S2.01	1.85	0.79	VB	E5	Riffle-Pool	17 (Fair)
Andover Branch	T5.S3.01	1.08	1.54	SC	B3	Riffle-Pool	19 (Fair)
	T5.S3.02	1.19	1.93	SC	A2	Plane Bed	20 (Fair)
	T5.S3.03	1.00	1.81	VB	C3	Riffle-Pool	18 (Fair)
	T5.S3.04	0.89	1.59	BD	B3	Riffle-Pool	22 (Fair)
	T5.S3.05	0.80	1.64	BD	C4	Riffle-Pool	21 (Fair)
Potash Brook	T5.S3.a.01	1.17	3.62	SC	B4	Step-Pool	17 (Fair)
Trout Brook	T5.S3.b.01	0.77	5.19	SC	A3	Step-Pool	19 (Fair)
Trebo Brook	T7.01	0.78	1.58	NW	B3	Riffle-Pool	15 (Fair)
Whitmore Brook	T8.01	0.38	1.91	SC	A3	Riffle-Pool	19 (Fair)

* SC= Semi-confined; NW= Narrow; BD=Broad; VB=Very Broad, NC=No Confinement; † per Rosgen, 1994

‡ per Montgomery and Buffington, 1997

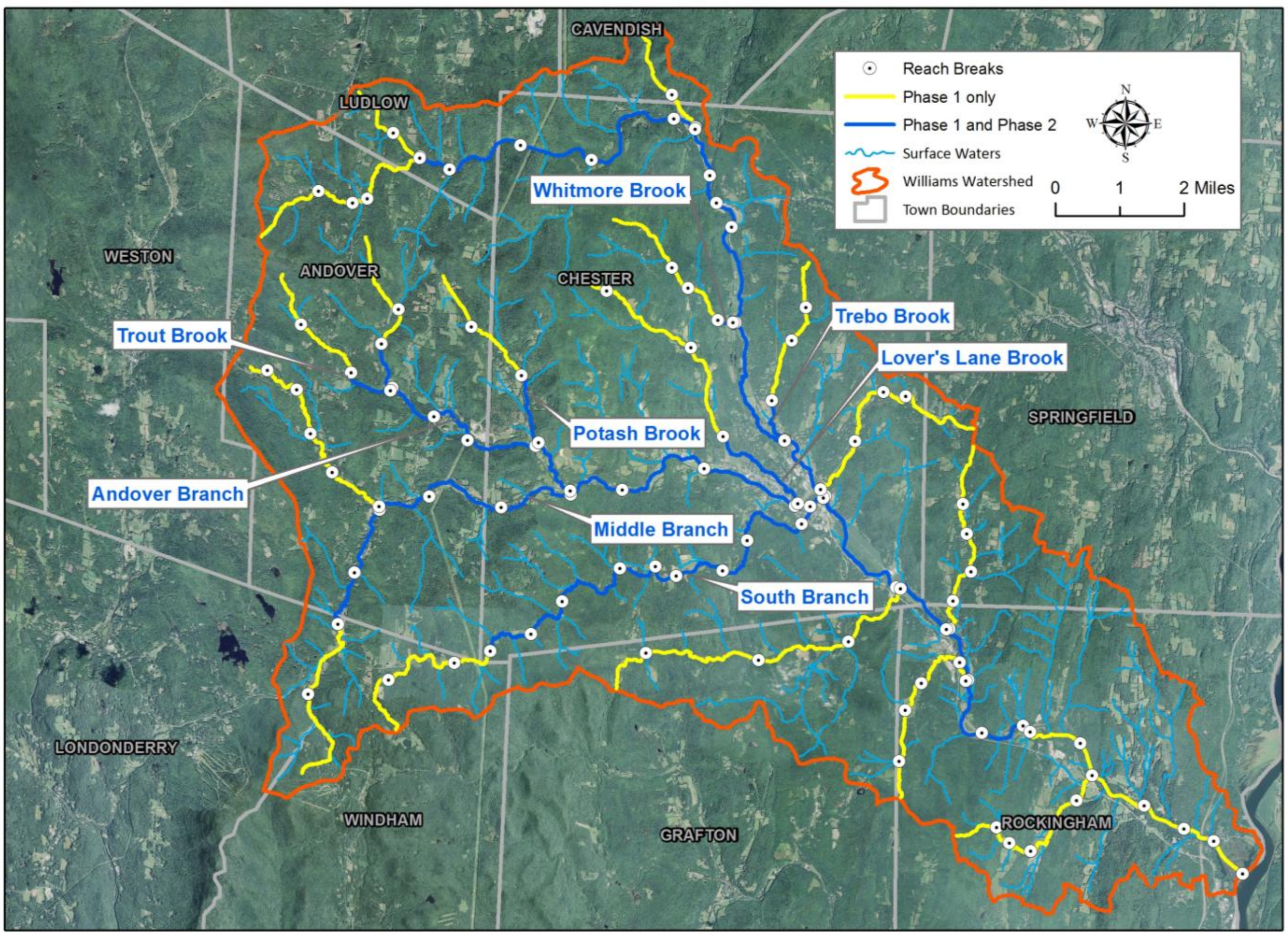


Figure 3.6: Phase 2 reach selection for the Williams River watershed.

4.0 Phase 2 Results and River Corridor Planning

Phase 2 assessments were conducted on the 44 selected reaches during the summer and fall of 2014 and 2015. Eleven (11) reaches were segmented including four (4) with multiple segments, for a total of 59 reaches and segments covering 47 miles (Figures 4.1-4.3). Three (3) segments were not fully assessed due to a large dam (M07.A), impoundment from beaver dams (T7.01.A), and property access (T5.05.C).

4.1 Phase 2 Segment Summary Sheets

One page summaries for each Phase 2 segment/reach are presented in this section. The impact summary section includes color-coded designations of Not Significant, **Low**, or **High** levels of impact based on data collected during the Phase 2 assessments. Impact levels were assigned based on the longitudinal effect (<5% - Not Significant, 5-20% - Low, and >20% - High), and the overall impact of discrete features on the reach/segment (constrictions, stormwater inputs, steep riffles, etc.). Based on our professional judgment; potential impacts for bridges (B), culverts (C), and other (O) constrictions were summarized with the following abbreviations:

- **AOP**: Aquatic organism passage
- **D**: Deposition upstream and/or downstream
- **E**: Bank erosion upstream and/or downstream
- **I**: Ice/Debris jamming
- **R/R**: Failing bank armor upstream and/or downstream
- **S**: Scour upstream and/or downstream

Incision Ratio and Entrenchment Ratios are important indicators of the degree of stream departure from reference condition. Incision ratio describes the degree of floodplain accessibility: values close to 1.0 represent reference conditions with an accessible floodplain, values greater than 2.0 indicate an extreme disconnection of floodplain typically associated with a stream type departure. Entrenchment ratio describes the width of the floodprone area in relation to the bankfull channel width. Reference entrenchment ratios vary with stream type and valley setting. Stream impacts such as encroachment, incision, widening, and straightening may all lower the entrenchment ratio. C-type streams typically have entrenchment ratios greater than 2.0 and values below 2.0 or 1.4 represent stream type departures to B or F-type respectively. Definitions for technical terminology within the summary sheets are provided in the Glossary of Terms in Section 8.0.

Habitat assessment rankings for large woody debris and pool counts (measured in reference to predicted bankfull width - wbkf) are defined in Table 4.1.

Table 4.1: LWD and Pool Ranking for RHA.

Rank	LWD		Pool	
	Diameter (ft)	Length (relative to wbkf)	Depth (ft)	Length/Width (relative to wbkf)
1	0.5≤D<1.0	<0.5	1.0≤D<2.0	<0.5
2	0.5≤D<1.0	≥0.5	1.0≤D<2.0	≥0.5
3	1.0≤D<2.0	<0.5	2.0≤D<3.0	<0.5
4	1.0≤D<2.0	≥0.5	2.0≤D<3.0	≥0.5
5	D≥2.0	<0.5	D≥3.0	<0.5
6	D≥2.0	≥0.5	D≥3.0	≥0.5
7	--	--	D≥3.0	≥1.0

4.1.1 Lower Mainstem of the Williams River and Trebo Brook Phase 2 Assessment Summary

The Phase 2 assessed reaches/segments on the lower mainstem of the Williams River and Trebo brook include 7 reaches and a total of 10 segments, which flow through the towns of Rockingham, Chester, and a small portion of Springfield.

- Williams River (M07.A – M12)
  - Encroachment, historic straightening, and armoring were present along most of these segments and resulted in many stream type departures and areas of moderate to high incision.
  - Despite these historic alterations some segments maintained elevated floodplains that were accessed in T.S. Irene. The floodplain in segment M08.B remains easily accessible due to major aggradation within the segment, which has resulted in planform adjustment.
  - Channel beds have minimal features and are lacking in stream woody debris.
  - The Phase 2 assessment began upstream of Brockway Mills Dam; Segment M07-A was not assessed due to the impoundment extending upstream from the dam

- Trebo Brook (T7.01.A-T7.01.B)
  - Segment A was not assessed since it was heavily influenced by a beaver complex. Segment B is deeply incised from historic straightening and bank armor. The bed had no major features and appears to be continuing to incise.

Segment M07. B of the Williams River

Reach M10 of the Williams River

Segment T7.01-B of Trebo Brook

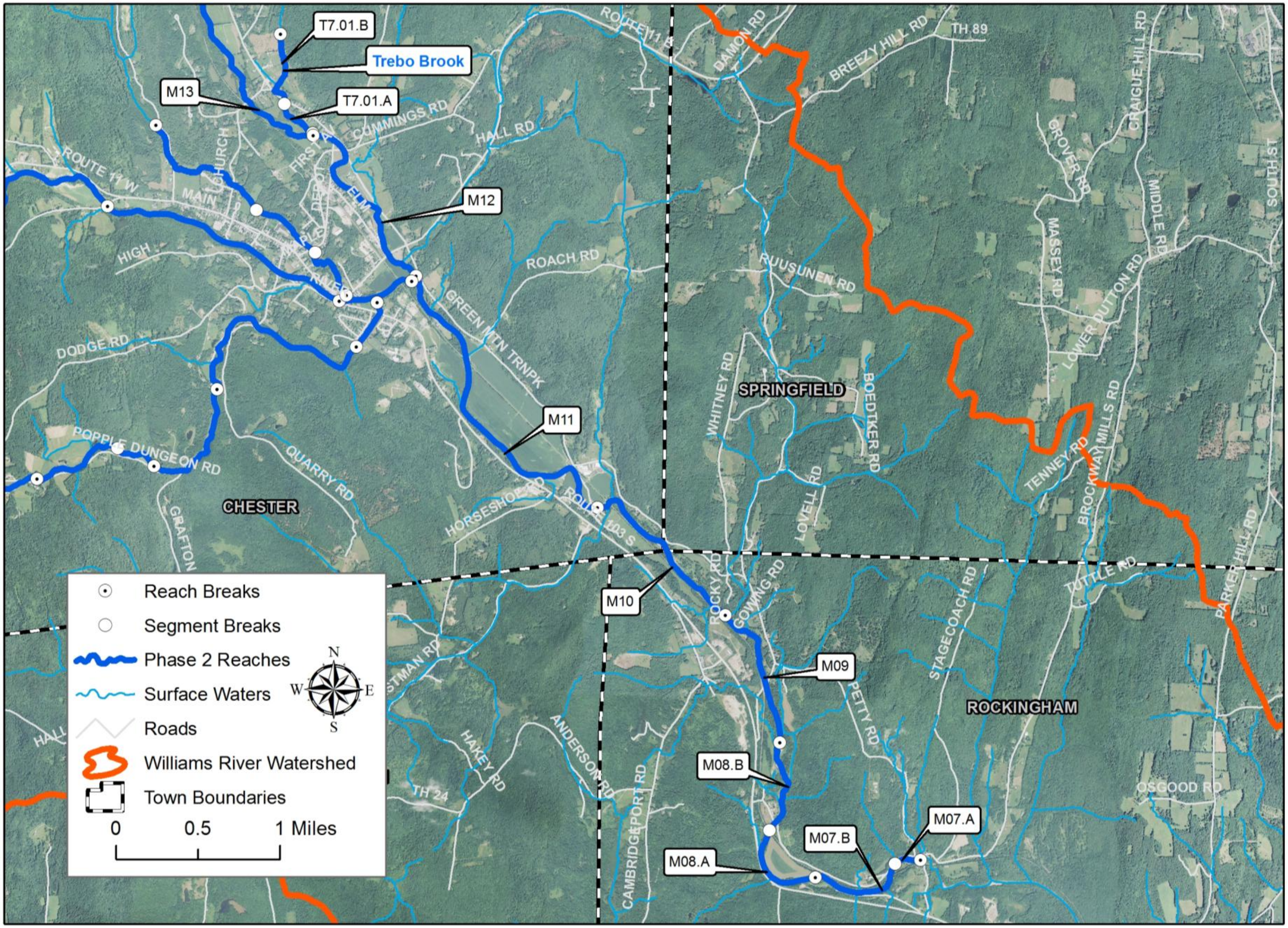


Figure 4.1: Lower Mainstem and Trebo Brook Reach Locator Map

Stream: Williams Mainstem **Reach:** M07.B **Town:** Rockingham **Date Assessed**:8/11/2014

Channel Length (ft): 3,284 **Channel Slope (%):** 0.5 **Sinuosity:** 1.05 **Watershed Area (mi^2):** 101.96

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Semi-Confined	Semi-Confined
Bedform	Riffle Pool	Plane Bed
Median Substrate	Gravel	Gravel
Stream Type	Bc	F

Ph2 Cross-Section Data

Curve Width (ft)	100.2
Bankfull Width (ft)	90
Max Depth (ft)	6.0
Width/Depth Ratio	23
Entrenchment Ratio	1.4
Incision Ratio	2.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	120%	None

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	8	0
2	0	0
3	0	0
4	0	0
5	0	1
6	0	0
7	0	2
#/mile	13	5

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	75/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	35
Dominant Adjustment	Degradation
CEM Model Stage	F II
Stream Type Departure	B to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- LWR-1: Unstable slope leading to a construction site; stabilize and vegetate slope to reduce sediment inputs and protect house

Reach Highlights: This reach lies in a naturally semi-confined valley that is encroached upon by both roads and rail. The channel is deeply incised and likely stuck there from natural and man-made hard banks. Localized areas of aggradation were observed with moderate to heavy scour along most of the banks. Potential for widening and planform adjustment are minimal due to encroachment and bank armoring.

Incised channel

Scour line from recent large storm

Stream: Williams Mainstem **Reach:** M08.A **Town:** Rockingham **Date Assessed:**8/11/2014

Channel Length (ft): 3,136 **Channel Slope (%):** 0.5 **Sinuosity:** 1.21 **Watershed Area (mi^2):** 101.12

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Gravel
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	99.9
Bankfull Width (ft)	67
Max Depth (ft)	5.8
Width/Depth Ratio	15.1
Entrenchment Ratio	1.5
Incision Ratio	2.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	105%	D

# of Other Constrictions: 0
# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	0
2	0	0
3	2	1
4	0	0
5	0	1
6	0	0
7	0	0
#/mile	10	3

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	55/Poor
Habitat Type Departure	Plane Bed
RGA Score / Condition	29/Fair
Dominant Adjustment	Degradation
CEM Model Stage	F/II
Stream Type Departure	C to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- LWR-2a: Buffer Plantings recommended for long-term bank stabilization and corridor protection helping to reduce erosion and further sedimentation in the channel.

Reach Highlights: Currently the channel bed is smooth and relatively featureless. A large hayfield provides some floodplain access in large storm events, though most potential flood plain is disconnected due to extreme incision. Some evidence of aggradation and widening/planform adjustment indicate that this reach may slowly transition out of stage II.

Slumping and eroding banks without a buffer

Banks straightened and armored for long sections

Stream: Williams Mainstem **Reach:** M08.B **Town:** Rockingham **Date Assessed:**8/11/2014

Channel Length (ft): 3,216 **Channel Slope (%):** 0.6 **Sinuosity:** 1.21 **Watershed Area (mi^2):** 100.62

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	99.9
Bankfull Width (ft)	149
Max Depth (ft)	4.3
Width/Depth Ratio	61
Entrenchment Ratio	5.0
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Williams Rd.	65%	S

# of Other Constrictions: 0
# of Grade Controls:0

Rapid Habitat Assessment

Rank	LWD	Pools
1	11	2
2	0	0
3	7	4
4	0	0
5	0	1
6	0	1
7	0	0
#/mile	30	13

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	84/Fair
Habitat Type Departure	None
RGA Score / Condition	31/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	Very High

Impact Summary

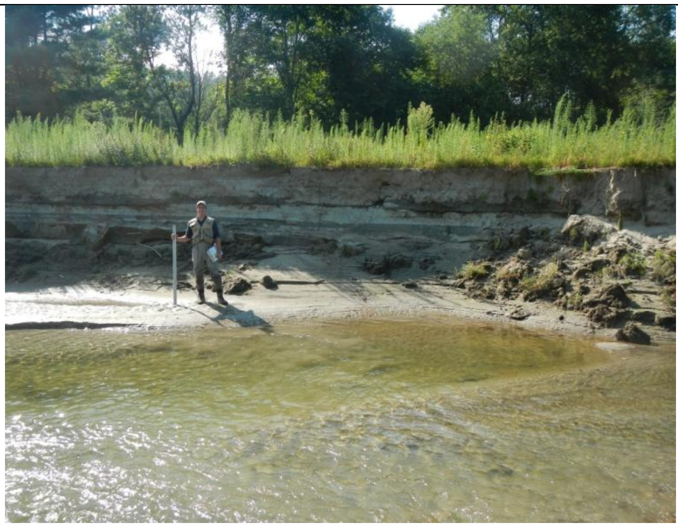
Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- LWR-2b: Buffer Plantings recommended for bank stabilization and corridor protection helping to reduce long-term erosion and further sedimentation in the channel.
- LWR-3: Replace Williams Rd bridge to reduce the current channel constriction.
- LWR-4a: Conserve areas of floodplain critical for continued attenuation of sediment, debris, and floodwaters.

Reach Highlights: During T.S. Irene this segment widened followed by major aggradation and planform adjustment. Large volumes of sediment continue to work through this segment contributing to ongoing meander development. We assessed this reach as Stage IV. The numerous recent and active flood chutes and channel avulsions observed support this designation.

Large depositional features causing planform adjustment



Eroding banks provide a large source of sediment

Stream: Williams Mainstem **Reach:** M09 **Town:** Rockingham **Date Assessed**:8/12/2014

Channel Length (ft): 4,831 **Channel Slope (%):** 0.5 **Sinuosity:** 1.02 **Watershed Area (mi^2):** 95.86

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Gravel
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	97.5
Bankfull Width (ft)	116
Max Depth (ft)	4.0
Width/Depth Ratio	37.9
Entrenchment Ratio	2.2
Incision Ratio	1.8

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Lower Bartonsville Rd.	144%	D

# of Other Constrictions: 0
# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	18	2
2	0	0
3	7	1
4	0	1
5	0	0
6	0	2
7	0	3
#/mile	27	10

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	71/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	31/Fair
Dominant Adjustment	Widening
CEM Model Stage	F/III
Stream Type Departure	C to B
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- LWR-5: Replace bank armor along the railroad making sure to key in at the base of the embankment to discourage undermining by scour.

Reach Highlights: Despite variable confinement, ranging from narrow to semi-confined depending on encroachment, channel dimensions throughout this reach were very consistent. Small areas of floodplain accessible in large events were observed throughout. During T.S. Irene the channel widened wherever possible, and continues to do so in areas without armoring. Large depositional bars are forming as sediment from the flood continues to work through the reach. This reach is assessed as recently transitioned to Stage III.

View of Bartonsville covered bridge

Bedrock outcroppings provided sediment storage

Stream: Williams Mainstem **Reach:** M10 **Town:** Chester,Rcknhm,Sprfld **Date Assessed:** 08/12/14

Channel Length (ft): 6,007 **Channel Slope (%):** 0.4 **Sinuosity:** 1.07 **Watershed Area (mi^2):** 92.29

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Semi-Confined
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Sand
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	95.9
Bankfull Width (ft)	89
Max Depth (ft)	4.6
Width/Depth Ratio	22.6
Entrenchment Ratio	3.1
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	111%	D

\# of Other Constrictions: 0
\# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	10	1
2	0	0
3	5	3
4	0	1
5	1	0
6	0	0
7	0	2
#/mile	14	6

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	63/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	33/Fair
Dominant Adjustment	Widening
CEM Model Stage	F/III
Stream Type Departure	None
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- LWR-2c: Buffer Plantings recommended for bank stabilization and corridor protection helping to reduce erosion and further sedimentation in the channel.
- LWR-4b: Conserve areas of floodplain critical for continued attenuation of sediment, debris, and floodwaters.

Reach Highlights: This incised and highly straightened/encroached reach was difficult to classify, since it exhibited numerous active processes concurrently and the channel had degraded. During T.S. Irene the reach widened slightly and deposited large volumes of sand over two primary floodplain areas. Following the flood, the channel has aggraded with sand and continues to widen. Since no active incision was observed this reach is assessed as Stage III. The high degree of armoring and semi-confined valley from encroachment will slow the widening and planform adjustment processes.

Majority of reach is deep and slow, very few riffles

Bank erosion at confluence with tributary

Stream: Williams Mainstem **Reach:** M11 **Town:** Chester **Date Assessed**: 09/09/14

Channel Length (ft): 11,236 **Channel Slope (%):** 0.42 **Sinuosity:** 1.15 **Watershed Area (mi^2):** 80.90

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Gravel	Gravel
Median Substrate	Riffle-Pool	Riffle-Pool
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	90.5
Bankfull Width (ft)	111
Max Depth (ft)	4.8
Width/Depth Ratio	35.1
Entrenchment Ratio	1.4
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	166%	D,S
B	Missing Link Rd	66%	D

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	28	3
2	14	3
3	11	2
4	4	1
5	1	2
6	0	1
7	0	2
#/mile	27	7

Number of Debris Jams: 3

Step 6/7 Summary

RHA Score/Condition	62/Fair
Habitat Type Departure	None
RGA Score / Condition	23/Poor
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	C to B
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- LWR-2d: Buffer Plantings recommended for long-term bank stabilization.
- LWR-4c: Conserve areas of floodplain critical for continued attenuation of sediment, debris, and floodwaters.
- LWR-6: Reconfigure Missing Link Rd bridge armor
- LWR-7: Bank stabilization of mass failure after trees were cut
- LWR-8: Railroad Bridge replacement with single span structure.
- LWR-9: Relocate Chester WWTP or increase flood protection

Reach Highlights: The channel in this reach widened and eroded historic armoring in several locations during T.S. Irene. The channel is continuing to widen as it adjusts planform. Large adjacent floodplains are currently inaccessible, however may be restored through aggradation. Currently large volumes of sediment are working through the reach. Even though this reach remains incised and entrenched it was assessed as Stage IV due to the aggradation, and planform adjustment in the channel.


Large diagonal riffle indicates planform adjustment


Major bank erosion source of material for deposition

Stream: Williams Mainstem **Reach:** M12 **Town:** Chester **Date Assessed:** 9/09/2014

Channel Length (ft): 6,877 **Channel Slope (%):** 1.80 **Sinuosity:** 1.18 **Watershed Area (mi²):** 30.68

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Gravel
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	59.1
Bankfull Width (ft)	42
Max Depth (ft)	3.0
Width/Depth Ratio	20.5
Entrenchment Ratio	1.5
Incision Ratio	1.5

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt-11	135%	None
B	First Ave.	56%	None
B	Depot Rd.	152%	None

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	6	2
2	7	7
3	5	0
4	3	3
5	3	0
6	1	1
7	0	0
#/mile	19	10

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	79/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	36/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- LWR-10: Replace Flamstead Rd. Bridge with a structure that can span the bankfull channel and not restrict floodflows.

Reach Highlights: The incision and entrenchment in this reach results from historic armoring and straightening. Currently the channel is narrower than curve width and does not have access to the adjacent floodplain. Only a few areas of planform adjustment or widening were observed, the reach is mostly stable. This reach was assessed as a stage II and is expected it to remain there for a long time, due to the incision and entrenchment observed, and the extensive armoring and encroachment.

Portions of M12 have accessible high flood plains.

Armoring results in loss of floodplain due to incision.

Stream: Trebo Brook **Reach:** T7.01.B **Town:** Chester **Date Assessed:** 10/14/14

Channel Length (ft): 2,624 **Channel Slope (%):** 0.75 **Sinuosity:** 1.12 **Watershed Area (mi^2):** 1.74

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very-Broad	Very-Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	17.1
Bankfull Width (ft)	9
Max Depth (ft)	1.4
Width/Depth Ratio	8.6
Entrenchment Ratio	1.9
Incision Ratio	2.4

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Cemetery Access	41%	S,A
C	Rt. 103	58%	D

\# of Other Constrictions:1
\# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	1
2	10	2
3	2	0
4	1	0
5	0	0
6	1	0
7	0	0
#/mile	32	6

Number of Debris Jams: 3

Step 6/7 Summary

RHA Score/Condition	62/Fair
Habitat Type Departure	None
RGA Score / Condition	31/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to B
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach:

- TRE-1: Work with landowner to reduce or eliminate dredging in this reach. Possibly conserve entire field to the south eliminating need to dredge. This would reduce the disturbance to the wetland complex and reduce sedimentation.
- TRE-2: Buffer plantings along edge of channel and floodplain and encourage corridor protection to eliminate threat of future development.

Reach Highlights: Historic straightening and armoring have caused this channel to deeply incise, resulting in the C to B stream type departure. The channel bed had no major bars and there were very limited riffle-pool sequences. A large berm was constructed upstream of the cemetery following the 1970's flood where Trebo Brook impacted the properties along Rt. 103. This reach showed a very limited ability to widen and is thus stuck in stage II for the foreseeable future.

Historically straightened along field edge

Forested B-type channel with floodplain benches

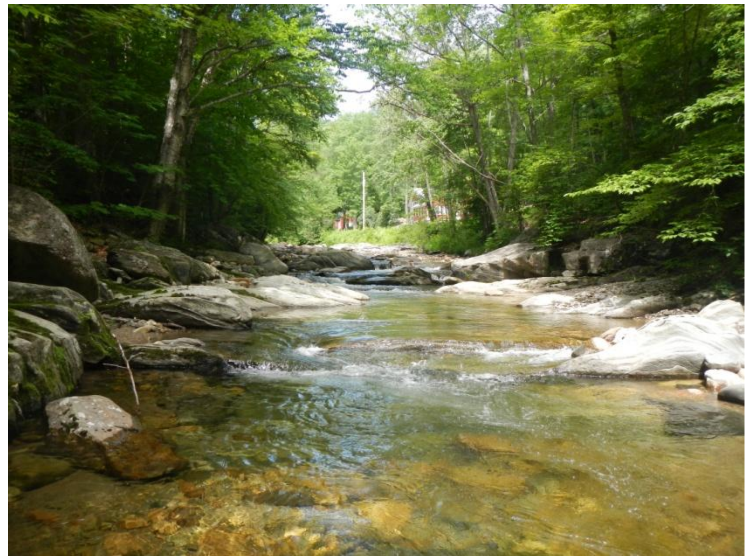
4.1.2 Upper Mainstem of the Williams River and Whitmore Brook Phase 2 Assessment Summary

The Phase 2 assessed reaches/segments on the upper mainstem of the Williams River and Whitmore brook include 11 reaches and a total of 14 segments, which flow through the Towns of Ludlow and Chester.

- Upper Mainstem along Route 103 (M13-M18)
  - Historic straightening, berms, encroachment, and armoring were present along many of these segments and resulted in many stream type departures and areas of moderate to high incision. Large volumes of material were deposited in the mainstem during T.S. Irene filling many of the pools and creating bars within the channel.
  - Despite similar impacts along the segments they are responding in a variety of stages of channel evolution including widening, incision, and planform adjustment.

- Upper Mainstem along Smokeshire Rd. (M19-M22)
  - Bedrock grade controls become more prevalent as the slope and confinement increase along Smokeshire Rd. Bedrock is also present along the banks in many areas and limits the channel's ability to widen. The reaches with heavy encroachment and armor, in addition to bedrock, see slower channel adjustment. After T.S. Irene many of the deep pools seen throughout these segments were filled in with sediment.
  - Segments M20.A and M22 were less encroached upon by Smokeshire Rd. and maintain floodplain access and served as depositional areas. These areas have widened and filled in with depositional material. Reach M22 is highly active with an alluvial fan located mid-reach.

- Whitmore Brook (T8.01)
  - This reach flowed from a forested floodplain down through a large hayfield floodplain. The reach is relatively stable with signs of aggradation throughout. Localized areas of planform adjustment also occur.



Segment M19.A of the Williams River

Reach T8.01 along Whitmore Brook

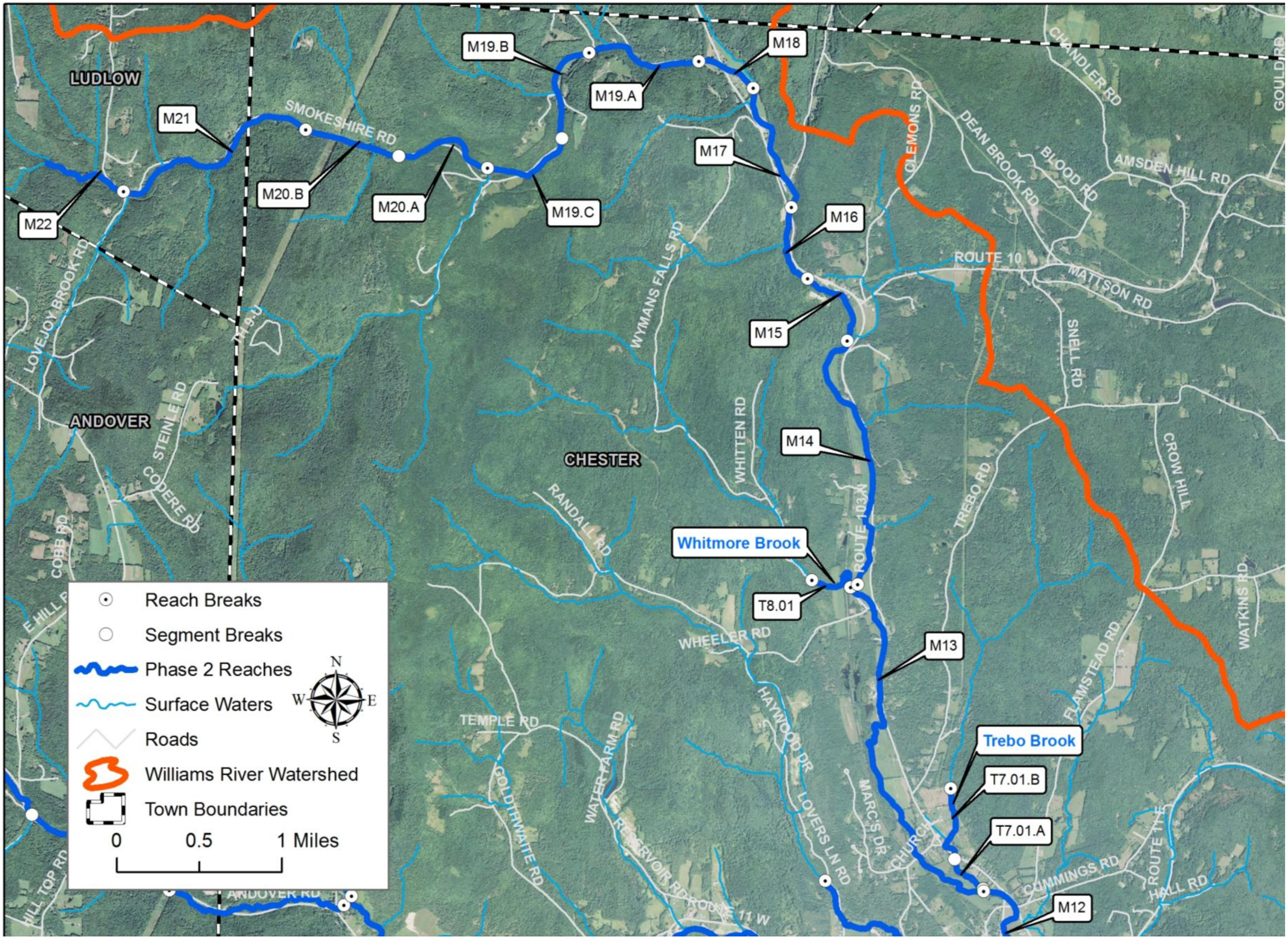


Figure 4.2: Upper Mainstem and Whitmore Brook reach locator map

Stream: Williams Mainstem **Reach:** M13 **Town:** Chester **Date Assessed:** 10/15/14

Channel Length (ft): 13,062 **Channel Slope (%):** 0.80 **Sinuosity:** 1.11 **Watershed Area (mi^2):** 24.5

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very-Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	53.5
Bankfull Width (ft)	47
Max Depth (ft)	2.4
Width/Depth Ratio	23.6
Entrenchment Ratio	1.2
Incision Ratio	2.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Church Rd	206%	D
B	Colburn Rd	67%	None
B	Willard Rd	67%	None
B	Wyman Falls Rd	97%	D, S
O	Old Abtmnt	52%	D

# of Other Constrictions: 0

# of Grade Controls: 3

Rapid Habitat Assessment

Rank	LWD	Pools
1	8	6
2	18	15
3	2	2
4	2	9
5	1	1
6	2	2
7	0	0
#/mile	13	14

Number of Debris Jams: 3

Step 6/7 Summary

RHA Score/Condition	75/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	33/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-1: Remove old bridge abutments in lower portion of reach
- UWR-2a-b: Buffer Plantings recommended for bank stabilization and corridor protection helping to reduce erosion and further sedimentation in the channel, while discouraging future development.
- UWR-3: Remove old bridge abutments to reduce channel constriction
- UWR-4: Willard Rd bridge retrofit assessment. Determine if bridge abutments can be retrofitted to reduce or eliminate channel constriction.

Reach Highlights: This reach is deeply incised from historic straightening and armoring. During T.S. Irene the channel widened and began to adjust planform in a few areas. The widening process will slowly continue due to ongoing aggradation, however the channel is still locked in stage II from deep incision. Two cross-sections were collected to capture the varying bankfull width, though no segmentation was necessary since the channel was consistently entrenched.

Channel straightened along road with F-type geometry

No floodplain benches due to bank scour and armor

Stream: Williams Mainstem **Reach:** M14 **Town:** Chester **Date Assessed:** 10/20/14

Channel Length (ft): 8,908 **Channel Slope (%):** 1.00 **Sinuosity:** 1.09 **Watershed Area (mi^2):** 20.62

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	49.6
Bankfull Width (ft)	42
Max Depth (ft)	2.4
Width/Depth Ratio	22.4
Entrenchment Ratio	1.3
Incision Ratio	2.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Thompson Rd	58%	S
B	Jewett Rd	81%	D,S
B	Palmer Rd	101%	D
B	Railroad	141%	A
B	Railroad	141%	D,S,A

\# of Other Constrictions: 0

\# of Grade Controls: 7

Rapid Habitat Assessment

Rank	LWD	Pools
1	8	8
2	11	5
3	1	6
4	0	5
5	0	1
6	0	0
7	0	0
#/mile	12	15

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	61/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	37/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-2c-d: Buffer Plantings recommended for long-term bank stabilization and corridor protection helping to reduce erosion and further sedimentation in the channel, while discouraging future development.
- UWR-5: Assess embankment stability and replace or install riprap as necessary.
- UWR-6: Assess the possibility of pushing the stacked stone footers back to reduce the channel constriction of the Thompson Rd. bridge.

Reach Highlights: Historic straightening and armoring have caused this reach to deeply incise. Large floodplains throughout the reach are only accessible during the largest events. The channel bed does not appear to be incising any further, and some areas of aggradation were observed. This indicates that the transition to stage III may slowly be underway.

Straightening and bank armor frequent throughout M14

Banks erode as the channel moves away from the armor

Stream: Williams Mainstem **Reach:** M15 **Town:** Chester **Date Assessed**: 10/20/14

Channel Length (ft): 2,859 **Channel Slope (%):** 0.9 **Sinuosity:** 1.00 **Watershed Area (mi^2):** 18.11

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Cobble
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	46.9
Bankfull Width (ft)	50
Max Depth (ft)	2.9
Width/Depth Ratio	26.7
Entrenchment Ratio	1.9
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	149%	S
B	Private	96%	D,A

\# of Other Constrictions: 0
\# of Grade Controls: 5

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	0
2	11	2
3	2	1
4	4	1
5	1	2
6	0	1
7	0	0
#/mile	37	13

Number of Debris Jams: 2

Step 6/7 Summary

RHA Score/Condition	86/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	37/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	C to B
Stream Sensitivity	High

Impact Summary

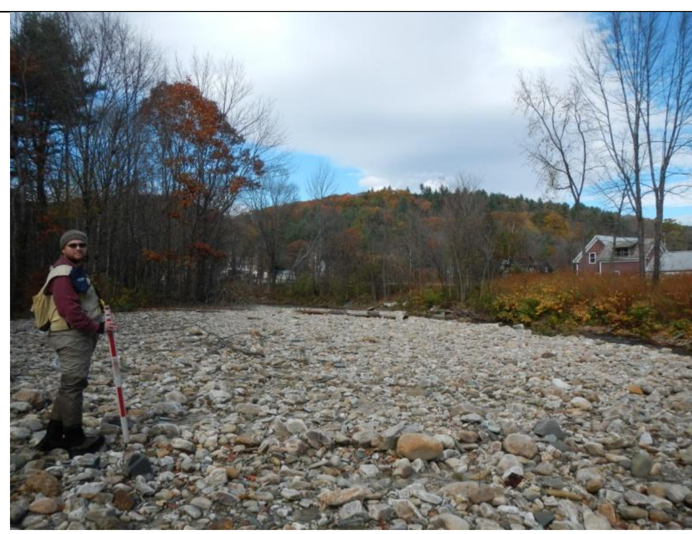
Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-7: Assess the need for bank stabilization downstream of the railroad bridge to reduce further migration and protect the adjacent homes.

Reach Highlights: Historically this reach was incised due to straightening and armoring. During T.S. Irene the channel widened and scoured the lower banks throughout. The channel is currently adjusting planform in several locations as it redevelops meander bends. We assessed this reach as stage IV because of the ongoing aggradation and channel migration. The stream departed from a C to a B-type channel due to incision and entrenchment.


Channel aggrading and floodplain benches remain


3-4ft of gravel deposited from T.S. Irene

Stream: Williams Mainstem **Reach:** M16 **Town:** Chester **Date Assessed**: 06/16/15

Channel Length (ft): 2,669 **Channel Slope (%):** 1.39 **Sinuosity:** 1.04 **Watershed Area (mi^2):** 17.92

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Semi-Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	Bc	F

Ph2 Cross-Section Data

Curve Width (ft)	46.6
Bankfull Width (ft)	51
Max Depth (ft)	2.3
Width/Depth Ratio	30.4
Entrenchment Ratio	1.4
Incision Ratio	4.9

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	60%	D
B	Rt-103	129%	D

# of Other Constrictions: 1
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	0	0
2	2	4
3	0	5
4	1	2
5	0	0
6	0	1
7		1
#/mile	5	25

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	74/Fair
Habitat Type Departure	None
RGA Score / Condition	43/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-8: Remove the concrete bank that is currently undermined and constricting the channel. Replace the bank with a stacked stone wall.

Reach Highlights: The M16 corridor is encroached upon from both the railroad and Rt-103, which has caused the channel to incise. Many depositional bars were left behind from T.S. Irene. Channel widening is limited by heavy bank armor, thus the channel remains stuck in stage II.

Large diagonal bar indicating planform adjustment

Paved left bank represented in alternate cross section

Stream: Williams Mainstem **Reach:** M17 **Town:** Chester **Date Assessed:** 06/17/15

Channel Length (ft): 4,504 **Channel Slope (%):** 0.96 **Sinuosity:** 1.07 **Watershed Area (mi^2):** 16.98

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	45.6
Bankfull Width (ft)	39.0
Max Depth (ft)	3.0
Width/Depth Ratio	17.3
Entrenchment Ratio	1.3
Incision Ratio	2.4

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	154%	D
B	Cavendish Rd.	70%	None

# of Other Constrictions: 1
# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	5	2
2	15	1
3	3	1
4	3	3
5	0	1
6	0	0
7		3
#/mile	30	12

Number of Debris Jams: 5

Step 6/7 Summary

RHA Score/Condition	80/Fair
Habitat Type Departure	None
RGA Score / Condition	47/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-9: Assess feasibility of raising the railroad bridge to increase capacity for sediment and floodwaters, since it is located in an area of active aggradation.
- UWR-10: Remove the berm along Rt-103 to restore floodplain access.

Reach Highlights: Berms, the railroad, and Rt-103 all have encroached and reduced potential floodplain for reach M17. Many mid-channel and side bars were formed from the deposition that occurred during T.S. Irene. The possibility of channel widening and planform adjustment is greatly reduced in this reach due to armoring along both banks; therefore this reach is expected to remain in Stage II.

Railroad bridge with low capacity due to aggradation

Historic bank armoring eliminated floodplain access

Stream: Williams Mainstem **Reach:** M18 **Town:** Chester **Date Assessed:** 06/17/15

Channel Length (ft): 1,927 **Channel Slope (%):** 1.20 **Sinuosity:** 1.01 **Watershed Area (mi^2):** 15.06

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	43.2
Bankfull Width (ft)	41
Max Depth (ft)	2.5
Width/Depth Ratio	24.6
Entrenchment Ratio	1.4
Incision Ratio	2.8

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt-103	88%	None

# of Other Constrictions: 0

# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	1	2
2	1	0
3	1	0
4	0	1
5	0	0
6	0	0
7		0
#/mile	8	8

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	75/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	48/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- UWR-5: Assess embankment stability and replace or install riprap as necessary.
- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.

Reach Highlights: Historic berms and encroachment have reduced floodplain access along reach M18. Over time incision has further reduced floodplain accessibility causing a stream type departure from C to F. This reach is still working through the sediment deposited by T.S. Irene as it incises further. This reach remains in Stage II due to incision.

View upstream of Route 103 bridge

A berm on the right bank protects houses

Stream: Williams Mainstem **Reach:** M19.A **Town:** Chester **Date Assessed:** 06/25/15

Channel Length (ft): 3,862 **Channel Slope (%):** 3.50 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 14.97

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrowly-Confined
Bedform	Riffle-Pool	Step-Pool
Median Substrate	Cobble	Cobble
Stream Type	Ab	Ab

Ph2 Cross-Section Data

Curve Width (ft)	43.1
Bankfull Width (ft)	54
Max Depth (ft)	3.2
Width/Depth Ratio	27.8
Entrenchment Ratio	1.2
Incision Ratio	1.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
N/A			

# of Other Constrictions: 0
# of Grade Controls: 37

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	10
2	16	15
3	0	6
4	2	3
5	0	1
6	0	4
7		1
#/mile	34	54

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	84/Fair
Habitat Type Departure	Step-Pool
RGA Score / Condition	48/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	None
Stream Sensitivity	High

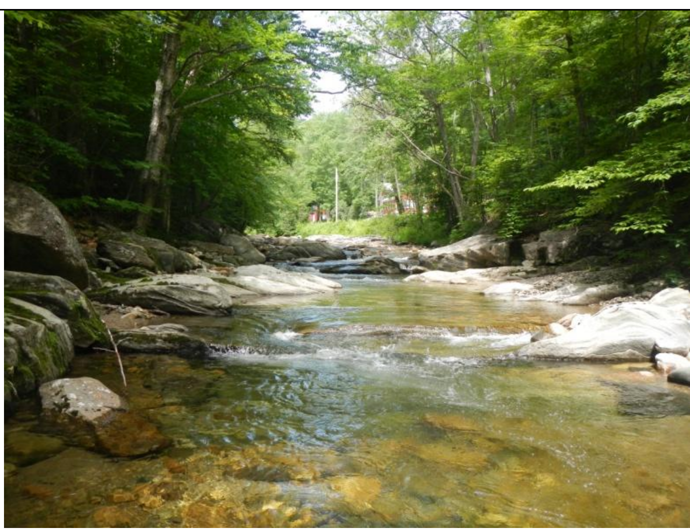
Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.

Reach Highlights: M19.A has predominantly bedrock banks and channel bottom. The impacts of encroachment from the adjacent Smokeshire Rd. are minimal because of the presence of natural bedrock. In recent floods this channel has widened by scouring away lower benches. Large volumes of sediment are currently working through the reach. The presence of scouring and a few areas of active erosion indicate the channel is widening as it works through the sediment left behind from the 2011 and 2014 floods, thus resulting in Stage III designation.



Bedrock on either bank maintains channel geometry

Many large pools now filled in with fines from T.S. Irene

Stream: Williams Mainstem **Reach:** M19.B **Town:** Chester **Date Assessed:** 06/25/15

Channel Length (ft): 3,454 **Channel Slope (%):** 2.00 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 14.07

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrowly Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	43.1
Bankfull Width (ft)	42
Max Depth (ft)	2.4
Width/Depth Ratio	26.1
Entrenchment Ratio	1.4
Incision Ratio	3.1

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Smokeshire Rd.	46%	D
B	Smokeshire Rd.	111%	None

# of Other Constrictions: 0
# of Grade Controls: 14

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	2
2	5	10
3	1	5
4	2	0
5	0	2
6	1	1
7		0
#/mile	16	30

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	90/Fair
Habitat Type Departure	None
RGA Score / Condition	45/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

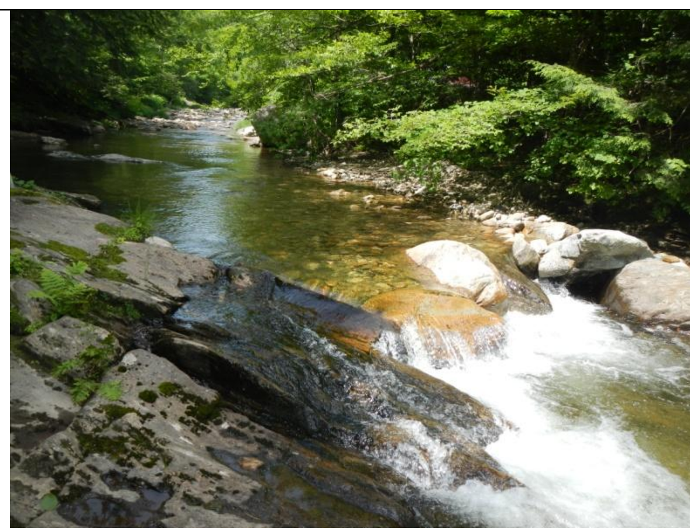
Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.

Reach Highlights: Smokeshire Rd. encroaches M19.B for the majority of the segment, changing the confinement type and causing the channel bottom to incise to bedrock. This incision drove the stream type departure from C to F. This segment is likely stuck in Stage II due to bedrock and bank armoring limiting the possibility for channel widening or planform adjustment.

Road reduces river's ability to migrate within the valley



Sediment is stored behind grade controls and fills in pools

Stream: Williams Mainstem **Reach:** M19.C **Town:** Chester **Date Assessed**: 06/25/15

Channel Length (ft): 3,039 **Channel Slope (%):** 2.00 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 13.11

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Semi-Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	43.1
Bankfull Width (ft)	48
Max Depth (ft)	2.6
Width/Depth Ratio	27.9
Entrenchment Ratio	1.6
Incision Ratio	2.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Smokeshire Rd.	97%	D

\# of Other Constrictions: 0
\# of Grade Controls: 7

Rapid Habitat Assessment

Rank	LWD	Pools
1	1	2
2	0	4
3	3	3
4	2	1
5	1	2
6	1	0
7		0
#/mile	13	20

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	90/Fair
Habitat Type Departure	None
RGA Score / Condition	38/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	C->B
Stream Sensitivity	High

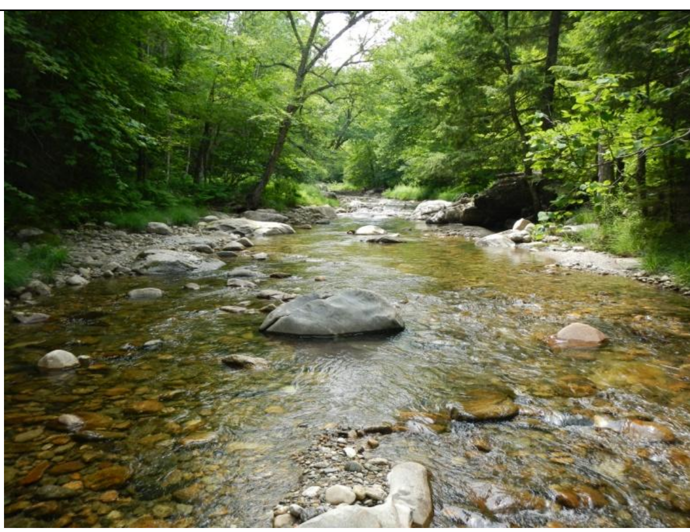
Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.

Reach Highlights: T.S. Irene deposited large volumes of gravel and cobble throughout the reach. Historic encroachment from Smokeshire Rd. has caused incision, however during T.S. Irene the channel widened and aggraded from the deposition. This segment is a C-type channel in a narrow valley by reference, however the encroachment has caused a departure to a Bc type channel in a semi-confined valley. This segment is designated as stage IV due to the consistent scour and aggradation.


River maintains a floodplain bench away from road


Many depositional features form as the channel widens

Stream: Williams Mainstem **Reach:** M20.A **Town:** Chester **Date Assessed:** 07/29/15

Channel Length (ft): 3,457 **Channel Slope (%):** 1.71 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 10.10

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	B	Bc

Ph2 Cross-Section Data

Curve Width (ft)	36.2
Bankfull Width (ft)	43
Max Depth (ft)	2.0
Width/Depth Ratio	34.4
Entrenchment Ratio	1.5
Incision Ratio	3.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Smokeshire Rd.	122%	D
B	VAST trail	133%	D

# of Other Constrictions: 0

# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	5	3
2	6	5
3	0	1
4	5	0
5	0	0
6	0	0
7		0
#/mile	24	13

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	87/Fair
Habitat Type Departure	None
RGA Score / Condition	46/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	High

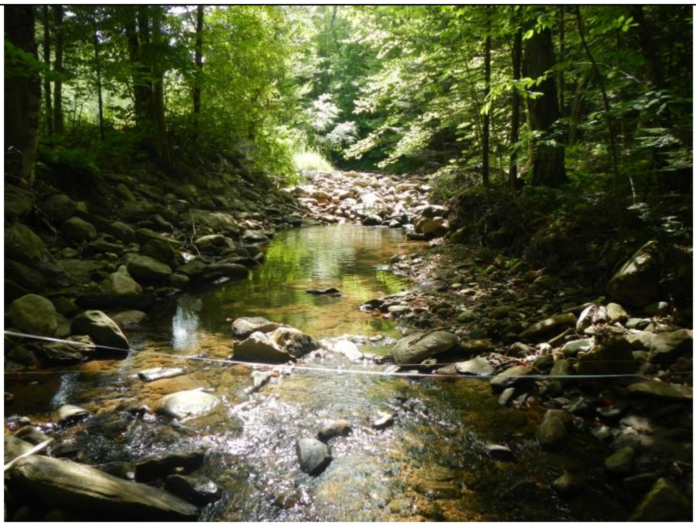
Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

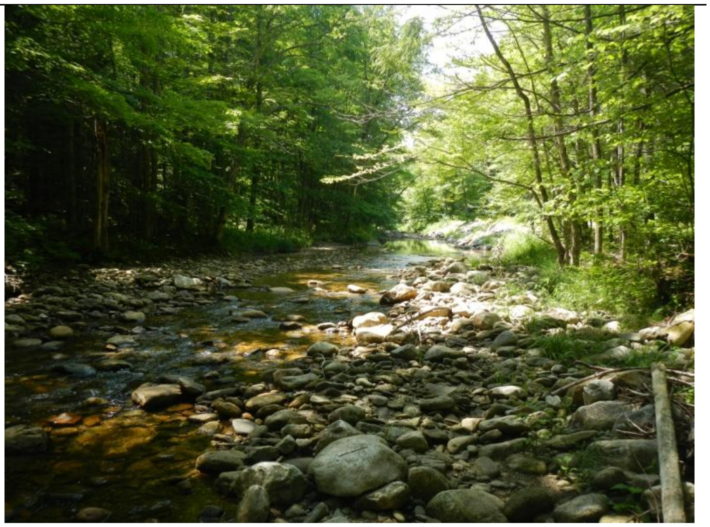
Potential Projects in Reach

- UWR-2e: Buffer Plantings recommended for long-term bank stabilization and corridor protection helping to reduce erosion and further sedimentation in the channel, while discouraging future development.
- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.
- UWR-12: Remove the spoils berm to restore access to historic channel as a flood chute to increase floodplain access.

Reach Highlights: Despite being encroached upon by Smokeshire Rd. segment M20.A maintains access to flood benches. T.S. Irene scoured away this segment's low benches as the channel widened and then filled back in with cobble and gravel. These floodplain benches have been reformed as the deposits have been moved. This channel adjustments suggest Stage IV of the channel evolution model due to the frequent bank scour and the large number of bars created from the flood material.



Many cobble aggradational features present



Floodplain benches still remain accessible

Stream: Williams Mainstem **Reach:** M20.B **Town:** Chester **Date Assessed:** 07/29/15

Channel Length (ft): 3,127 **Channel Slope (%):** 1.71 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 9.80

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Semi Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	B	F

Ph2 Cross-Section Data

Curve Width (ft)	36.2
Bankfull Width (ft)	47
Max Depth (ft)	1.8
Width/Depth Ratio	44.3
Entrenchment Ratio	1.2
Incision Ratio	4.2

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
N/A			

# of Other Constrictions: 0
# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	4
2	3	1
3	0	0
4	1	0
5	3	0
6	0	0
7		0
#/mile	15	8

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	80/Fair
Habitat Type Departure	None
RGA Score / Condition	37/Fair
Dominant Adjustment	Widening
CEM Model Stage	F/III
Stream Type Departure	B->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.
- UWR-13a: Several areas where the road elevation is very low relative to bankfull, repeat issues with ice during spring melt.

Reach Highlights: The encroachment present in segment M20.B has eliminated floodplain access and caused historic incision. During T.S. Irene the channel aggraded from flood deposition and is now widening through scour. This scour and the increase in channel width indicate that this channel is in stage III.

Floodplain is greater than 2x Wbkf

High degree of bed roughness in portions of segment

Stream: Williams Mainstem **Reach:** M21 **Town:** Chester, Ludlow **Date Assessed:** 08/19/15

Channel Length (ft): 7,285 **Channel Slope (%):** 2.02 **Sinuosity:** 1.02 **Watershed Area (mi^2):** 8.62

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Semi Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	B	F

Ph2 Cross-Section Data

Curve Width (ft)	33.8
Bankfull Width (ft)	35
Max Depth (ft)	1.8
Width/Depth Ratio	28.5
Entrenchment Ratio	1.2
Incision Ratio	3.4

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Private	118%	None
B	Lovejoy Brook Rd.	112%	D

\# of Other Constrictions: 0
\# of Grade Controls: 12

Rapid Habitat Assessment

Rank	LWD	Pools
1	32	11
2	31	12
3	2	8
4	2	2
5	0	0
6	0	0
7		0
#/mile	48	23

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	90/Fair
Habitat Type Departure	None
RGA Score / Condition	38/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B -> F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-5d: Assess road embankment stability and replace or install riprap as necessary.
- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.

Reach Highlights: Incision is present throughout most of the reach and is due to the encroachment of Smokeshire Rd. Grade controls are very common and will prevent further bed incision. Many side and mid channel bars were created in T.S. Irene from deposited cobbles and gravel. When the stream was away from Smokeshire Road it was able to adjust planform with flood chutes and a channel avulsion. Recently exposed grade controls throughout the reach provide evidence that this reach is still incising and is in Stage II of channel evolution.

Bank scour and evidence of widening

Smokeshire Rd. ditches add sediment in the river

Stream: Williams Mainstem **Reach:** M22 **Town:** Ludlow **Date Assessed:** 08/19/15

Channel Length (ft): 2,829 **Channel Slope (%):** 1.00 **Sinuosity:** 1.09 **Watershed Area (mi^2):** 5.72

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	Cb	Cb

Ph2 Cross-Section Data

Curve Width (ft)	28.2
Bankfull Width (ft)	43
Max Depth (ft)	2.7
Width/Depth Ratio	26.9
Entrenchment Ratio	2.3
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
O	Bank Armor	53%	None

# of Other Constrictions: 0

# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	35	9
2	46	7
3	11	0
4	13	0
5	2	0
6	0	0
7		0
#/mile	199	29

Number of Debris Jams: 5

Step 6/7 Summary

RHA Score/Condition	107/Good
Habitat Type Departure	None
RGA Score / Condition	48/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	**Head Cut**
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- UWR-11: Reduce sedimentation along Smokeshire Rd by improving ditch maintenance, installing check dams, and improving road grading.
- UWR-13: Conservation easement for the segment of the reach upstream of Smokeshire Rd. This very active segment would be protected from future development and channel management. Eliminate berms in this segment to improve floodplain access.

Reach Highlights: Reach M22 was very active during T.S. Irene. A large alluvial fan was observed in the middle of the reach with numerous flood chutes, a channel avulsion, and large depositional features. There were multiple historic berms along the reach; though many have failed from previous high flow events. This reach is assessed as Stage IV due to ongoing planform adjustments following major widening and deposition from T.S. Irene.

Alluvial fan created from sharp decrease in channel slope

Consistent bank scour illustrates channel widening

Stream: Whitmore Brook **Reach:** T8.01 **Town:** Chester **Date Assessed:** 10/15/14

Channel Length (ft): 2,023 **Channel Slope (%):** 1.1 **Sinuosity:** 1.24 **Watershed Area (mi^2):** 2.35

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	19.1
Bankfull Width (ft)	22
Max Depth (ft)	1.9
Width/Depth Ratio	15.5
Entrenchment Ratio	2.5
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
C	Field Access	10%	D,S,A
B	Railroad	58%	D,A
B	Goodright Rd.	105%	D,A
B	VAST trail	94%	D
B	Goodright Rd.	89%	D,S,A

\# of Other Constrictions:0

\# of Grade Controls: 3

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	11
2	10	12
3	4	3
4	2	0
5	1	0
6	0	0
7	0	0
#/mile	63	68

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	94/Fair
Habitat Type Departure	None
RGA Score / Condition	45/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- WHB-1: Replace culvert at farm road crossing with a larger structure to increase bankfull and floodprone widths and reduce the scour and erosion up and downstream.
- WHB2: Buffer planting along the edge of the pasture is suggested to reduce further erosion. Corridor protection is encouraged to maintain access to important floodplain within the reach.

Reach Highlights: This reach is primarily stable with relatively consistent floodplain access. There is a very undersized farm culvert causing channel instability, braiding, and sediment deposition at the bottom of the reach. A localized area of channel incision was observed upstream of Wymans Falls Rd. This reach is stage IV due to planform adjustment, with many areas of aggradation.

Outlet of severely undersized culvert under farm road

Upper reach easily accessible floodplain

4.1.3 Middle Branch, South Branch, and Tributaries of the Williams River Phase 2 Assessment Summary

The Phase 2 assessed reaches/segments on the T5 tributaries of the Williams River include the Middle Branch (T5), South Branch (T5.S1), Lovers Lane Brook (T5.S2), Andover Branch (T5.S3), Potash Brook (T5.S3.a), and Trout Brook (T5.S3.b). The assessed reaches of the T5 tributaries flow through the towns of Chester, Andover, and Windham.

- Middle Branch of the Williams River (T5.01–T5.09.C)
  Encroachment along Route 11 has caused the middle branch to both incise and widen. Deposition from T.S. Irene and subsequent floods has resulted in vertical and lateral instability; planform adjustment is severe in areas where encroachment and straightening were not significant.
- South Branch of the Williams River (T5.S1.01–T5.S1.09)
  The majority of reaches in the South Branch are encroached upon by Grafton (Rt. 35) and Popple Dungeon Roads. This encroachment has caused incision or widening from past incision. In areas with less encroachment severe deposition was observed as the channel would widen and deposit sediment and debris generated from recent floods.
- Lover's Lane Brook (T5.S2.01.A-T5.S2.01.C)
  There is extensive straightening along all three segments. In many areas the channel has narrowed significantly, especially when flowing through historic and current farm fields. There are a few select areas that are not currently straightened, which have retained some flood plain access.
- Andover Branch (T5.S3.01–T5.S3.05.B)
  Encroachment, bank armor, and historic straightening are highly variable within these segments. Areas that are affected by these impacts exhibit continued incision, while the segments less impacted are widening and adjusting planform. Major bank erosion or scour was seen throughout most segments depositing sediment in areas of lower slope.
- Potash Brook (T5.S3.A.01)
  Potash Brook was severely impacted in T.S. Irene and the July 2014 storm washing out the road in multiple locations as the channel incised and widened. A large volume of sediment is still moving through the channel and is being stored by the many debris jams in the channel.
- Trout Brook (T5.S3.B.01)
  Trout Brook has increased slope compared to Andover Branch. Both natural valley walls and armoring along Weston-Andover road limit the brook's ability to widen or adjust planform; therefore the reach is very incised. The July 2014 flood scoured the channel bottom and deposited many large boulders in the channel leaving little fine sediment behind.

Mass slope failures along Reach T5.06 on the Middle Branch of the Williams River

Incised channel on Reach T5.S3.a.01 on Potash Brook

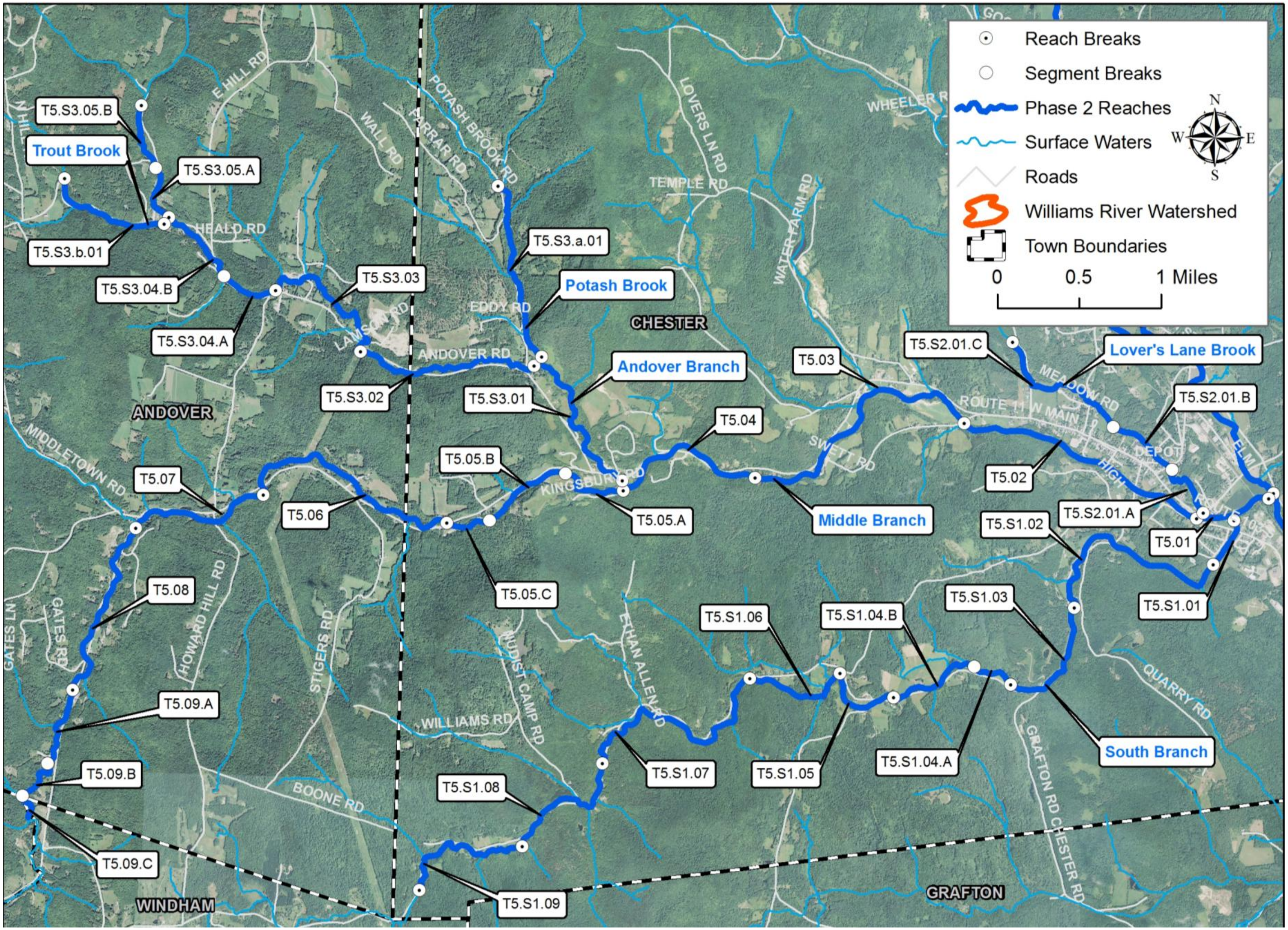


Figure 4.3: Middle Branch, South Branch, and tributaries locator map

Fitzgerald Environmental

Stream: Middle Branch **Reach:** T5.01 **Town:** Chester **Date Assessed**: 10/02/14

Channel Length (ft): 2,533 **Channel Slope (%):** 0.79 **Sinuosity:** 1.08 **Watershed Area (mi^2):** 48.11

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Gravel
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	72.0
Bankfull Width (ft)	102
Max Depth (ft)	3.6
Width/Depth Ratio	34.5
Entrenchment Ratio	4.6
Incision Ratio	1.4

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Railroad	122%	D,S,A
B	Rt-103	133%	D,S

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	2
2	3	3
3	1	1
4	1	1
5	0	0
6	0	1
7		0
#/mile	18	16

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	64/Fair
Habitat Type Departure	None
RGA Score / Condition	35/Fair
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	None
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- MBWR-1a: Protect floodplain areas and eliminate risk of future development; Buffer planting for long-term bank stabilization.
- MBWR-2: Replace railroad bridge with a larger (i.e., taller) structure to increase capacity for floodwater and sediment during storm events.

Reach Highlights: Prior to T.S. Irene this channel was likely F-type due to incision. During the flood the channel widened and filled with sediment. This aggradation had restored some floodplain access in several areas and has caused the channel to adjust planform. This planform adjustment has left tall eroding banks. The railroad bridge is a major constriction during large events, which has caused overbank flow to the south through the baseball field.

Highly erodible banks along agricultural fields

Planform adjustment displayed by diagonal riffles

Stream: Middle Branch **Reach:** T5.02 **Town:** Chester **Date Assessed**: 10/02/14

Channel Length (ft): 8,416 **Channel Slope (%):** 0.92 **Sinuosity:** 1.01 **Watershed Area (mi^2):** 33.5

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Plane Bed
Median Substrate	Gravel	Gravel
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	61.4
Bankfull Width (ft)	96
Max Depth (ft)	3.0
Width/Depth Ratio	41.7
Entrenchment Ratio	1.1
Incision Ratio	2.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Grafton Rd.	147%	D

\# of Other Constrictions: 0
\# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	11
2	7	5
3	0	1
4	2	5
5	0	1
6	0	1
7		0
#/mile	10	15

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	66/Fair
Habitat Type Departure	Plane Bed
RGA Score / Condition	27/Poor
Dominant Adjustment	Widening
CEM Model Stage	F/III
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- MBWR-3a: Assess unstable slopes for riprap installation or replacement. Bank stabilization will reduce erosion and sedimentation.

Reach Highlights: Due to straightening, armoring, and dredging T5.02 was historically widened and deeply incised. Currently the channel is overwidened and F-type as its low benches were likely scoured away during T.S. Irene and the July 2014 flood. The floods also left the channel with minimal floodplain access and a relatively smooth bed profile. The channel may continue to widen as it does not appear to be actively incising.

Major widening occurred throughout the reach

Channel working through July 2014 deposits

Stream: Middle Branch **Reach:** T5.03 **Town:** Chester **Date Assessed**: 09/22/15

Channel Length (ft): 9,163 **Channel Slope (%):** 1.09 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 32.25

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Braided
Median Substrate	Gravel	Cobble
Stream Type	C	D

Ph2 Cross-Section Data

Curve Width (ft)	60.4
Bankfull Width (ft)	124.0
Max Depth (ft)	2.35
Width/Depth Ratio	85.0
Entrenchment Ratio	4.88
Incision Ratio	1.64

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Blue Hill Rd	116%	S
B	Swett Rd.	66%	S

\# of Other Constrictions: 0
\# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	67	13
2	38	1
3	28	2
4	6	8
5	4	1
6	3	5
7		0
#/mile	84	17

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	82/Fair
Habitat Type Departure	Braided
RGA Score / Condition	24/Poor
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	C ->D
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- MBWR-1b: Protect floodplain areas and eliminate risk of future development; Buffer planting for long-term bank stabilization.
- MBWR-3b: Assess unstable slopes for riprap installation or replacement. Bank stabilization will reduce erosion and sedimentation.
- MBWR-4: Berm removal and floodplain protection to increase conserve critical floodplain access.

Reach Highlights: This reach is located in a transitional zone as the channel moves from being incised to widened. The transition is a result of the valley being encroached upon by Rt-11 before moving into a wide and less encroached setting. Large volumes of sediment generated from upstream mass failures are deposited in this reach, causing extreme widening in areas. Several properties are still at risk of bank retreat despite bank armor. Berms are present along the hayfield on the left bank in the lower reach.

Channel has widened from recent large floods

Banks are scoured and eroded from channel widening

Stream: Middle Branch **Reach:** T5.04 **Town:** Chester **Date Assessed:** 09/23/15

Channel Length (ft): 5,334 **Channel Slope (%):** 0.9% **Sinuosity:** 1.03 **Watershed Area (mi²):** 28.29

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Semi-Confined
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	57.0
Bankfull Width (ft)	68.5
Max Depth (ft)	2.9
Width/Depth Ratio	34.13
Entrenchment Ratio	1.15
Incision Ratio	1.83

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt-11	119%	D
B	Rt-11	126%	D

\# of Other Constrictions: 0
\# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	41	7
2	25	8
3	4	1
4	13	6
5	0	0
6	1	2
7		0
#/mile	83	23

Number of Debris Jams: 6

Step 6/7 Summary

RHA Score/Condition	92/Fair
Habitat Type Departure	None
RGA Score / Condition	33/Fair
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	C ->F
Stream Sensitivity	High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- MBWR-3c: Assess unstable slopes for riprap installation or replacement. Bank stabilization will reduce erosion and sedimentation.

Reach Highlights: Route 11 has historically encroached upon reach T5.04 causing incision throughout. T.S. Irene caused the channel bed to aggrade from an increased sediment supply from mass failures within T5.04 and the upstream reaches. Two bridges within T5.04 are floodprone constrictions that increase sediment deposition upstream.


Multiple active mass failures present throughout T5.04


Upper cross-section left (north) unstable bank

Stream: Middle Branch **Reach:** T5.05.A **Town:** Chester **Date Assessed:** 09/23/15

Channel Length (ft): 2,329 **Channel Slope (%):** 1.45 % **Sinuosity:** 1.09 **Watershed Area (mi²):** 14.74

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Braided
Median Substrate	Gravel	Gravel
Stream Type	C	D

Ph2 Cross-Section Data

Curve Width (ft)	42.8
Bankfull Width (ft)	104.5
Max Depth (ft)	2.7
Width/Depth Ratio	81.0
Entrenchment Ratio	4.8
Incision Ratio	1.52

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Kingsbury Rd	56%	D,S

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	54	1
2	37	2
3	7	0
4	5	3
5	0	0
6	0	0
7		0
#/mile	233	13

Number of Debris Jams: 6

Step 6/7 Summary

RHA Score/Condition	60/Fair
Habitat Type Departure	Braided
RGA Score / Condition	24/Poor
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	C ->D
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- MBWR-1c: High priority corridor protection site to eliminate risk of future development and ensure long-term sediment and debris attenuation in corridor.
- MBWR-5: Replace the Kingsbury Rd bridge with an appropriately-sized bankfull structure.

Reach Highlights: T5.05.A gets away from the encroachment of Rt 11 as the valley becomes broad and unconfined. This area acted like an alluvial fan during both T.S. Irene and the July 2014 flood, where large volumes of sediment and debris were deposited across the valley, leading to further channel bifurcation. Multiple threads are not active in very low flows. All channels fill in bankfull flows and greater.

Braided channels throughout valley

Many debris jams present throughout braided segment

Stream: Middle Branch **Reach:** T5.05.B **Town:** Chester **Date Assessed**: 09/23/15

Channel Length (ft): 3,051 **Channel Slope (%):** 1.50 % **Sinuosity:** 1.09 **Watershed Area (mi^2):** 14.43

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	42.8
Bankfull Width (ft)	55.0
Max Depth (ft)	2.0
Width/Depth Ratio	46.7
Entrenchment Ratio	1.4
Incision Ratio	1.4

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
N/A			

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	12	2
2	34	8
3	0	0
4	4	1
5	0	0
6	1	0
7		0
#/mile	88	19

Number of Debris Jams: 4

Step 6/7 Summary

RHA Score/Condition	89/Fair
Habitat Type Departure	None
RGA Score / Condition	35/Fair
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- None

Reach Highlights: Several residential properties and Rt 11 encroach on the channel in this segment. The channel bed has scoured down and widened since T.S. Irene and subsequent floods, which also left large depositional bars throughout the reach. This segment is in Stage III due to active bank erosion and continued deposition. The stream type departure from C to F occurred as the channel bed scoured down and widened, resulting in a disconnected floodplain.

Road occupies historic floodplain along majority of reach

Channel bed is aggrading after recent channel scouring

Stream: Middle Branch **Reach:** T5.06 **Town:** Andover, Chester **Date Assessed**: 09/23/15

Channel Length (ft): 8,015 **Channel Slope (%):** 1.47 % **Sinuosity:** 1.12 **Watershed Area (mi²):** 13.74

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	41.5
Bankfull Width (ft)	55
Max Depth (ft)	2.3
Width/Depth Ratio	35.2
Entrenchment Ratio	1.3
Incision Ratio	2.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Trombley Rd	72%	D
B	Rt-11	120%	D

\# of Other Constrictions: 0
\# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	14	7
2	33	13
3	17	2
4	18	8
5	3	1
6	8	0
7		0
#/mile	61	20

Number of Debris Jams: 6

Step 6/7 Summary

RHA Score/Condition	95/Fair
Habitat Type Departure	None
RGA Score / Condition	28/Fair
Dominant Adjustment	Widening
CEM Model Stage	F/III
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- MBWR-3d-e: Assess unstable slopes for riprap installation or replacement. Bank stabilization will reduce erosion and sedimentation.

Reach Highlights: Large mass failures, consistent bank scour and erosion were observed throughout the reach. Both T.S. Irene and subsequent flooding (July 2014) has left large volumes of material collected into depositional bars. This aggradation has allowed portions of this reach to regain floodplain access and exhibit C-type channel geometry, while adjusting planform. However, the majority of the reach remains F-type with no floodplain access. The consistent bank scour and erosion, as well as the widened channel indicates this reach is currently still in Stage III.


Multiple active mass failures are present in the reach


Channel bed is aggrading from mass failure material

Stream: Middle Branch **Reach:** T5.07 **Town:** Andover **Date Assessed:** 09/22/15

Channel Length (ft): 4,868 **Channel Slope (%):** 2.16% **Sinuosity:** 1.06 **Watershed Area (mi^2):** 12.16

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	B	F

Ph2 Cross-Section Data

Curve Width (ft)	41.5
Bankfull Width (ft)	45.0
Max Depth (ft)	2.9
Width/Depth Ratio	27.4
Entrenchment Ratio	1.2
Incision Ratio	2.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Howard Hill Rd	82%	D

\# of Other Constrictions: 0
\# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	5	3
2	38	12
3	0	2
4	18	2
5	0	0
6	5	0
7		0
#/mile	71	20

Number of Debris Jams: 5

Step 6/7 Summary

RHA Score/Condition	89/Fair
Habitat Type Departure	None
RGA Score / Condition	41/Fair
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	B->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- MBWR-6: The property immediately upstream of the Rt-11 bridge is part of a FEMA buyout. Following removal of the house the existing berms should be removed and the road embankment armor should be assessed for stability.

Reach Highlights: T.S. Irene and subsequent flooding (July 2014) scoured the channel bottom disconnecting much of the reach from its floodplain. The channel has since filled in with flood deposits generating large side and point bars. There are still some areas of active incision, while others have active widening and deposition. Due to the lack of migration features this reach remains in Stage III, but the presence of diagonal and mid-channel bars indicate that it is progressing towards stage IV.

Raw eroding banks are present throughout the reach

Large depositional bars and channel widening

Stream: Middle Branch **Reach:** T5.08 **Town:** Andover **Date Assessed:** 09/22/15

Channel Length (ft): 6,345 **Channel Slope (%):** 1.89% **Sinuosity:** 1.12 **Watershed Area (mi^2):** 5.73

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	28.2
Bankfull Width (ft)	34
Max Depth (ft)	2.1
Width/Depth Ratio	23.9
Entrenchment Ratio	1.4
Incision Ratio	1.9

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt-11	74%	None
B	Rt-11	89%	S
B	Rt-11	319%	D,S
B	Rt-11	92%	None
B	Rt-11	99%	D,S

# of Other Constrictions: 0

# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	3	4
2	30	8
3	2	4
4	24	3
5	0	0
6	4	1
7		0
#/mile	52	16

Number of Debris Jams: 13

Step 6/7 Summary

RHA Score/Condition	87/Fair
Habitat Type Departure	None
RGA Score / Condition	40/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- MBWR-1d: Protect floodplain areas and eliminate risk of future development; Buffer planting for long-term bank stabilization.

Reach Highlights: Historically this channel incised and widened due to the encroachment from Rt-11. Both T.S. Irene and July 2014 floods caused extensive bank scour and erosion leading the channel to aggrade as it deposits. Many steep riffles and mid-channel bars are a result of this deposition, as the channel adjusts planform. The portions of the reach that flow adjacent to road bank armor had less ability to adjust planform, however did not show signs of incision. Many flood chutes and migrational features were present away from the bank armor, therefore this reach is currently in Stage IV.

Gully cutting down through mass failure

Depositional features and eroding banks

Stream: Middle Branch **Reach:** T5.09.A **Town:** Andover **Date Assessed**: 08/20/15

Channel Length (ft): 2,747 **Channel Slope (%):** 1.99 **Sinuosity:** 1.17 **Watershed Area (mi²):** 4.6

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	Bc	F

Ph2 Cross-Section Data

Curve Width (ft)	25.6
Bankfull Width (ft)	22
Max Depth (ft)	2.1
Width/Depth Ratio	14.2
Entrenchment Ratio	1.1
Incision Ratio	2.2

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Driveway	70	R/R
B	O's Rd	86	

# of Other Constrictions: 1
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	8	5
2	22	10
3	0	0
4	5	1
5	0	0
6	1	0
7		0
#/mile	69	30

Number of Debris Jams: 4

Step 6/7 Summary

RHA Score/Condition	98/Fair
Habitat Type Departure	None
RGA Score / Condition	45/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B->F
Stream Sensitivity	Extreme

Impact Summary

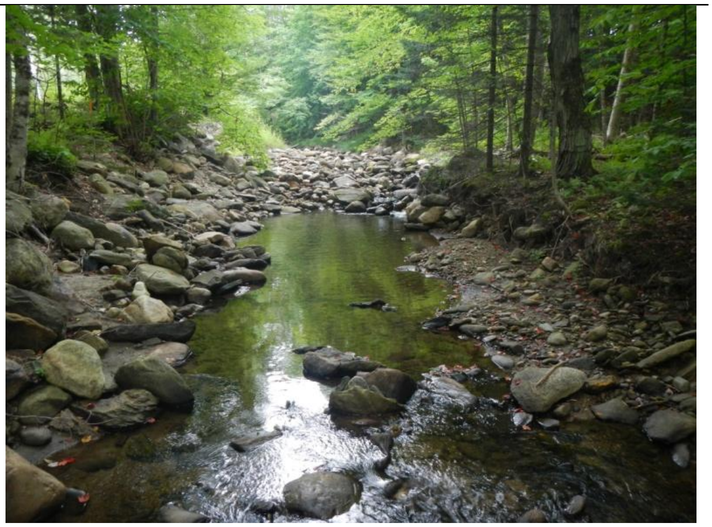
Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- No projects in segment

Reach Highlights: This segment is heavily straightened as it is pinned against Rt-11 and its opposite bank is steep with intermittent bank armoring. This encroachment and straightening has caused considerable incision locking the channel in Stage II and causing a stream type departure from B to F. One small portion of this reach breaks away from the encroachment and armoring and is able to meander and adjust planform through flood deposits. This stretch was not long enough to warrant a segment, since the majority of the reach remains pinned against the road and continues to incise.

Deposition occurs when channel has space to widen



Heavy bank scour and incision

Stream: Middle Branch **Reach:** T5.09.B **Town:** Andover **Date Assessed:** 08/20/15

Channel Length (ft): 1,673 **Channel Slope (%):** 2.75 **Sinuosity:** 1.17 **Watershed Area (mi^2):** 3.83

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	Bc	B

Ph2 Cross-Section Data

Curve Width (ft)	25.6
Bankfull Width (ft)	27
Max Depth (ft)	1.7
Width/Depth Ratio	21.3
Entrenchment Ratio	2.2
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
N/A			

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	21	2
2	16	19
3	0	0
4	2	0
5	1	0
6	2	0
7		0
#/mile	132	66

Number of Debris Jams: 4

Step 6/7 Summary

RHA Score/Condition	103/Fair
Habitat Type Departure	None
RGA Score / Condition	54/Good
Dominant Adjustment	NA/Stable
CEM Model Stage	F/I
Stream Type Departure	None
Stream Sensitivity	Moderate

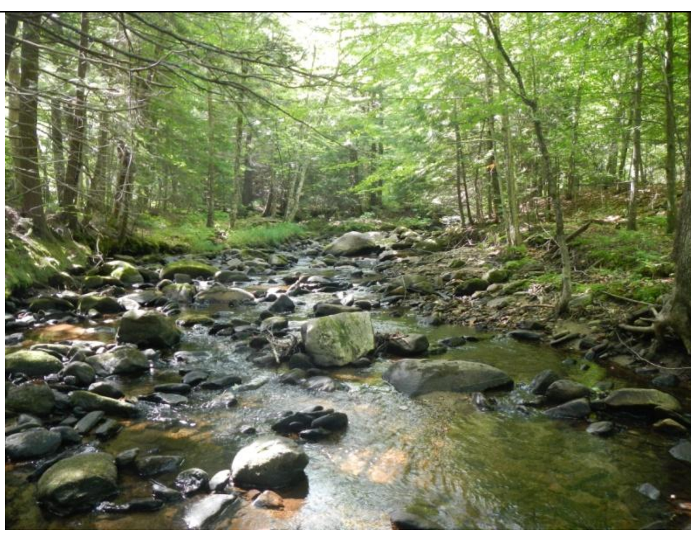
Impact Summary

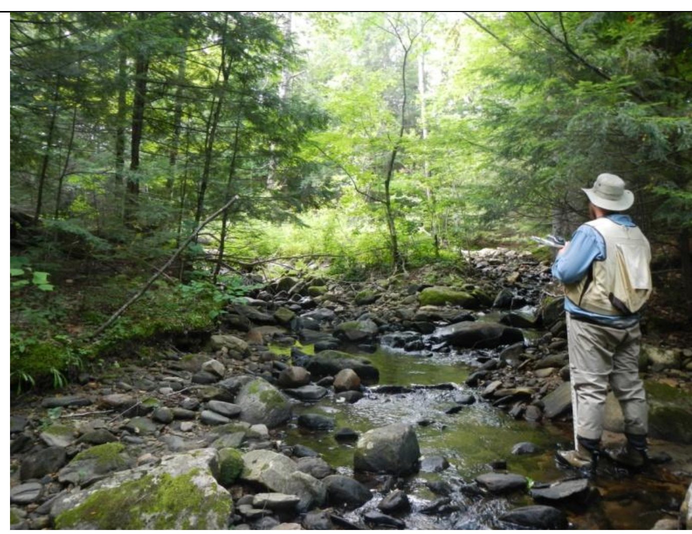
Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- No projects in segment

Reach Highlights: The channel conditions suggest some widening and incision occurred during recent episodic flooding, however it was not enough to indicate an active channel adjustment process. The reach is currently stable and has access to primary floodplain, with minimal evidence of planform adjustment. Therefore this reach was assessed as stage I.


Channel has access to floodplain benches


Confluence of historic and new channels after avulsion

Stream: Middle Branch **Reach:** T5.09.C **Town:** Londonderry, Windham **Date Assessed:** 08/20/15

Channel Length (ft): 866 **Channel Slope (%):** 1.99 **Sinuosity:** 1.17 **Watershed Area (mi^2):** 3.57

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	E	E

Ph2 Cross-Section Data

Curve Width (ft)	25.6
Bankfull Width (ft)	16.5
Max Depth (ft)	1.9
Width/Depth Ratio	8.9
Entrenchment Ratio	2.7
Incision Ratio	1.5

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts

\# of Other Constrictions: 0
\# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	0
2	4	3
3	0	0
4	1	0
5	0	0
6	0	0
7		0
#/mile	73	18

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	103/Fair
Habitat Type Departure	None
RGA Score / Condition	55/Good
Dominant Adjustment	NA/Stable
CEM Model Stage	F/I
Stream Type Departure	None
Stream Sensitivity	High

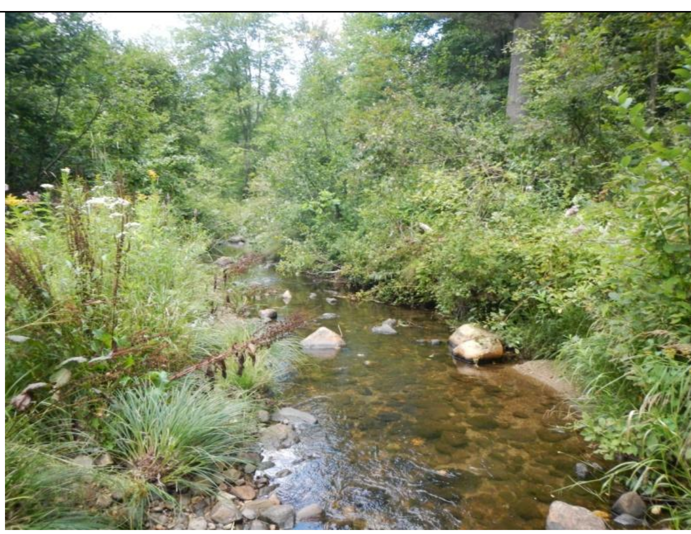
Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- No projects in segment

Reach Highlights: Not influenced by Rt-11 this segment has the ability to meander. The channel has scoured down and filled with deposits after T.S. Irene and subsequent flooding (July 2014). The channel has become more sinuous as it works through the flood deposits. The channel is moderately incised, but does not show any signs of further incision. No indication of active channel migration or widening were observed, therefore the reach was assessed as Stage I.



Narrow channel and steep banks indicate E-type channel

Planform adjustments present throughout segment

Stream: Williams South Branch **Reach:** T5.S1.01 **Town:** Chester **Date Assessed**: 08/11/14

Channel Length (ft): 1,680 **Channel Slope (%):** 1.5 **Sinuosity:** 1.02 **Watershed Area (mi^2):** 10.89

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	37.5
Bankfull Width (ft)	31
Max Depth (ft)	2.6
Width/Depth Ratio	15.4
Entrenchment Ratio	1.3
Incision Ratio	3.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt 103	133%	D

# of Other Constrictions: 0

# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	9	2
2	3	0
3	4	0
4	0	1
5	0	1
6	0	0
7	0	0
#/mile	50	13

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	73/Fair
Habitat Type Departure	None
RGA Score / Condition	33/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to F
Stream Sensitivity	Extreme

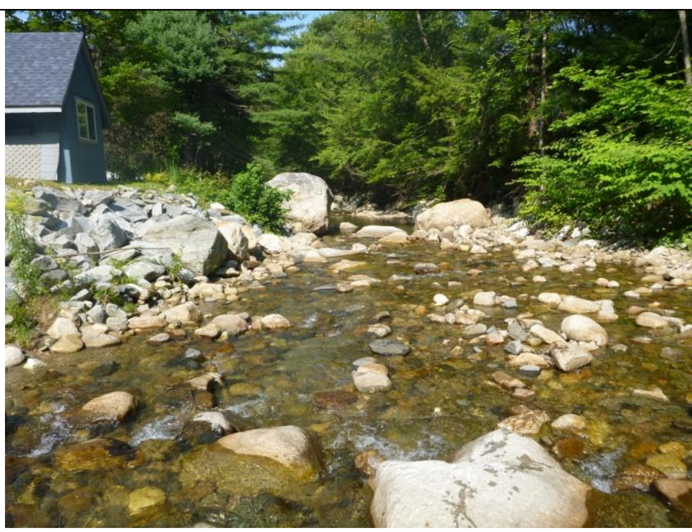
Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

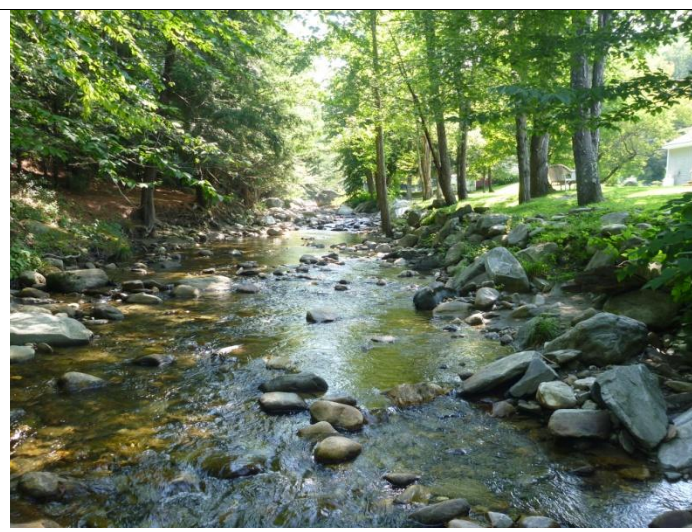
Potential Projects in Reach

- SBWR-1: Monitor Route-103 bridge for sediment deposition. Some sediment removal may be required to increase the bridge's capacity and reduce risk of damage to both the bridge and adjacent properties.

Reach Highlights: This reach has minimal connected floodplain due to the historic straightening and armoring causing the channel to incise. According to local accounts this reach was historically dredged following floods in the 1970's to reduce flood vulnerability to homes along Marshall Rd. The bed was primarily featureless, with the exception of some large cobble deposits around the Rt 103 bridge. This reach is likely stuck in Stage II, as no significant signs of widening or planform adjustment were observed.



Channel aggraded 2-3' since T.S. Irene along Marshall Rd.



View upstream of lower reach

Stream: Williams South Branch **Reach:** T5.S1.02 **Town:** Chester **Date Assessed:** 08/12/14

Channel Length (ft): 7,530 **Channel Slope (%):** 2.11 **Sinuosity:** 1.07 **Watershed Area (mi²):** 10.80

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	Cb	F

Ph2 Cross-Section Data

Curve Width (ft)	37.3
Bankfull Width (ft)	53
Max Depth (ft)	2.1
Width/Depth Ratio	38.4
Entrenchment Ratio	1.3
Incision Ratio	2.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt. 35	64%	D
B	Rt. 35	188%	D

\# of Other Constrictions: 0
\# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	44	42
2	52	8
3	5	4
4	25	3
5	0	1
6	0	1
7	0	0
#/mile	88	41

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	92/Fair
Habitat Type Departure	None
RGA Score / Condition	32/Fair
Dominant Adjustment	Widening
CEM Model Stage	F/III
Stream Type Departure	C to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- SBWR-2: Replace Grafton Rd bridge left bank riprap with a stacked stone wall to increase capacity under the bridge. The increased capacity would reduce the risk of damage during flooding.

Reach Highlights: The upper portion of this reach has some straightening and encroachment, but further downstream the channel flows through a primarily undeveloped valley. Historically the channel has incised and is now widening as the bed works through a large amount of sediment deposited in the reach during the T.S. Irene flood.

Channel widening and aggrading as bars redevelop

Mass failure posing future threat to home

Stream: Williams South Branch **Reach:** T5.S1.03 **Town:** Chester **Date Assessed**: 08/12/14

Channel Length (ft): 4,171 **Channel Slope (%):** 2.5 **Sinuosity:** 1.05 **Watershed Area (mi^2):** 9.78

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Semi Confined
Bedform	Step-Pool	Step-Pool
Median Substrate	Cobble	Cobble
Stream Type	B	B

Ph2 Cross-Section Data

Curve Width (ft)	35.7
Bankfull Width (ft)	35
Max Depth (ft)	2.4
Width/Depth Ratio	21.2
Entrenchment Ratio	1.6
Incision Ratio	1.8

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt. 35	168%	D

\# of Other Constrictions: 1

\# of Grade Controls: 6

Rapid Habitat Assessment

Rank	LWD	Pools
1	14	23
2	6	8
3	8	1
4	5	4
5	0	0
6	0	0
7	0	0
#/mile	42	46

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	77/Fair
Habitat Type Departure	None
RGA Score / Condition	43/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	None
Stream Sensitivity	High

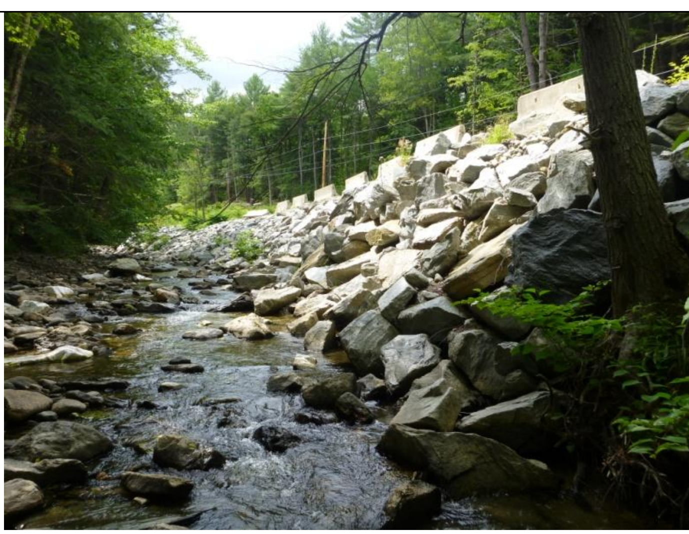
Impact Summary

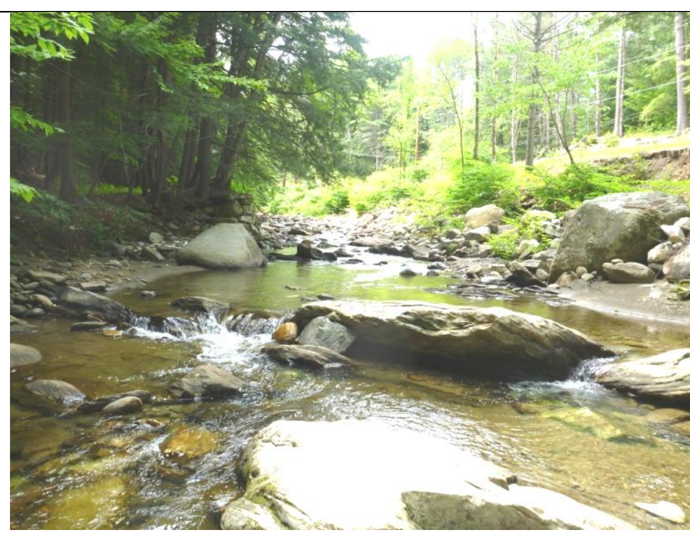
Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	**Dredging**

Potential Projects in Reach

- SBWR-3: Remove old stacked stone abutments to increase the channel and floodprone width.
- SBWR-4a: Stabilize and replace areas of failing armor, making sure new armor is keyed into the channel bottom to reduce the risk of undermining.

Reach Highlights: Both Popple Dungeon and Grafton Road have encroached this reach causing it to incise and lose access to its floodplain. This incision is relatively stable now due to the numerous grade controls, however there was no indication of widening. The reach presents little opportunity for widening or planform adjustment. The Stage II designation is a result of the current incision within the channel, even though the channel is unlikely to incise further.


Bank armor along Grafton Rd, approximately 12' tall


Old abutments constricting channel causing erosion

Stream: Williams South Branch **Reach:** T5.S1.04.A **Town:** Chester **Date Assessed**: 10/02/14

Channel Length (ft): 1,487 **Channel Slope (%):** 1.26 **Sinuosity:** 1.07 **Watershed Area (mi^2):** 9.31

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very-Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	Bc	F

Ph2 Cross-Section Data

Curve Width (ft)	35.0
Bankfull Width (ft)	46
Max Depth (ft)	3.5
Width/Depth Ratio	20.7
Entrenchment Ratio	1.2
Incision Ratio	2.9

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
N/A			

# of Other Constrictions:0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	4
2	10	4
3	0	1
4	4	2
5	0	0
6	0	0
7	0	0
#/mile	64	39

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	94/Fair
Habitat Type Departure	None
RGA Score / Condition	39/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B to F
Stream Sensitivity	Extreme

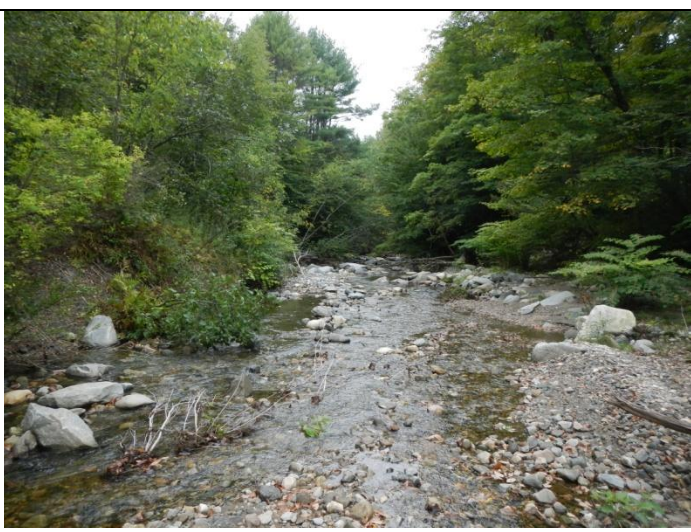
Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- No projects in reach

Reach Highlights: This channel is straightened and in a narrow valley, likely causing the historic incision seen in the reach. During T.S. Irene the channel widened as its lower floodplain benches were scoured away. Currently the channel is aggrading and shows signs of planform adjustment. The lower benches may be restored with further aggradation, returning it to a B-type channel. This reach however remains in Stage II due to incision.


Scouring and widening removed floodplain benches


Riprap armor along south bank mid-segment

Stream: Williams South Branch **Reach:** T5.S1.04.B **Town:** Chester **Date Assessed:** 09/10/14

Channel Length (ft): 3,223 **Channel Slope (%):** 1.6 **Sinuosity:** 1.07 **Watershed Area (mi²):** 9.17

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	35.0
Bankfull Width (ft)	33
Max Depth (ft)	3.0
Width/Depth Ratio	13.5
Entrenchment Ratio	1.3
Incision Ratio	2.0

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Private	51%	None

# of Other Constrictions:0
# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	2
2	7	8
3	7	3
4	2	0
5	0	0
6	0	0
7	0	0
#/mile	33	21

Number of Debris Jams: 3

Step 6/7 Summary

RHA Score/Condition	76/Fair
Habitat Type Departure	None
RGA Score / Condition	37/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- SBWR-4b: Stabilize and replace areas of failing armor, making sure new armor is keyed into the channel bottom to reduce the risk of undermining.

Reach Highlights: Historic straightening and bank armoring have caused this channel to incise and become entrenched. The bed has continued bar formation along channel margins, but is primarily stable. The downstream portion of this reach was able to erode through the bank armoring, likely in T.S. Irene, resulting in planform adjustment. However, the rest of the reach remains locked in place. This reach is currently in stage II, but may transition towards stage III as the channel continues to aggrade.

Buffer <25ft and flood plain not easily accessible

Channel widened to 90’ and filled with 2-3’ of deposits

Stream: Williams South Branch **Reach:** T5.S1.05 **Town:** Chester **Date Assessed:** 09/09/14

Channel Length (ft): 2,656 **Channel Slope (%):** 1.5 **Sinuosity:** 1.03 **Watershed Area (mi^2):** 8.67

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Narrow	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Gravel
Stream Type	Bc	F

Ph2 Cross-Section Data

Curve Width (ft)	33.9
Bankfull Width (ft)	42
Max Depth (ft)	2.7
Width/Depth Ratio	23.1
Entrenchment Ratio	1.2
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Private	147%	None
B	Popple Dungeon Rd	83%	A

# of Other Constrictions:0

# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	9	5
2	14	2
3	4	3
4	2	0
5	3	0
6	3	0
7	0	0
#/mile	70	20

Number of Debris Jams: 2

Step 6/7 Summary

RHA Score/Condition	96/Fair
Habitat Type Departure	None
RGA Score / Condition	39/Fair
Dominant Adjustment	Aggradation
CEM Model Stage	F/III
Stream Type Departure	B to F
Stream Sensitivity	Extreme

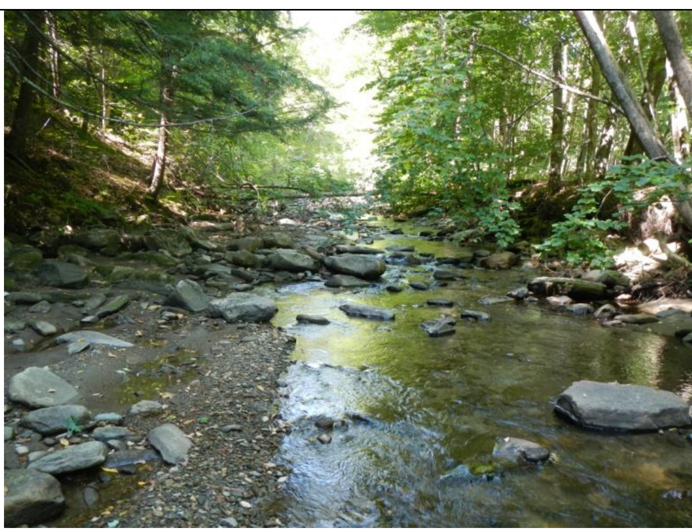
Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- No projects in reach

Reach Highlights: This reach has incised from historic straightening and encroachment, but widened during T.S. Irene. The lower benches throughout this reach were scoured away by the floods resulting in a stream type departure from B to F. The bars are reforming within the widened channel and aggradation may slowly restore floodplain access. The recent widening and current aggradation, and no sign of incision, suggests this reach is in stage III of the channel evolution model.



Channel has poor planform as it works through deposits

Many areas of bank scour visible from channel widening

Stream: Williams South Branch **Reach:** T5.S1.06 **Town:** Chester **Date Assessed:** 10/01/14

Channel Length (ft): 3,540 **Channel Slope (%):** 1.68 **Sinuosity:** 1.14 **Watershed Area (mi^2):** 8.23

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	33.1
Bankfull Width (ft)	40
Max Depth (ft)	2.5
Width/Depth Ratio	25.5
Entrenchment Ratio	1.5
Incision Ratio	1.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
N/A			

# of Other Constrictions:0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	10
2	12	3
3	1	0
4	1	0
5	1	0
6	0	0
7	0	0
#/mile	25	19

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	94/Fair
Habitat Type Departure	None
RGA Score / Condition	35/Fair
Dominant Adjustment	Widening
CEM Model Stage	F/III
Stream Type Departure	C to B
Stream Sensitivity	High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	Constrictions
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- SBWR-5: Remove the 300ft berm to regain access to the floodplain south of Popple Dungeon Rd.

Reach Highlights: Historic straightening, armoring, and berming have caused Reach T5.S1.06 to incise. During T.S. Irene the channel widened by scouring away its lower floodplain benches. This reduction in floodplain access and changed channel geometry caused a stream type departure from C to B. The channel does not appear to be incising further and has some areas of deposition and widening driving its stage III designation.

Channel widened and still maintained floodplain bench

Boulders collect and imbricate as channel constricts

Stream: Williams South Branch **Reach:** T5.S1.07 **Town:** Chester **Date Assessed**: 10/02/14

Channel Length (ft): 3,540 **Channel Slope (%):** 2.5 **Sinuosity:** 1.16 **Watershed Area (mi^2):** 7.01

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Broad
Bedform	Step-Pool	Step-Pool
Median Substrate	Gravel	Cobble
Stream Type	B	F

Ph2 Cross-Section Data

Curve Width (ft)	30.9
Bankfull Width (ft)	34
Max Depth (ft)	2.7
Width/Depth Ratio	22.0
Entrenchment Ratio	1.1
Incision Ratio	3.3

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Private Driveway	117%	D,S
C	Popple Dungeon Rd.	53%	D,S,A

# of Other Constrictions:0
# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	14	13
2	45	8
3	11	7
4	17	1
5	0	0
6	0	1
7	0	0
#/mile	130	45

Number of Debris Jams: 10

Step 6/7 Summary

RHA Score/Condition	77/Fair
Habitat Type Departure	None
RGA Score / Condition	27/Poor
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	**Head Cut**
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- SBWR6-: Restore access to floodplain along Popple Dungeon Rd by removing three berms totaling 550ft.
- SBWR-7: Replace a culvert near Zezza Rd with a larger culvert and an extended north wingwall to increase capacity of the structure and reduce damage potential.

Reach Highlights: This reach is highly active as large amounts of sediment are working through and being stored in this reach. The channel has incised and entrenched causing the reach to depart from a B to an F type channel. During T.S. Irene the channel incised then widened, scouring away the lower floodplain benches. Coarse material has begun to deposit throughout the channel and finer material has collected on the margins. This reach is assessed as stage II from incision, though it may transition to stage III soon if aggradation continues.

Channel widened, but hasn't rebuilt floodplain benches

Mass failure due to debris jam and channel widening

Stream: Williams South Branch **Reach:** T5S1.08 **Town:** Chester **Date Assessed**: 10/02/14

Channel Length (ft): 4,715 **Channel Slope (%):** 2.5 **Sinuosity:** 1.07 **Watershed Area (mi²):** 5.38

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Step-Pool	Plane-Bed
Median Substrate	Cobble	Cobble
Stream Type	B	F

Ph2 Cross-Section Data

Curve Width (ft)	27.5
Bankfull Width (ft)	33
Max Depth (ft)	2.3
Width/Depth Ratio	19.3
Entrenchment Ratio	1.3
Incision Ratio	2.2

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Nudist Camp Rd.	153%	D, A
B	Popple Dungeon Rd.	73%	S,A

# of Other Constrictions:0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	0	7
2	12	1
3	2	4
4	8	1
5	0	0
6	0	0
7	0	0
#/mile	25	15

Number of Debris Jams: 4

Step 6/7 Summary

RHA Score/Condition	73/Fair
Habitat Type Departure	Plane-Bed
RGA Score / Condition	33/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B to F
Stream Sensitivity	Extreme

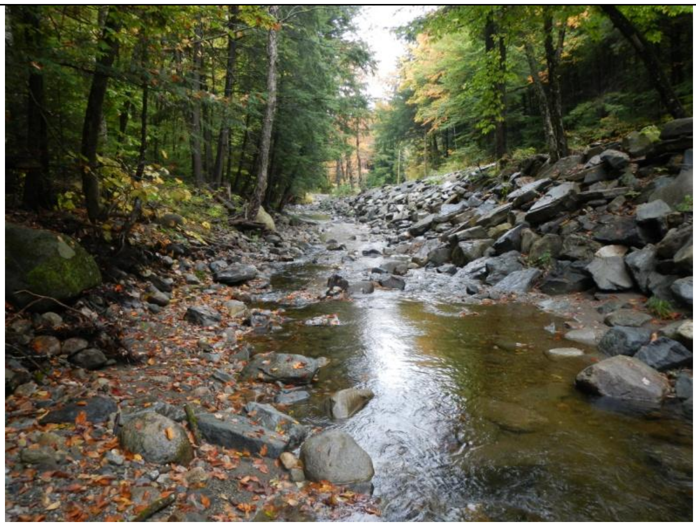
Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	**Head Cut**
Mass Failure	Straightening
Flow Regulation	**Dredging**

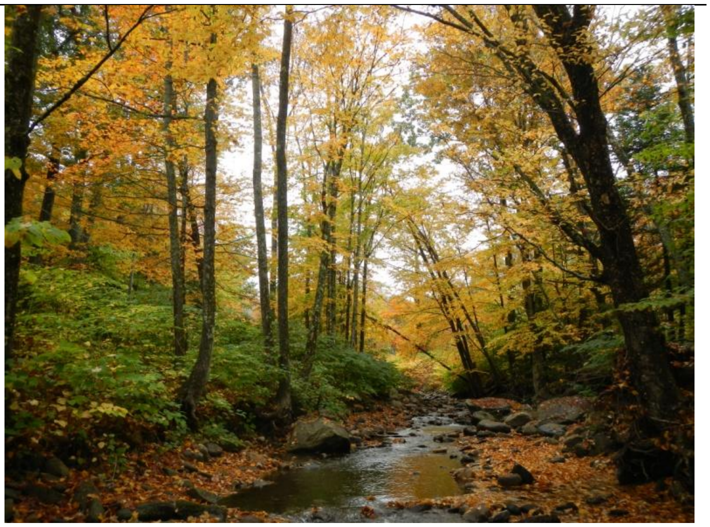
Potential Projects in Reach

- SBWR-4c: Stabilize and replace areas of failing armor, making sure new armor is keyed into the channel bottom to reduce the risk of undermining.

Reach Highlights: By reference this reach has a B type channel with floodplain on one or both banks throughout. The channel has incised due to historic armoring and encroachment along Popple Dungeon Road. The channel incised and widened scouring away the lower floodplain benches causing the channel to depart from a B to and F type channel. The channel margins have begun to fill in with deposits, but the channel still appears to be incising in many areas due to the lack of grade control. This incision indicates the reach remains in stage II.



Channel armored against Popple Dungeon road



Room for channel to widen away from road, but still F

Stream: Williams South Branch **Reach:** T5.S1.09 **Town:** Chester **Date Assessed:** 10/02/14

Channel Length (ft): 4,993 **Channel Slope (%):** 2.2 **Sinuosity:** 1.17 **Watershed Area (mi^2):** 3.89

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	Cb	F

Ph2 Cross-Section Data

Curve Width (ft)	23.8
Bankfull Width (ft)	30
Max Depth (ft)	2.0
Width/Depth Ratio	20.2
Entrenchment Ratio	1.3
Incision Ratio	1.9

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Private	84%	None

\# of Other Constrictions:0
\# of Grade Controls: 2

Rapid Habitat Assessment

Rank	LWD	Pools
1	2	4
2	22	8
3	12	3
4	10	2
5	1	0
6	0	0
7	0	0
#/mile	50	18

Number of Debris Jams: 4

Step 6/7 Summary

RHA Score/Condition	90/Fair
Habitat Type Departure	None
RGA Score / Condition	32/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B to F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- SBWR-4d-e: Stabilize and replace areas of failing armor, making sure new armor is keyed into the channel bottom to reduce the risk of undermining.

Reach Highlights: This reach has incised and departed from C to F type channel geometry. This departure likely happened in stages prior to T.S. Irene then channel likely incised and departed to B type, but during T.S. Irene the low floodplain benches likely scoured away leaving the channel very incised with F type geometry. Deposition was present along much of the widened channel. The limited amount of bedrock grade controls has allowed the channel to incise further. This reach is currently in stage II as it continues to incise, but when deposition becomes the dominant process it will transition to stage III.

T.S. Irene scour and widening

Reference C, now aggrading to regain floodplain access

Stream: Lover's Lane Brook **Reach:** T5.S2.01.A **Town:** Chester **Date Assessed:** 06/16/15

Channel Length (ft): 2,219 **Channel Slope (%):** 0.79 **Sinuosity:** 1.16 **Watershed Area (mi^2):** 3.6

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	E	E

Ph2 Cross-Section Data

Curve Width (ft)	23.0
Bankfull Width (ft)	14
Max Depth (ft)	1.9
Width/Depth Ratio	10.5
Entrenchment Ratio	15.2
Incision Ratio	1.5

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Pleasant St.	165%	None
C	Private	43%	D

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	18	6
2	12	9
3	7	4
4	2	2
5	0	2
6	0	0
7		0
#/mile	92	54

Number of Debris Jams: 6

Step 6/7 Summary

RHA Score/Condition	97/Fair
Habitat Type Departure	None
RGA Score / Condition	50/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	None
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- LLB-1: Remove the steel culvert under the abandoned trail immediately upstream of the Middle Branch confluence. The embankments should be cut back to a stable slope.

Reach Highlights: This reach is pinned against the left valley wall and has been historically straightened. The reach maintains sufficient floodplain access for an E type stream, despite being incised. The upper portion of this reach is less straightened and resembles more reference conditions. There were no real signs of widening or channel adjustment, therefore this reach is assessed as a stage II for its incision.

E-type channel geometry with dense bank growth

Culvert at confluence that should be removed

Stream: Lover's Lane Brook **Reach:** T5.S2.01.B **Town:** Chester **Date Assessed:** 06/16/15

Channel Length (ft): 2,438 **Channel Slope (%):** 0.50 **Sinuosity:** 1.16 **Watershed Area (mi^2):** 3.55

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	23.0
Bankfull Width (ft)	23
Max Depth (ft)	2.4
Width/Depth Ratio	11.8
Entrenchment Ratio	5.3
Incision Ratio	1.9

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Depot Rd.	235%	None
C	Maple St.	65%	None

# of Other Constrictions: 0

# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	4
2	5	8
3	5	2
4	2	0
5	0	0
6	0	0
7		0
#/mile	41	30

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	103/Fair
Habitat Type Departure	None
RGA Score / Condition	51/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	None
Stream Sensitivity	High

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- LLB-2: Protect the large forested floodplain along the north bank of the brook on the Chester Elementary School property. Reduces risk of future development and ensures floodplain access in the future.

Reach Highlights: This reach historically has been straightened and armored to remain along the edge of a field near the valley wall. The channel has incised, but still has access to the large surrounding hay and forested floodplains. No active incision, widening, or planform adjustment were observed. This reach is assessed as stage II, but widening or planform adjustment may occur as flood sediment and debris work through the reach.

Floodplain becomes more accessible from aggradation

Bank scour along cemetery downstream from armor

Stream: Lover's Lane Brook **Reach:** T5.S2.01.C **Town:** Chester **Date Assessed:** 06/16/15

Channel Length (ft): 5,124 **Channel Slope (%):** 0.35 **Sinuosity:** 1.16 **Watershed Area (mi^2):** 3.45

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	E

Ph2 Cross-Section Data

Curve Width (ft)	23.0
Bankfull Width (ft)	12
Max Depth (ft)	2.2
Width/Depth Ratio	7.7
Entrenchment Ratio	6.7
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Church St.	65%	None
B	VAST	139%	None
C	Private	26%	None
C	Lover's Ln.	39%	None

# of Other Constrictions: 0
# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	21	6
2	20	21
3	6	6
4	2	5
5	1	0
6	1	0
7		0
#/mile	52	39

Number of Debris Jams: 6

Step 6/7 Summary

RHA Score/Condition	108/Good
Habitat Type Departure	None
RGA Score / Condition	48/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C->E
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	Deposition
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- LLB-3: Replace a farm road culvert that is currently a major bankfull constriction with a larger structure. This would reduce damage from flooding by increasing its capacity.
- LLB-4: Restore an appropriately-sized channel and floodplain in a segment where the channel has deeply incised through a farm field. Plant buffer with native vegetation to stabilize banks. This channel restoration would allow floodplain access to be restored reducing the risk of flooding downstream.

Reach Highlights: Extensive road encroachment and historic straightening cause this segment to be highly variable. The channel geometry remains consistent, though several areas are highly impacted by historic straightening. The channel is narrow and incised, but still has access to adjacent floodplain. The channel exhibits E type geometry departed from C type. Widening and planform adjustment are limited by bank armoring and straightening, therefore the segment remains in stage II.

Channel shrinks along historical armor and straightening

Stream pinched against valley wall

Stream: Andover Branch **Reach:** T5.S3.01 **Town:** Chester **Date Assessed**: 06/25/15

Channel Length (ft): 5,701 **Channel Slope (%):** 1.25 **Sinuosity:** 1.18 **Watershed Area (mi^2):** 12.68

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	40.1
Bankfull Width (ft)	63
Max Depth (ft)	2.7
Width/Depth Ratio	36.8
Entrenchment Ratio	1.3
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Rt-11	75%	D

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	17	5
2	54	7
3	2	4
4	12	3
5	0	0
6	1	2
7		0
#/mile	79	19

Number of Debris Jams: 10

Step 6/7 Summary

RHA Score/Condition	87/Fair
Habitat Type Departure	None
RGA Score / Condition	36/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- AB-1a-b: Stabilize banks and replace failing armor with new armor keyed into the channel bottom to reduce the risk of undermining.
- AB-2a: Suggested corridor protection for undeveloped floodplain that plays an important role in sediment and floodwater attenuation.

Reach Highlights: This reach is extremely active since the flooding in July 2014. T5.S3.01 widened and aggraded with flood deposits during the storm. Many areas of active erosion and extensive bank scour exist along the reach, which indicates recent widening. This reach contains many large bars, including multiple mid-channel and diagonal bars. Large scour pools exist below steep riffles as the bed tries to regain a riffle-pool sequence. This reach is in stage IV due to its planform adjustments. There is moderate floodplain accessibility throughout the reach.

Raw bank erosion and armor along Rt-11

Large depositional features in highly active reach

Stream: Andover Branch **Reach:** T5.S3.02 **Town:** Chester, Andover **Date Assessed**: 06/26/15

Channel Length (ft): 6,309 **Channel Slope (%):** 1.93 **Sinuosity:** 1.09 **Watershed Area (mi^2):** 8.33

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Plane Bed	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	Bc	F

Ph2 Cross-Section Data

Curve Width (ft)	33.3
Bankfull Width (ft)	42
Max Depth (ft)	2.5
Width/Depth Ratio	24.7
Entrenchment Ratio	1.3
Incision Ratio	2.6

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Andover Rd	84%	D
C	Potash Brook Rd.	45%	D
C	Potash Brook Rd.	15%	D

# of Other Constrictions: 0
# of Grade Controls: 3

Rapid Habitat Assessment

Rank	LWD	Pools
1	10	5
2	36	5
3	5	7
4	12	0
5	3	2
6	1	0
7		0
#/mile	56	15

Number of Debris Jams: 11

Step 6/7 Summary

RHA Score/Condition	89/Fair
Habitat Type Departure	Riffle-Pool
RGA Score / Condition	38/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	B->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- AB-3: Replace Potash Brook Rd culvert for the flood chute with a much larger structure that has an overflow pipe to mitigate damage in high flow events. This larger structure will allow the flood chute to function properly and reduce flooding in storm events. An engineering study commissioned by the Town of Chester is currently in progress. An aluminum box culvert with a span of 26ft is expected to be installed to replace the undersized culvert in late 2016 or 2017.

Reach Highlights: The July 2014 flood caused this channel to scour down and widen, before depositing a large amount of cobble and gravel. Currently there are large mid-channel and diagonal bars as the river works through the deposits. Numerous flood chutes and avulsions are also present within the reach. Two cross sections were measured to depict its variability. The primary cross section is incised and has no floodplain access, but is actively aggrading. The secondary cross section is over-widened and filled with flood deposits, allowing some floodplain access. The major planform adjustments present in this reach result in its stage IV designation.

Diagonal riffle where channel is adjusting planform

Potential avulsion site with undersized culvert

Stream: Andover Branch **Reach:** T5.S3.03 **Town:** Andover **Date Assessed:** 06/26/15

Channel Length (ft): 5,287 **Channel Slope (%):** 1.25 **Sinuosity:** 1.18 **Watershed Area (mi^2):** 7.69

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	32.1
Bankfull Width (ft)	34
Max Depth (ft)	2.3
Width/Depth Ratio	20.4
Entrenchment Ratio	1.7
Incision Ratio	1.8

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Pettengill Rd	69%	None
B	Andover Rd	109%	D

\# of Other Constrictions: 0
\# of Grade Controls: 1

Rapid Habitat Assessment

Rank	LWD	Pools
1	14	5
2	42	4
3	6	5
4	8	1
5	1	1
6	0	0
7		0
#/mile	70	15

Number of Debris Jams: 9

Step 6/7 Summary

RHA Score/Condition	106/Good
Habitat Type Departure	None
RGA Score / Condition	39/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	C->B
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- AB-1c: Stabilize banks and replace failing armor with new armor keyed into the channel bottom to reduce the risk of undermining.
- AB-4: Move a utility pole away from the head of a very active mass failure, in order to not disrupt service.

Reach Highlights: Prior to the July 2014 flooding this reach was incised from historic straightening. Floodplain access was restored in many areas from aggradation during the July 2014 flood. By reference this is a C-type channel departed to an F-type from incision, but the aggradation during the flood has allowed the channel to move to a B-type channel with some areas of C-type. The planform adjustments from the aggrading channel are the reason for its stage IV in the channel evolution model.


Actively eroding bank along Lamson Rd.


Steep riffle formed by channel aggradation

Stream: Andover Branch **Reach:** T5.S3.04.A **Town:** Andover **Date Assessed:** 07/01/15

Channel Length (ft): 1,895 **Channel Slope (%):** 1.59 **Sinuosity:** 1.06 **Watershed Area (mi^2):** 5.88

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Cobble
Stream Type	C	F

Ph2 Cross-Section Data

Curve Width (ft)	28.6
Bankfull Width (ft)	25
Max Depth (ft)	2.0
Width/Depth Ratio	13.4
Entrenchment Ratio	1.3
Incision Ratio	3.8

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
N/A			

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	3	4
2	14	3
3	0	0
4	5	1
5	0	0
6	1	0
7		0
#/mile	64	22

Number of Debris Jams: 3

Step 6/7 Summary

RHA Score/Condition	100/Fair
Habitat Type Departure	None
RGA Score / Condition	50/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	Stormwater
Armoring	Constrictions
Riparian Buffer	Deposition
Encroachment	Migration
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- No projects in segment

Reach Highlights: This segment his encroached upon by Weston-Andover Rd, reducing its ability to adjust planform and causing the channel to incise. This incision is exacerbated by the presence of berms. This reach continues to be stuck in stage II, since incision is present and there were no signs of aggradation or planform adjustment.

Narrow channel, with F-type channel geometry

Widened channel, but still F-type channel geometry

Stream: Andover Branch **Reach:** T5.S3.04.B **Town:** Andover **Date Assessed:** 07/01/15

Channel Length (ft): 2,820 **Channel Slope (%):** 1.59 **Sinuosity:** 1.06 **Watershed Area (mi^2):** 5.44

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	28.6
Bankfull Width (ft)	26
Max Depth (ft)	2.2
Width/Depth Ratio	14.3
Entrenchment Ratio	13.4
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Andover Rd	112%	D
B	Andover Rd	175%	None
B	Private	175%	None

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	3	1
2	19	2
3	4	0
4	6	0
5	0	0
6	0	0
7		0
#/mile	59	5

Number of Debris Jams: 4

Step 6/7 Summary

RHA Score/Condition	83/Fair
Habitat Type Departure	None
RGA Score / Condition	47/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- AB-2b: Suggested corridor protection for undeveloped floodplain that plays an important role in sediment and floodwater attenuation.
- AB-5: Remove a berm along the eastern edge of Horseshoe Acres Campground in order to restore access to an important historic flood chute.
- AB-6: Remove portions of a 350ft historic berm to restore floodplain access along Weston Andover Rd. To ensure road embankment stability new armor should be installed along road if berm is removed.

Reach Highlights: Active planform adjustments are present in this segment. The lower reach includes a beaver complex where multiple dams greatly alter planform. Upstream there is a campground, which experienced a lot of flooding during T.S. Irene and the July 2014 flood. These floods have generated a large flood chute which has since been cut off by a berm. There is consistent floodplain access throughout the segment and there are local areas of incision and widening. This segment is designated as stage IV because of the active planform adjustments throughout the reach.

Floodplain access along campground

Berm cutting off access to flood chute by campground

Stream: Andover Branch **Reach:** T5.S3.05.A **Town:** Andover **Date Assessed**: 07/28/15

Channel Length (ft): 1,956 **Channel Slope (%):** 1.64 **Sinuosity:** 1.05 **Watershed Area (mi^2):** 2.93

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	Bc

Ph2 Cross-Section Data

Curve Width (ft)	21.0
Bankfull Width (ft)	17
Max Depth (ft)	1.7
Width/Depth Ratio	13.2
Entrenchment Ratio	1.4
Incision Ratio	2.2

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Old Gulf Rd.	62%	D
B	Private	43%	None
O	Private	57%	None

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	7	5
2	5	3
3	0	0
4	0	0
5	0	0
6	0	0
7		0
#/mile	32	21

Number of Debris Jams: 0

Step 6/7 Summary

RHA Score/Condition	90/Fair
Habitat Type Departure	None
RGA Score / Condition	43/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	C->B
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	**Migration**
Development	Steep Riffle
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- AB-7a-b: Secure exposed utility lines to the bottom of the bridges in the campground. The currently exposed utility lines risk service interruption.
- AB-8: Remove several small berms blocking many flood chutes and side channels, in order to restore access to this high-quality forested floodplain

Reach Highlights: This segment has departed from a C to B-type channel due to incision caused by encroachment, straightening, and bank armoring. The banks are consistently scoured from large flooding events, such as T.S. Irene and July 2014. Despite the bank scour this reach remains in stage II until it is able to widen and adjust planform beyond the bank armor.


Historic abutments constricting channel


Channel stuck in stage II with mostly stable banks

Stream: Andover Branch **Reach:** T5.S3.05.B **Town:** Andover **Date Assessed:** 07/28/15

Channel Length (ft): 2,279 **Channel Slope (%):** 1.64 **Sinuosity:** 1.05 **Watershed Area (mi²):** 2.83

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Very Broad	Very Broad
Bedform	Riffle-Pool	Riffle-Pool
Median Substrate	Gravel	Gravel
Stream Type	C	C

Ph2 Cross-Section Data

Curve Width (ft)	21.0
Bankfull Width (ft)	22
Max Depth (ft)	2.2
Width/Depth Ratio	15.9
Entrenchment Ratio	3.1
Incision Ratio	1.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Old Gulf Rd	69%	D

# of Other Constrictions: 0
# of Grade Controls: 0

Rapid Habitat Assessment

Rank	LWD	Pools
1	4	4
2	10	5
3	1	1
4	1	0
5	0	0
6	0	0
7		1
#/mile	37	25

Number of Debris Jams: 1

Step 6/7 Summary

RHA Score/Condition	104/Good
Habitat Type Departure	None
RGA Score / Condition	54/Fair
Dominant Adjustment	Planform
CEM Model Stage	F/IV
Stream Type Departure	None
Stream Sensitivity	Very High

Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	**Dredging**

Potential Projects in Reach

- No projects in segment

Reach Highlights: This reach winds through a historic beaver meadow. There are still areas of localized aggradation, but the dominant channel adjustment process is planform adjustment. This adjustment is seen as scour on the outside of meanders and the multiple mid-channel bars throughout the segment. These adjustments result in this reach being in stage IV of the channel evolution model.

Adjusting planform with accessible floodplain

Scoured banks depict recent widening by the channel

Stream: Potash Brook **Reach:** T5.S3.a.01 **Town:** Chester **Date Assessed:** 07/29/15

Channel Length (ft): 6,162 **Channel Slope (%):** 3.62 **Sinuosity:** 1.04 **Watershed Area (mi^2):** 3.75

Stream Type Summary

	P1 Reference	P2 Assessed
Confinement	Broad	Narrow
Bedform	Step-Pool	Riffle-Pool
Median Substrate	Cobble	Cobble
Stream Type	B	F

Ph2 Cross-Section Data

Curve Width (ft)	23.4
Bankfull Width (ft)	26
Max Depth (ft)	1.7
Width/Depth Ratio	21.1
Entrenchment Ratio	1.2
Incision Ratio	4.5

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Potash Brook Rd	77%	D
C	Potash Brook Rd	30%	D
C	Potash Brook Rd	57%	D,S
BR	Private	85%	None

# of Other Constrictions: 0
# of Grade Controls: 4

Rapid Habitat Assessment

Rank	LWD	Pools
1	34	10
2	97	4
3	10	1
4	23	1
5	0	0
6	2	0
7		1
#/mile	142	14

Number of Debris Jams: 20

Step 6/7 Summary

RHA Score/Condition	80/Fair
Habitat Type Departure	Riffle-Pool
RGA Score / Condition	39/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	B->F
Stream Sensitivity	Extreme

Impact Summary

Bank Erosion	**Stormwater**
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	Straightening
Flow Regulation	Dredging

Potential Projects in Reach

- PB-1: Replace failing armor downstream of the first Potash Brook Rd crossing, where the channel is migrating towards the house.
- PB-2: Replace the Potash Brook Rd. culvert with a structure that is designed to the curve width channel or greater given the high sediment and debris loads at this location. This project was completed by the Town of Chester in 2016.

Reach Highlights: This reach has a reduced valley width due to frequent encroachment by Potash Brook Rd. The flooding during July 2014 left behind a channel that incised then widened. Potash Brook Rd was severely damaged in many locations. The large woody debris in the channel is storing large volumes of sediment, but floodplain access remains limited. The ongoing incision has resulted in the stream type departure from B to F-type and the stage II designation.

Culvert needing replacement along Potash Brook Rd.

Sediment stored by debris jam

Stream: Trout Brook **Reach:** T5.S3.b.01 **Town:** Andover **Date Assessed**: 07/28/15

Channel Length (ft): 4,804 **Channel Slope (%):** 4.5 **Sinuosity:** 1.00 **Watershed Area (mi^2):** 2.20

Stream Type Summary

	P1 Reference	**P2 Assessed**
Confinement	Semi Confined	Semi Confined
Bedform	Step-Pool	Step-Pool
Median Substrate	Cobble	Cobble
Stream Type	A	A

Ph2 Cross-Section Data

Curve Width (ft)	18.5
Bankfull Width (ft)	19
Max Depth (ft)	2.3
Width/Depth Ratio	12.3
Entrenchment Ratio	1.5
Incision Ratio	2.7

Crossing/Constriction Summary

Type	Location	% wbkf	Impacts
B	Private	97%	D
B	Private	189%	D
B	Weston-Andover Rd.	378%	D

\# of Other Constrictions: 0

\# of Grade Controls: 3

Rapid Habitat Assessment

Rank	LWD	Pools
1	13	8
2	28	6
3	6	0
4	8	0
5	1	0
6	0	0
7		0
#/mile	72	18

Number of Debris Jams: 6

Step 6/7 Summary

RHA Score/Condition	71/Fair
Habitat Type Departure	None
RGA Score / Condition	32/Fair
Dominant Adjustment	Incision
CEM Model Stage	F/II
Stream Type Departure	None
Stream Sensitivity	Extreme

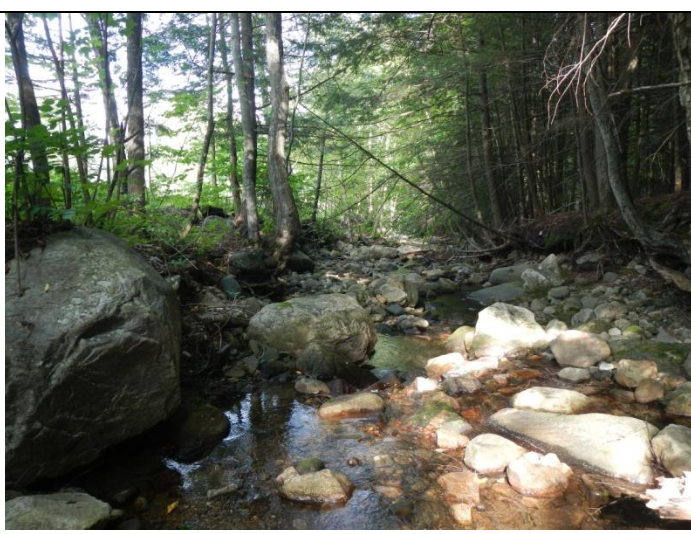
Impact Summary

Bank Erosion	Stormwater
Armoring	**Constrictions**
Riparian Buffer	**Deposition**
Encroachment	Migration
Development	**Steep Riffle**
Corridor LC	Head Cut
Mass Failure	**Straightening**
Flow Regulation	Dredging

Potential Projects in Reach

- TRB-1: Secure exposed utility lines to the bottom of the bridges in the campground. The currently exposed utility lines risk service interruption.
- TRB-2: Remove a poured concrete stream ford that is currently acting as a grade control and AOP barrier, and is no longer functional as a crossing. The structure should be replaced with a boulder step to reduce risk of upstream incision.

Reach Highlights: This reach is encroached heavily by Weston-Andover Rd, as well as straightened and bermed in many locations. Widening potential is severely limited by encroachment and a near continuous valley wall, which has resulted in channel incision. Significant scour occurred during the flooding in July 2014, which also deposited large boulders behind debris jams and areas of localizes slope increases. There is very little fine sediment being stored by this reach, which supports the stage II designation.



Channel filled with boulders and incised

Channel aggrades enough to overtop old bridge

4.2 Phase 2 Results Summary

Rapid Habitat Assessment (RHA) and Rapid Geomorphic Assessment (RGA) scores for all Phase 2 reaches/segments are summarized in Table 4.2 and Figures 4.4 and 4.5. We divided the "Fair" category into "Low Fair" and "High Fair" to better indicate which reaches were closer to "Poor" or "Good" respectively. The "Fair" scores were split at the numerical mean for the categories. Detailed summaries of geomorphic data for each segment are provided in Appendix A. Habitat assessment summary data is provided in Appendix B.

Table 4.2: Summary RHA and RGA data for all Phase 2 reaches and segments

Stream	Reach/Segment	RHA Score	RHA Condition	RGA Score	RGA Condition
Williams River	M07.A	*	Low Fair	*	Low Fair
	M07.B	47%	Low Fair	44%	Low Fair
	M08.A	35%	Low Fair	36%	Low Fair
	M08.B	53%	High Fair	39%	Low Fair
	M09	44%	Low Fair	39%	Low Fair
	M10	39%	Low Fair	41%	Low Fair
	M11	39%	Low Fair	29%	Poor
	M12	49%	Low Fair	45%	Low Fair
	M13	47%	Low Fair	41%	Low Fair
	M14	39%	Low Fair	46%	Low Fair
	M15	54%	High Fair	46%	Low Fair
	M16	46%	Low Fair	54%	High Fair
	M17	50%	High Fair	59%	High Fair
	M18	47%	Low Fair	60%	High Fair
	M19.A	54%	High Fair	69%	Good
	M19.B	56%	High Fair	56%	High Fair
	M19.C	58%	High Fair	47%	Low Fair
	M20.A	54%	High Fair	57%	High Fair
	M20.B	50%	High Fair	46%	Low Fair
	M21	56%	High Fair	47%	Low Fair
	M22	67%	Good	60%	High Fair
Middle Branch	T5.01	40%	Low Fair	44%	Low Fair
	T5.02	41%	Low Fair	34%	Low Fair
	T5.03	51%	High Fair	30%	Poor
	T5.04	56%	High Fair	41%	Low Fair
	T5.05.A	52%	High Fair	30%	Poor
	T5.05.B	56%	High Fair	44%	Low Fair
	T5.05.C	*	High Fair	*	Low Fair
	T5.06	59%	High Fair	35%	Low Fair
	T5.07	56%	High Fair	51%	High Fair

Table 4.2: Summary RHA and RGA data for all Phase 2 reaches and segments

Stream	Reach/Segment	RHA Score	RHA Condition	RGA Score	RGA Condition
	T5.08	54%	High Fair	50%	High Fair
	T5.09.A	61%	High Fair	56%	High Fair
	T5.09.B	70%	Good	68%	Good
	T5.09.C	65%	Good	69%	Good
South Branch	T5.S1.01	46%	Low Fair	41%	Low Fair
	T5.S1.02	58%	High Fair	40%	Low Fair
	T5.S1.03	48%	Low Fair	54%	High Fair
	T5.S1.04.A	59%	High Fair	49%	Low Fair
	T5.S1.04.B	48%	Low Fair	46%	Low Fair
	T5.S1.05	60%	High Fair	49%	Low Fair
	T5.S1.06	59%	High Fair	44%	Low Fair
	T5.S1.07	48%	Low Fair r	34%	Poor
	T5.S1.08	46%	Low Fair	41%	Low Fair
	T5.S1.09	56%	High Fair	40%	Low Fair
Lovers Lane Brook	T5.S2.01.A	61%	High Fair	63%	High Fair
	T5.S2.01.B	64%	High Fair	64%	High Fair
	T5.S2.01.C	66%	Good	60%	High Fair
Andover Branch	T5.S3.01	54%	High Fair	45%	Low Fair
	T5.S3.02	56%	High Fair	47%	Low Fair
	T5.S3.03	66%	Good	49%	Low Fair
	T5.S3.04.A	63%	High Fair	63%	High Fair
	T5.S3.04.B	52%	High Fair	59%	High Fair
	T5.S3.05.A	56%	High Fair	54%	High Fair
	T5.S3.05.B	65%	Good	68%	Good
Potash Brook	T5.S3.a.01	50%	High Fair	49%	Low Fair
Trout Brook	T5.S3.b.01	44%	Low Fair	40%	Low Fair
Trebo Brook	T7.01.A	*	Good	*	High Fair
	T7.01.B	39%	Low Fair	39%	Low Fair
Whitmore Brook	T8.01	59%	High Fair	56%	High Fair

* RHA and RGA assigned based on administrative judgment full assessments not conducted on M07.A, T5.05.C, and T7.01.A

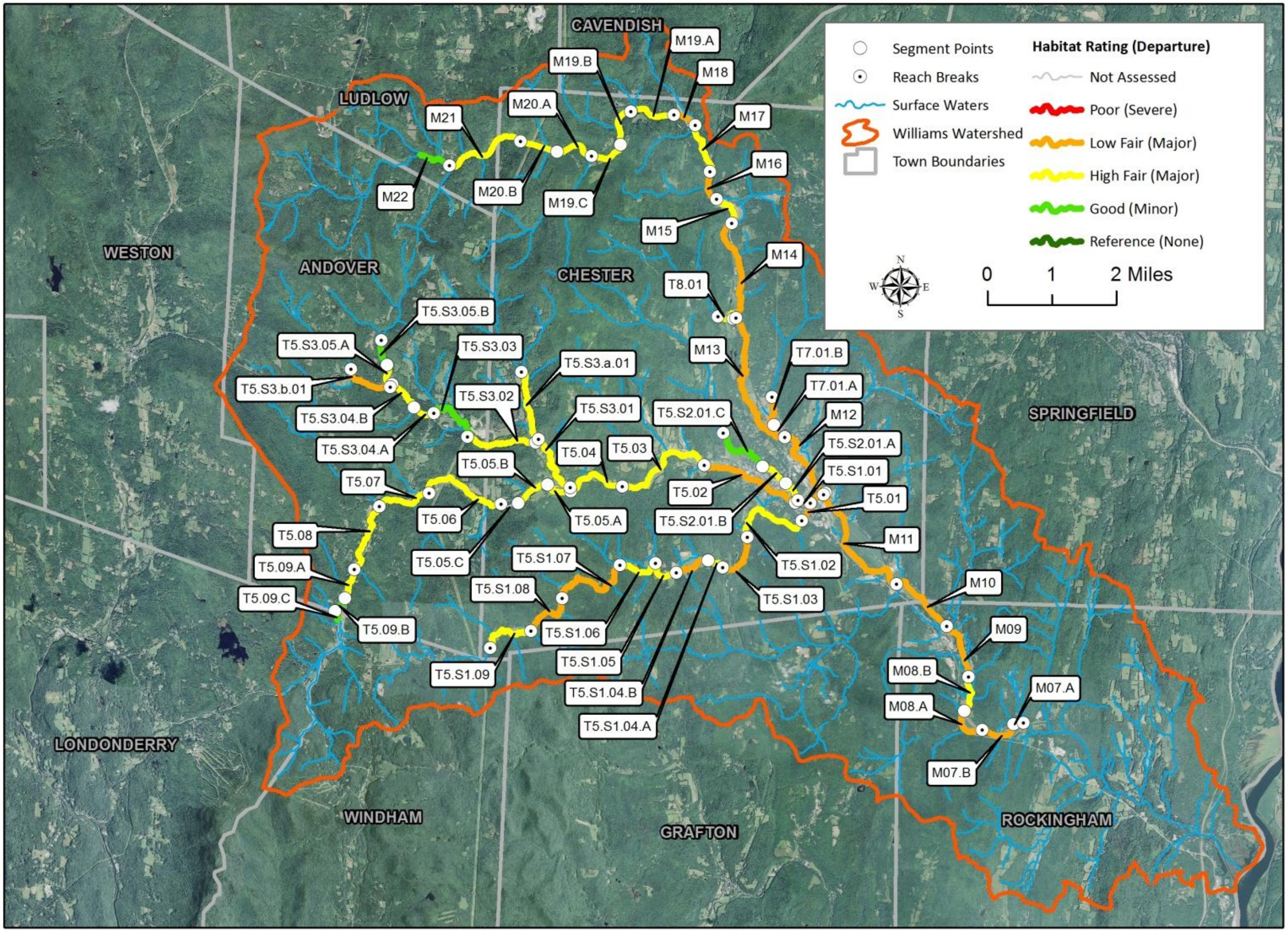


Figure 4.4: Rapid Habitat Assessment Ratings for the Williams River Watershed.

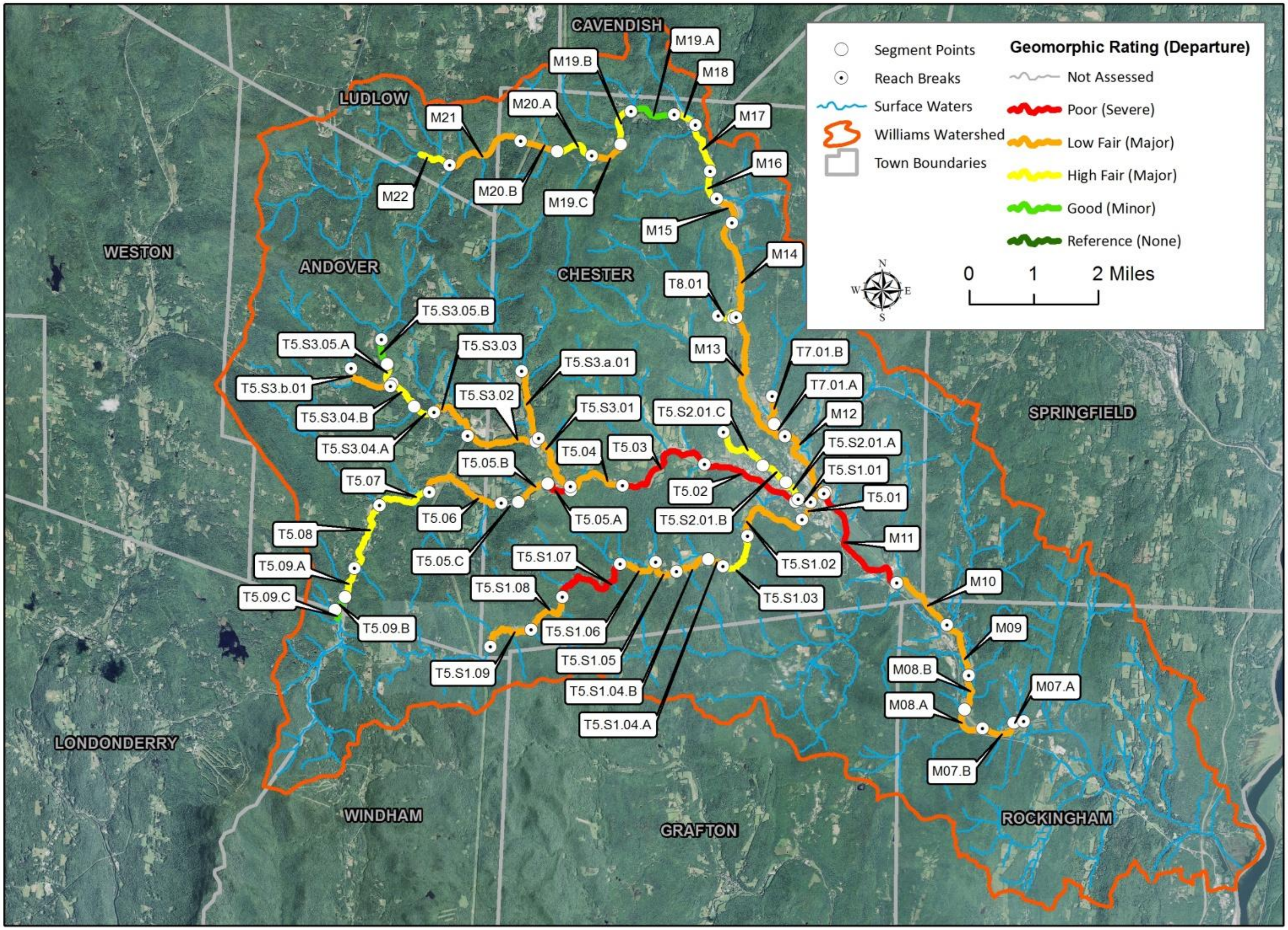


Figure 4.5: Rapid Geomorphic Assessment Ratings for the Williams River Brook Watershed.

4.3 River Corridor Planning

The following sections summarize the stressor identification and departure maps. The data collected through the Phase 1 and 2 SGA studies provides the basis for assessing the impacts to the hydrologic and sediment regimes, and the channel riparian and boundary conditions. These data, when combined with other watershed-scale data developed in this study, allows for the assessment of physical departure from reference conditions, and serves to validate watershed-scale patterns and stream conditions observed in the field. The mapping of physical stressors and natural or human constraints allowed for 1) a process-based approach to understanding stream conditions at different scales, and 2) an evaluation of the connectivity of stressors along the channel network. The maps were referenced during the project identification process summarized in Section 5.0.

4.3.1 Stressor Maps

Modifications to Riparian and Boundary Condition

The boundary conditions of a river encompass the bed and bank substrate, and the vegetation and root material found along the riverbank. Human alterations to the river boundary conditions are often made to increase the resistance of the banks and bed to reduce lateral and vertical adjustments. However, extensive removal of riparian vegetation in the absence of bank hardening can cause a decrease in boundary resistance, and lead to increased lateral migration. Other natural and human-installed features within the channel, such as bedrock ledges and dams, affect boundary resistance in an upstream and downstream direction by controlling vertical adjustment processes.

Alterations to the channel boundary conditions and riparian areas in the Williams River study area have been mapped using the variables extracted from the Phase 2 field dataset (Figure 4.16-4.18). Bank armoring (e.g., rip-rap) highlights areas of increased resistance to lateral migration, whereas bank erosion highlights reaches where significant lateral adjustments are found. Additional data showing the location of natural and man-made channel features (e.g., ledges and dam) depict areas that have a resistance to channel change.

Areas influencing riparian zone and boundary conditions include:

Increased Boundary Resistance

- Areas with numerous (> 2/mile) natural grade control on segments: M09, M14, M15, M17, M19.A-M22, T5.02, T5.S1.03, T5.S1.09, T5.S2.01.C, T5.S3.02, T5.S3.a.01, T5.S3.b.01, T8.01 (Figures 4.6-4.8).
- A large run of the river dam is located at Brockway Mills just downstream of the M06/M07 reachbreak, resulting in a minor impoundment not assessed in segment M07.A (Figure 4.9)
- Extensive bank armoring on segments (at least 1 bank >20%) : M07.B, M08.A, M09, M10, M12-M14, M16- M19.B, M20.A-M21, T5.01, T5.03, T5.07, T5.08, T5.09.A, T5.S1.01, T5.S1.03, T5.S1.04.B, T5.S1.07, T5.S1.08, T5.S2.01.B, T5.S2.01.C, T5.S3.05.A, T5.S3.b.01 (Figures 4.10 and 4.11).

Decreased Boundary Resistance

- High bank erosion in segments (one bank>20%): T5.02, T5.05.B, T5.S1.04.A (Figures 4.12 and 4.13).
- Large mass failures (>80ft long or ≥40ft tall) in segments: T5.02, T5.04, T5.06-T5.08 T5.S3.01, T5.S1.02, T5.S1.09, T5.S3.03 (Figures 4.14 and 4.15).
- Dredging in segments: M10-M12, M18, T5.02, T5.03, T5.07-T5.09.A, T5.S1.01-T5.S1.03, T5.S1.08, T5.S3.04.B, T5.S3.05.A, T5.S3.05.B, T5.S3.B.01
- High density of riparian buffer width impacts in segments M09.A, M09.B, M11, T1.01.S4.01.B, T2.01.A, T2.03.B, T3.02.B, T3.04 (Figures 4.16-4.18).

Figure 4.6: Numerous grade controls in segment M19.A

Figure 4.7: Grade control on reach T5.S3.02.

Figure 4.8: Five foot bedrock cascade on reach T5.S1.03.

Figure 4.9: Brockway Mills Dam


Figure 4.10: Stacked stone wall along Nudist Camp Rd in reach T5.S1.08.


Figure 4.11: Paved left bank along reach M16.


Figure 4.12: Major bank erosion in reach T5.01.


Figure 4.13: Extensive bank erosion along a pasture in reach M14.


Figure 4.14: Huge mass failure on reach T5.04.


Figure 4.15: Mass failure with gully along reach T5.08.

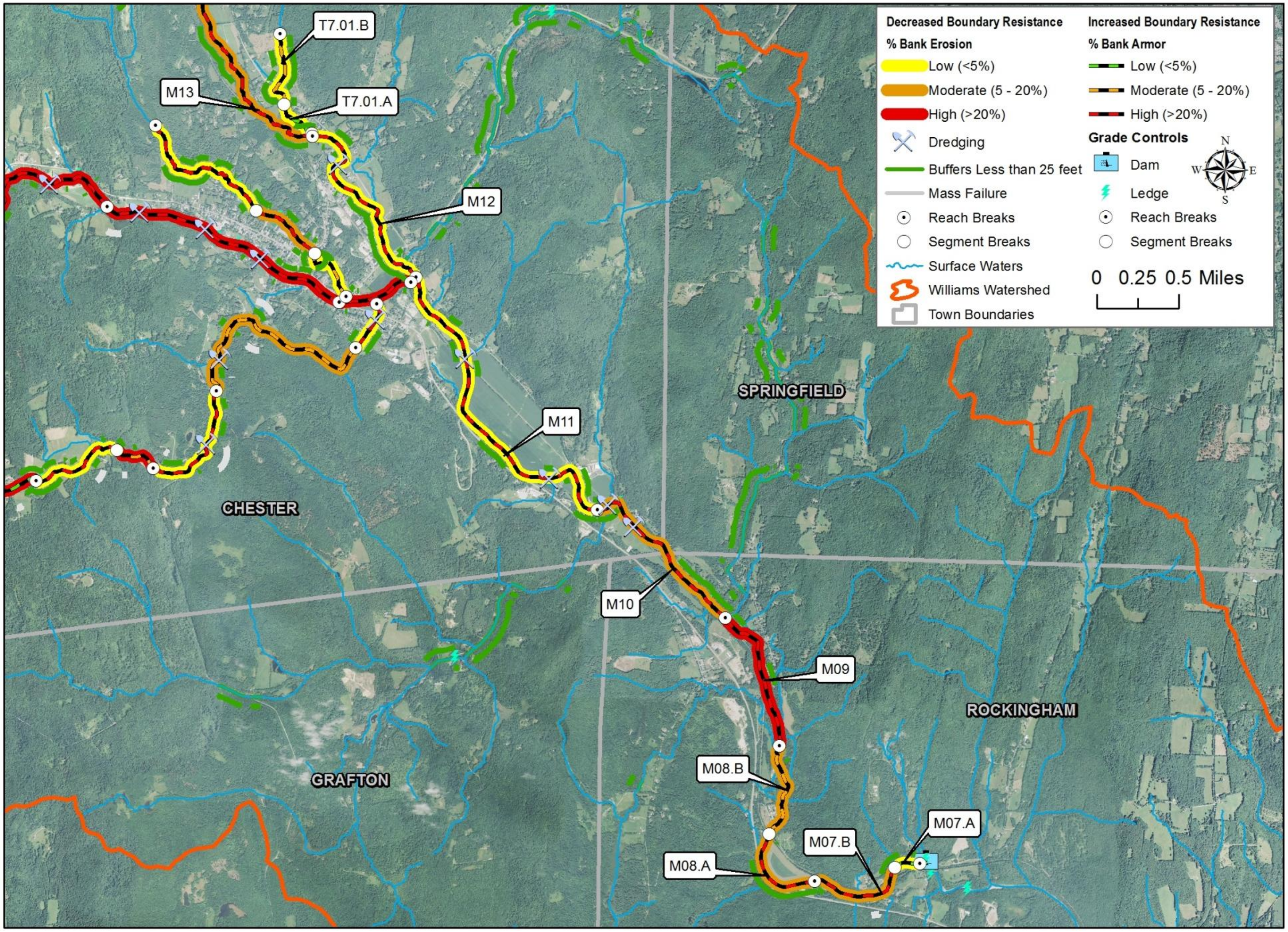


Figure 4.16: Riparian and boundary condition modifiers for the Lower Mainstem of the Williams River

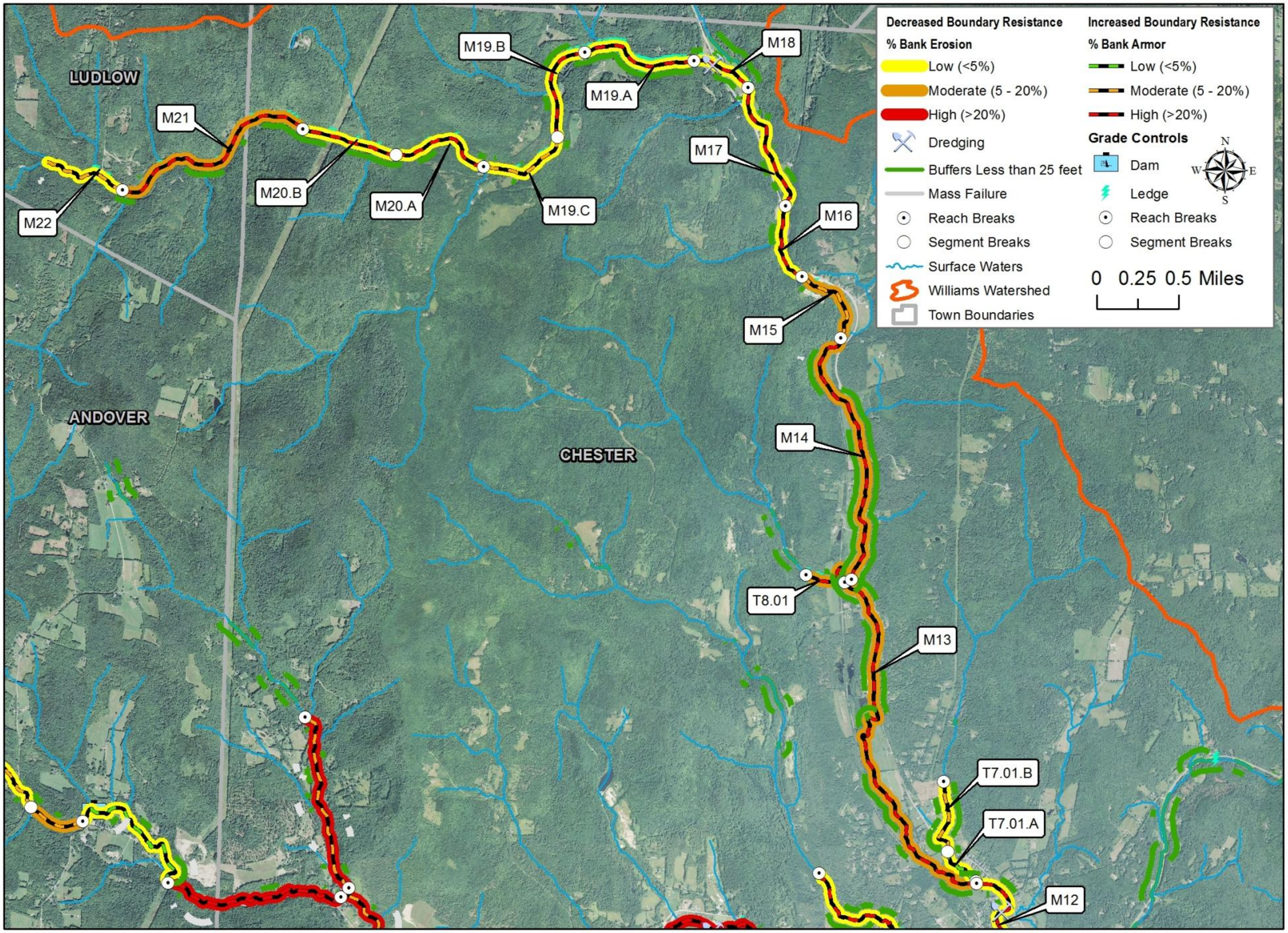


Figure 4.17: Riparian and boundary condition modifiers for the Upper Mainstem of the Williams River

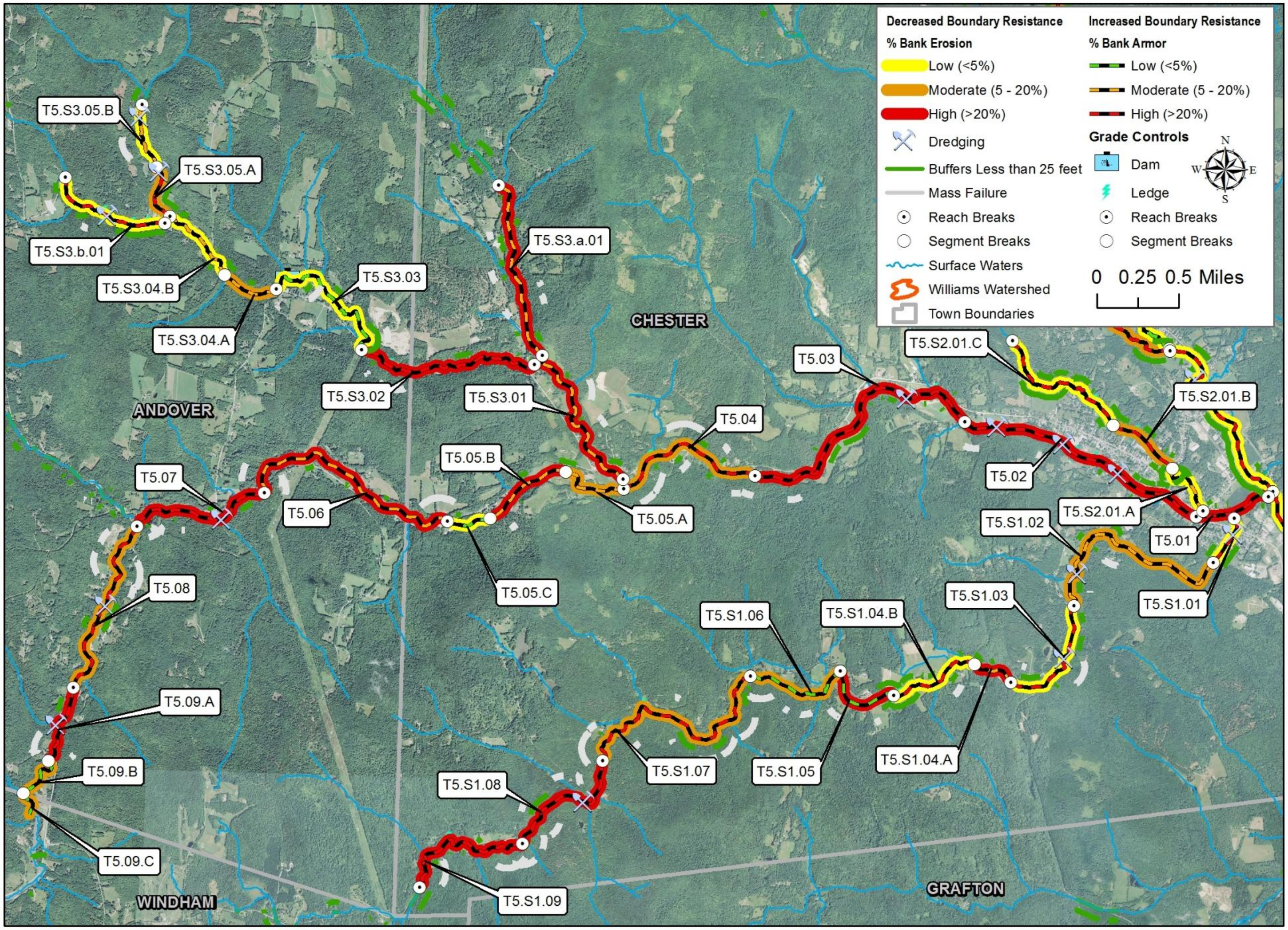


Figure 4.18: Riparian and boundary condition modifiers for the Middle Branch, South Branch, and tributaries of the Williams River

Channel Slope and Depth Modifiers

Many of Vermont's rivers and streams have been historically manipulated and straightened to maintain an unnaturally steep slope, allowing for a short term sense of security from flooding and subsequent encroachment of infrastructure in the floodplain. Over time, many alluvial rivers will seek to redevelop a sinuous planform through the deposition of sediments in unconfined valleys. Following flood events when alluvial rivers become energized enough to transport large amounts of coarse sediment into depositional zones of the watershed, lateral channel migration intensifies and further channel straightening is required to protect infrastructure found in the floodplain. In larger alluvial rivers of Vermont, straightening and channelization typically ranges between 25 and 75 percent of the total river channel length in Vermont (VTANR, 2010).

In addition to historic alterations to channel slope in Vermont's alluvial rivers, the lowering of stream beds (e.g., dredging) and the raising of floodplains (e.g., encroachments) have resulted in an increase in channel depth (VTANR, 2010). Channel depths have typically been increased through the encroachment on the floodplain by roads and railroads and subsequent filling and armoring required to construct and maintain this infrastructure. Increases in impervious cover have also led to the deepening and eventual widening of channels throughout urbanized areas of Vermont (Fitzgerald, 2007).

Alterations to channel slope and depth in the Williams River study area have been mapped using the variables extracted from the Phase 2 field dataset (Figures 4.25-4.27). Areas of channel straightening mapped during the Phase 1 and 2 assessments are included to depict areas of increased channel slope. Corridor encroachment data highlights where roads and development have reduced the floodplain area, typically resulting in increased stream power and channel deepening. Additional data showing the location of natural channel features (ledges) and man-made features such as dams which depict areas that have a resistance to vertical channel change.

Areas impacted by increases in slope and depth or influenced by controls on slope and depth include:

Increases in Slope and Depth

- Extreme channel straightening in segments: M08.A, M09, M10, T5.01, T5.S1.01, T5.S1.04.B, T5.S2.01.B, T5.S3.04.A, T5.S3.05.A, T7.01.B (Figures 4.19 and 4.20).
- High straightening in segments: M11, M12, M14, M15, M17, M18, T5.02, T5.05.C, T5.09.A, T5.S1.05, T5.S2.01.A, T5.S3.03, T5.S3.05.B, T5.S3.b.01, T8.01
- Extreme corridor encroachments from berms and adjacent roadways and embankments in segments: M08.A, M09, M10, M14, M16, M19.A, M19.B, M20.B, M21, T5.04, T5.07, T5.08, T5.09.A, T5.S1.03, T5.S1.07, T5.S1.08, T5.S3.04.A, T5.S3.05.A, T5.S3.b.01 (Figures 4.21 and 4.22).
- Dredging in segments: M10-M12, M18, T5.02, T5.03, T5.07-T5.09.A, T5.S1.01-T5.S1.03, T5.S1.08, T5.S3.04.B, T5.S3.05.A, T5.S3.05.B, T5.S3.B.01

Controls on Slope and Depth

- Areas with numerous (> 2/mile) natural grade control on segments: M09, M14, M15, M17, M19.A-M22, T5.02, T5.S1.03, T5.S1.09, T5.S2.01.C, T5.S3.02, T5.S3.a.01, T5.S3.b.01, T8.01 (Figures 4.23 and 4.24).

- A large run of the river dam is located at Brockway Mills just downstream of the M06/M07 reachbreak, resulting in a minor impoundment not assessed in segment M07.A (Figure 4.9).

Figure 4.19: Reach M14 straightened along Rt-103.

Figure 4.20: Stream straightened and pinned at the back edge of field along segment T5.S2.01.C.

Figure 4.21: Encroachment from development along Potash Brook (T5.S3.a.01).

Figure 4.22: Extreme encroachment along Route 11 on reach T5.08.

Figure 4.23: Dredged material blocking off a flood chute entrance on reach T5.S3.04.

Figure 4.24: Dredged material along the banks of segment M18.

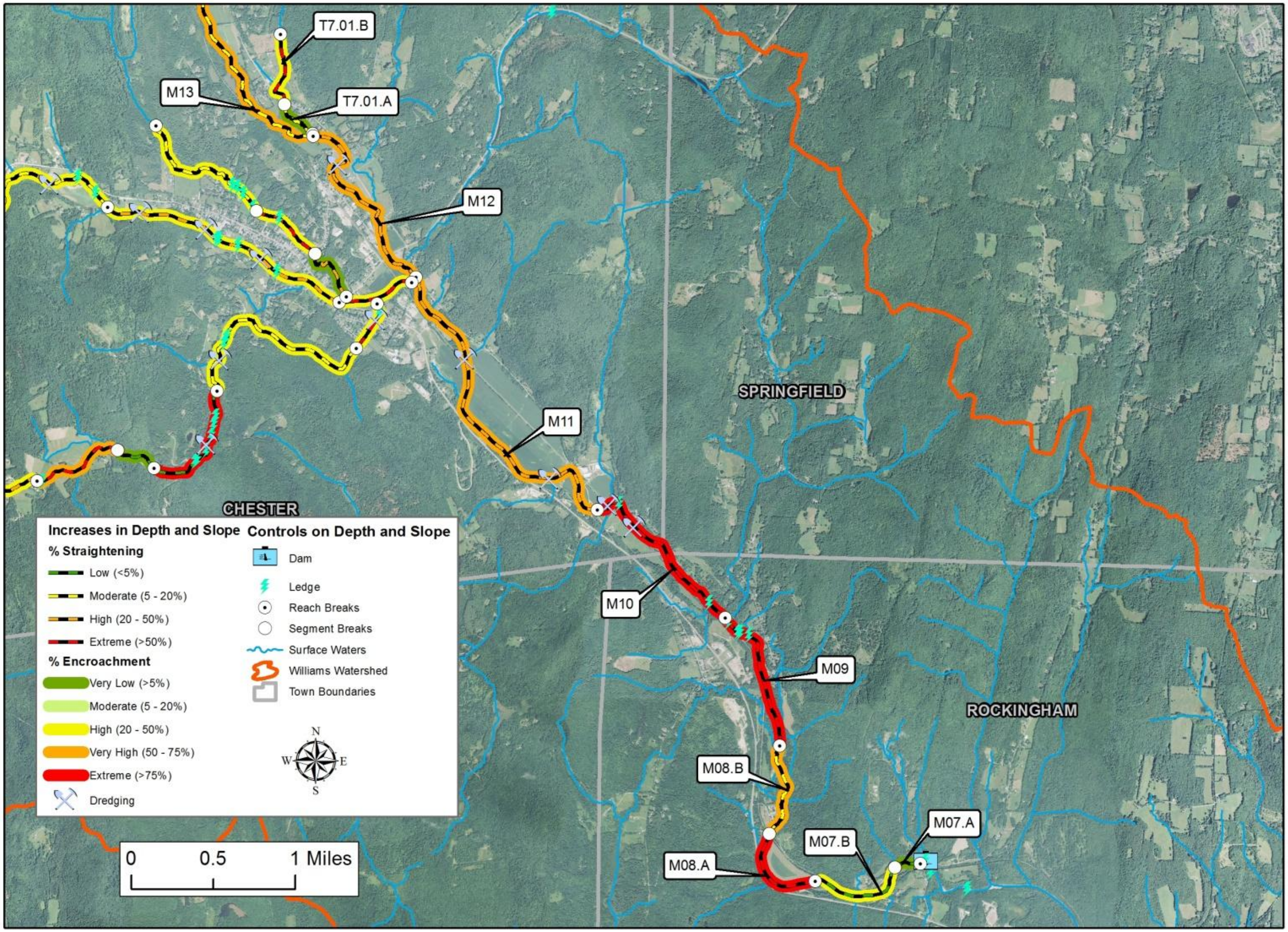


Figure 4.25: Controls on slope and depth for the Lower Williams River Watershed.

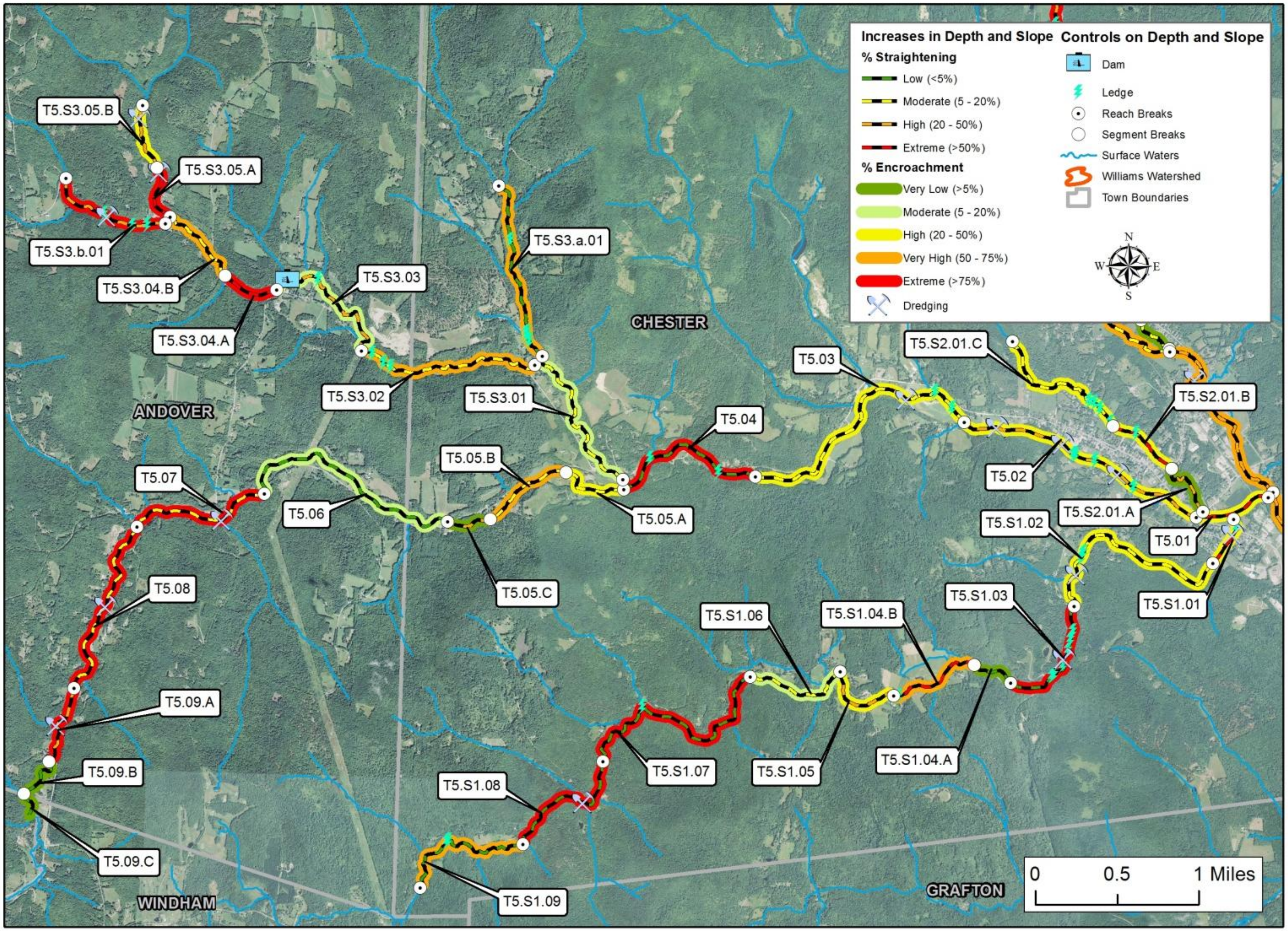


Figure 4.26: Controls on slope and depth for the T5 Portion of the Williams River Watershed.

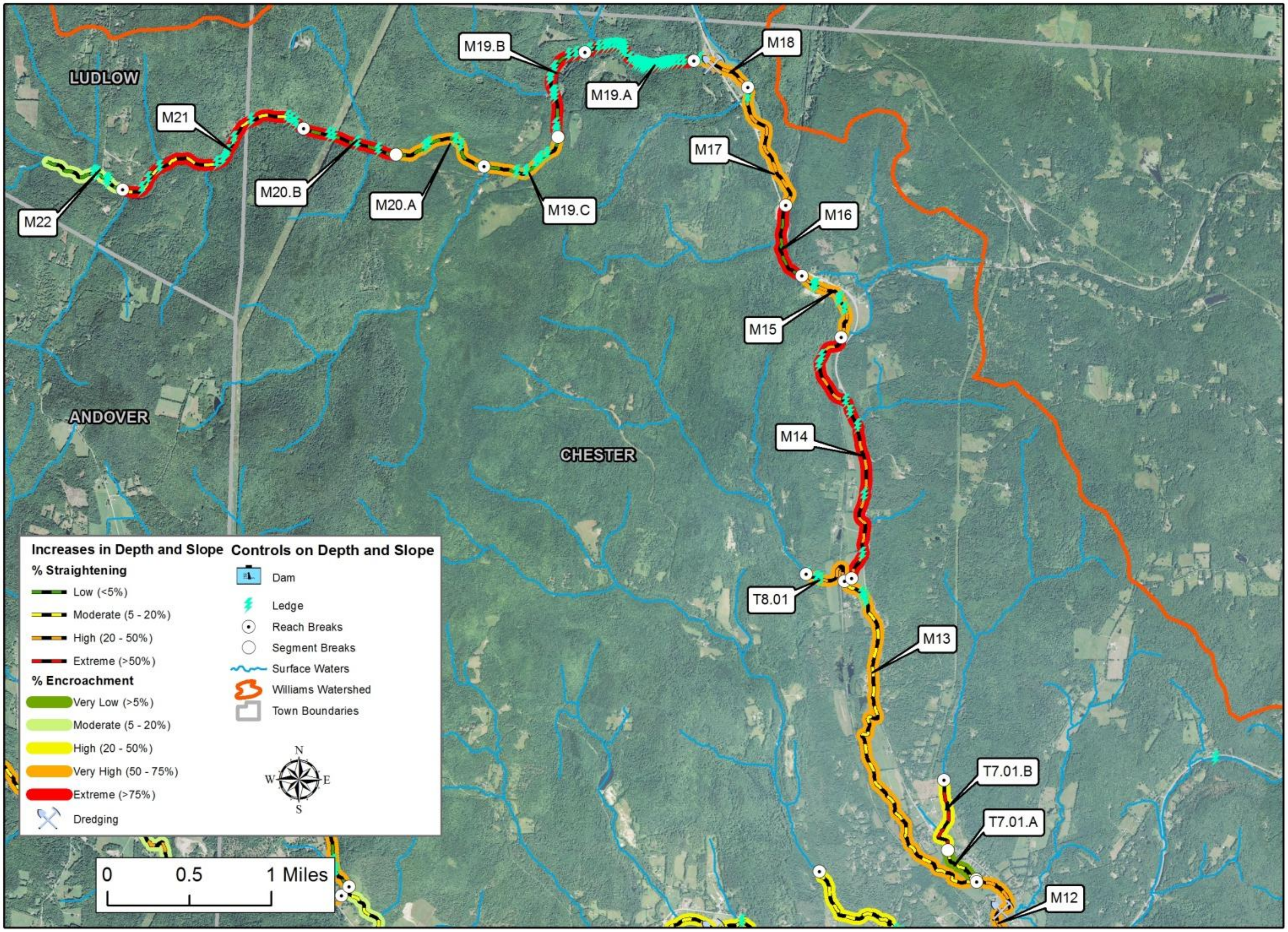


Figure 4.27: Controls on slope and depth for the Upper Williams River Watershed.

4.3.2 Departure Analysis

The reference and existing sediment regime types have been mapped using data from the Phase 1 and 2 assessments (Figures 4.28 and 4.29). Most segments in the Williams River study area have undergone a departure in both sediment regime and stream type due to channel incision and/or widening as a result of: 1) historical land uses, 2) encroachments or development in the river corridor, or 3) extensive straightening and bank armoring. Many of the channel adjustments caused by these historic stressors were exacerbated by the extreme floods of 2011 and 2014, leading to further stream type departures. M19.A, T5.09.B, T5.09.C, T5.S3.05.B and T8.01 were the only Phase 2 study segments that were assessed as stable and did not contain a stream type departure and/or a sediment regime departure.

Stream type departures (per Rosgen, 1994) are summarized below (Table 4.3) to better describe the reaches where physical changes in channel morphology have accompanied sediment regime changes.

Table 4.3: Summary of stream type departures from reference conditions

Phase 2 Segment ID	Stream Type Departure	Dominant Adjustment Type
M07.B	B to F	Incision from Historic Encroachment
M08.A	C to F	Incision from Historic Encroachment and Straightening
M09	C to B	Recent Widening and Historic Incision and Encroachment
M11	C to B	Recent Widening and Aggradation; Historic Straightening
M12	C to F	Incision from Historic Encroachment and Straightening
M13	C to F	Incision from Historic Encroachment and Straightening
M14	C to F	Incision from Historic Encroachment and Straightening
M15	C to B	Recent Aggradation and Historic Encroachment/Straightening
M16	B to F	Incision from Historic Encroachment and Bank Armoring
M17	C to F	Incision from Historic Encroachment and Bank Armoring
M18	C to F	Incision from Historic Encroachment and Bank Armoring
M19.B	C to F	Incision from Historic Encroachment
M19.C	C to B	Recent Widening/Aggradation and Historic Incision
M20.B	B to F	Recent Widening and Historic Incision and Encroachment
M21	B to F	Historic Incision
T5.02	C to F	Incision from Historic Encroachment and Straightening
T5.03	C to D	Recent Widening and Aggradation
T5.04	C to F	Incision from Historic Encroachment and Recent Aggradation
T5.05.A	C to D	Recent Aggradation
T5.05.B	C to F	Incision from Historic Encroachment and Recent Widening
T5.06	C to F	Recent Widening and Historic Incision
T5.07	B to F	Recent Incision and Widening
T5.08	C to F	Incision from Historic Encroachment and Recent Widening
T5.09.A	B to F	Incision from Historic Encroachment and Straightening
T5.S1.01	C to F	Incision from Historic Straightening and Encroachment

Table 4.3: Summary of stream type departures from reference conditions

Phase 2 Segment ID	Stream Type Departure	Dominant Adjustment Type
T5.S1.02	C to F	Incision from Historic Encroachment and Recent Widening
T5.S1.04.A	B to F	Incision from Historic Encroachment and Recent Widening
T5.S1.04.B	C to F	Incision from Historic Encroachment and Straightening
T5.S1.05	B to F	Incision from Historic Straightening and Recent Widening
T5.S1.06	C to B	Incision from Historic Straightening and Recent Widening
T5.S1.07	B to F	Incision from Historic Encroachment
T5.S1.08	B to F	Incision from Historic Encroachment
T5.S1.09	C to F	Incision from Historic Encroachment
T5.S2.01.C	C to E	Incision from Historic Armoring and Straightening
T5.S3.01	C to F	Recent Widening and Aggradation
T5.S3.02	B to F	Recent Widening and Aggradation
T5.S3.03	C to B	Recent Aggradation and Historic Incision from Straightening
T5.S3.04.A	C to F	Incision from Historic Encroachment and Straightening
T5.S3.05.A	C to F	Incision from Historic Encroachment and Straightening
T5.S3.a.01	B to F	Incision from Historic Encroachment
T5.S3.b.01	B to F	Incision from Historic Encroachment and Straightening
T7.01.B	C to B	Incision from Historic Encroachment and Straightening

In addition to these morphological stream type departures, several reaches/segments of the Williams River watershed have undergone departures in sediment regimes in the absence of stream type departures. All sediment regime departures are summarized below in Table 4.4. An additional map summarizing channel adjustment processes within each zone of the watershed is included in Figures 4.30 to 4.32.

Table 4.4: Summary of Sediment Regime Departures.

Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
M07.B	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic straightening
M08.A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic straightening and encroachment
M08.B	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and active aggradation
M09	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and historic incision/encroachment
M10	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Recent widening and aggradation and historic armoring
M11	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and aggradation, historic straightening
M12	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic straightening and encroachment
M13	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic straightening and encroachment
M14	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Historic straightening and encroachment
M15	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent aggradation and historic straightening and encroachment
M16	Coarse Equilibrium and Fine Deposition	Confined Source and Transport	Historic armoring and encroachment
M17	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic armoring and encroachment

Table 4.4: Summary of Sediment Regime Departures.

Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
M18	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic armoring and encroachment
M19.B	Coarse Equilibrium and Fine Deposition	Confined Source and Transport	Historic encroachment
M19.C	Coarse Equilibrium and Fine Deposition	Confined Source and Transport	Recent widening and historic encroachment
M20.B	Transport	Confined Source and Transport	Recent widening
M21	Transport	Confined Source and Transport	Historic incision
M22	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and migration
T5.01	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and migration
T5.02	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Historic incision from encroachment and straightening
T5.03	Coarse Equilibrium and Fine Deposition	Deposition	Recent widening and active aggradation
T5.04	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Historic incision/encroachment, recent aggradation
T5.05.A	Coarse Equilibrium and Fine Deposition	Deposition	Recent widening and active aggradation
T5.05.B	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Incision from historic encroachment

Table 4.4: Summary of Sediment Regime Departures.

Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
T5.06	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening with historic incision
T5.07	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and incision
T5.08	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening with historic encroachment
T5.09.A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision
T5.S1.01	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision
T5.S1.02	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening
T5.S1.03	Coarse Equilibrium and Fine Deposition	Confined Source and Transport	Historic incision and encroachment
T5.S1.04.A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment
T5.S1.04.B	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment
T5.S1.05	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening
T5.S1.06	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening
T5.S1.07	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment

Table 4.4: Summary of Sediment Regime Departures.

Phase 2 Segment ID	Reference Sediment Regime	Existing Sediment Regime	Cause of Departure
T5.S1.08	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment
T5.S1.09	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment
T5.S2.01.A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and straightening
T5.S2.01.B	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and straightening
T5.S2.01.C	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and straightening
T5.S3.01	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and aggradation
T5.S3.02	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Recent widening and aggradation
T5.S3.04.A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment
T5.S3.04.B	Coarse Equilibrium and Fine Deposition	Fine Source Transport and Coarse Deposition	Active planform adjustment
T5.S3.05.A	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment
T5.S3.a.01	Coarse Equilibrium and Fine Deposition	Unconfined Source and Transport	Historic incision and encroachment
T5.S3.b.01	Transport	Confined Source and Transport	Historic incision and encroachment

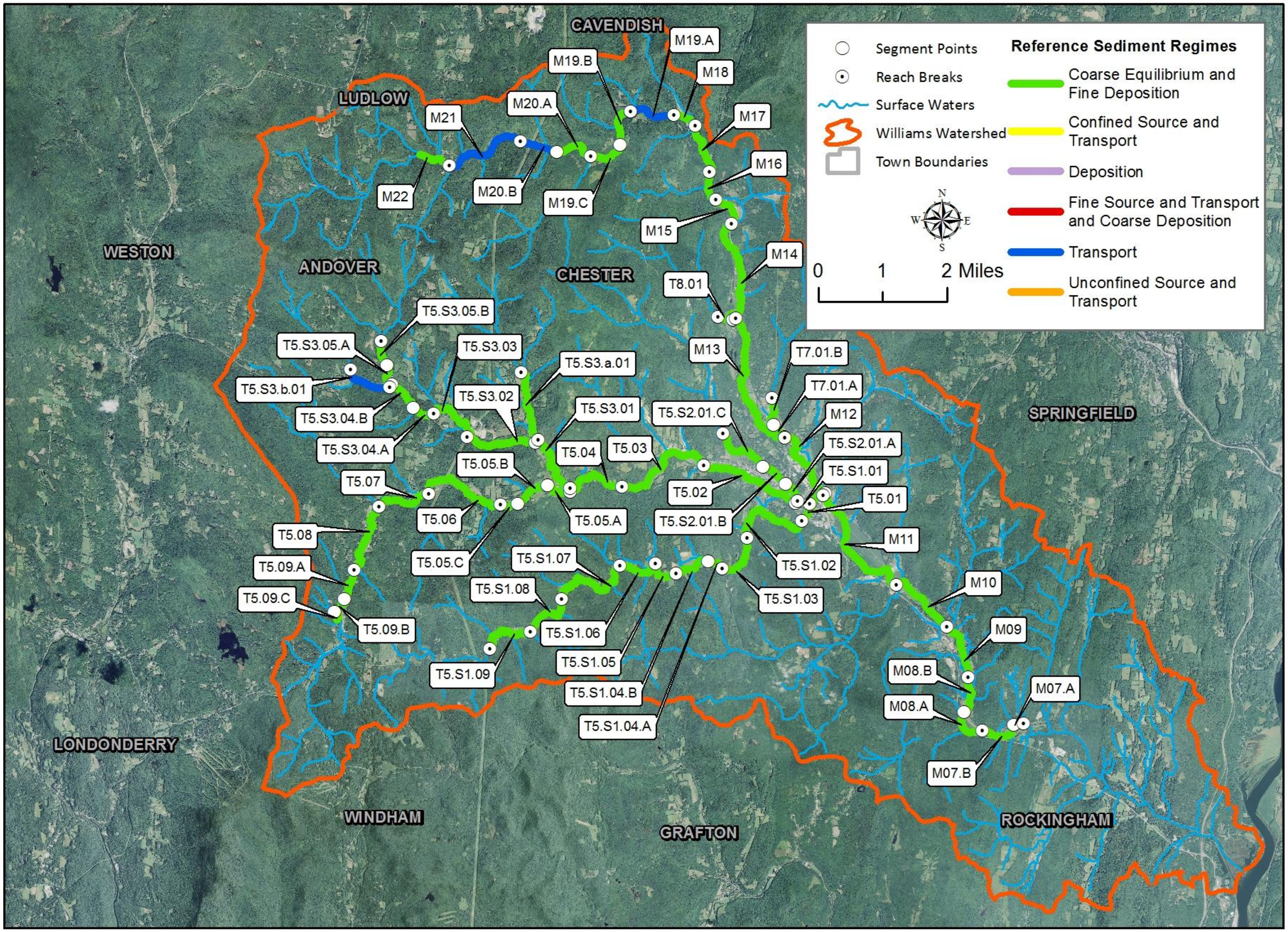


Figure 4.28: Reference Sediment Regime for the Williams River watershed.

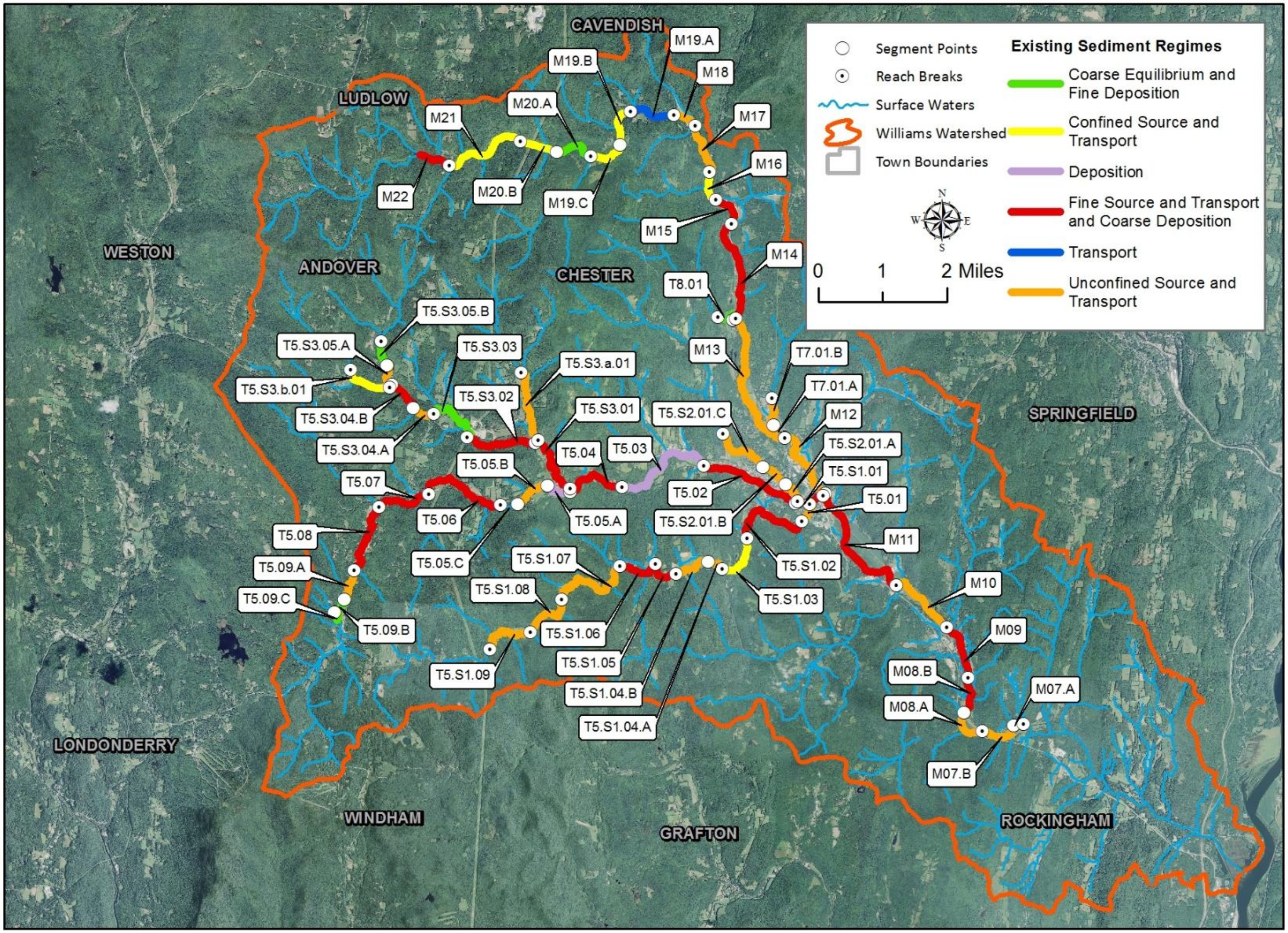


Figure 4.29: Existing Sediment Regime for the Williams River watershed.

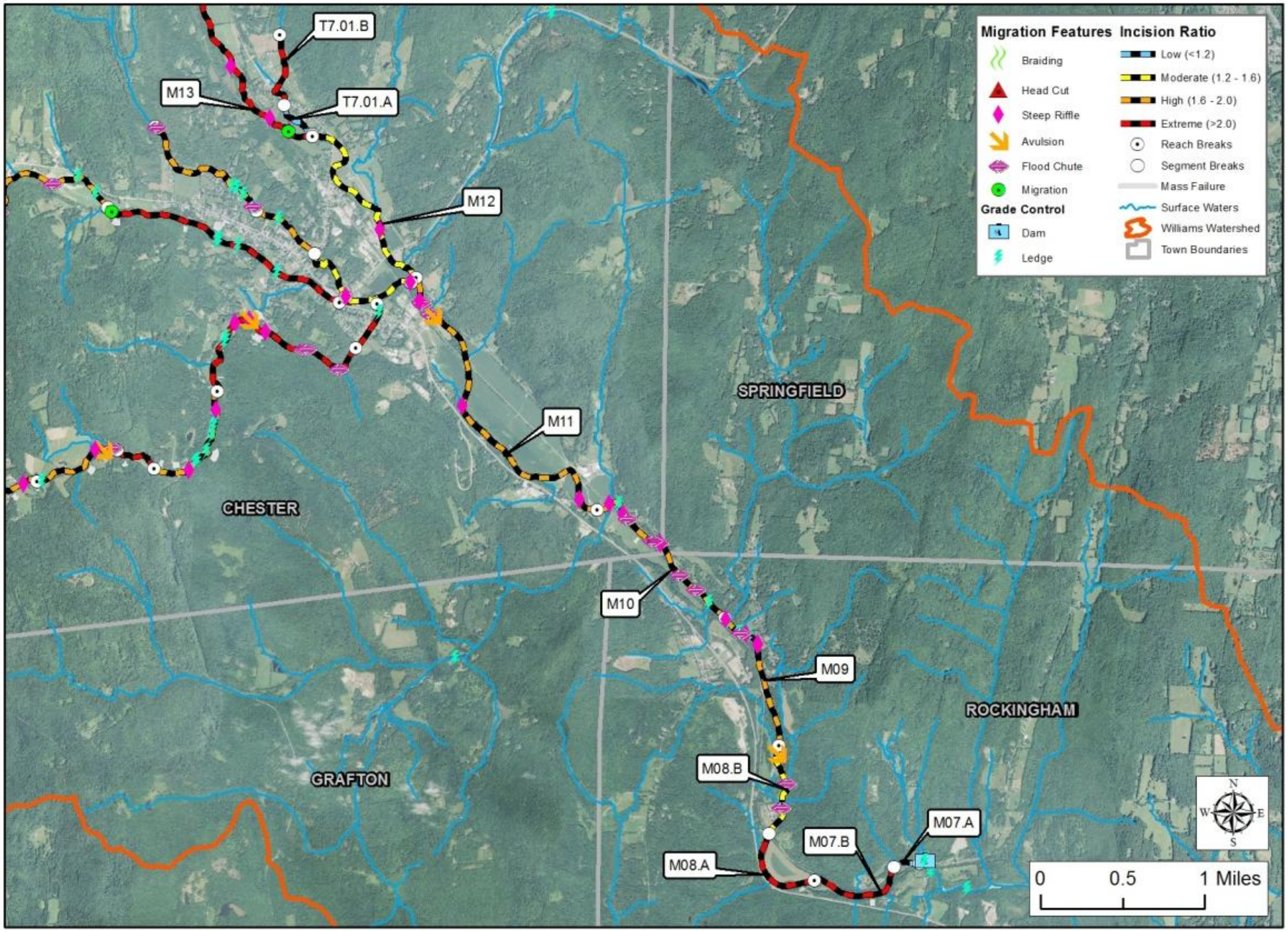


Figure 4.30: Channel adjustment processes for the Lower Williams River Watershed.

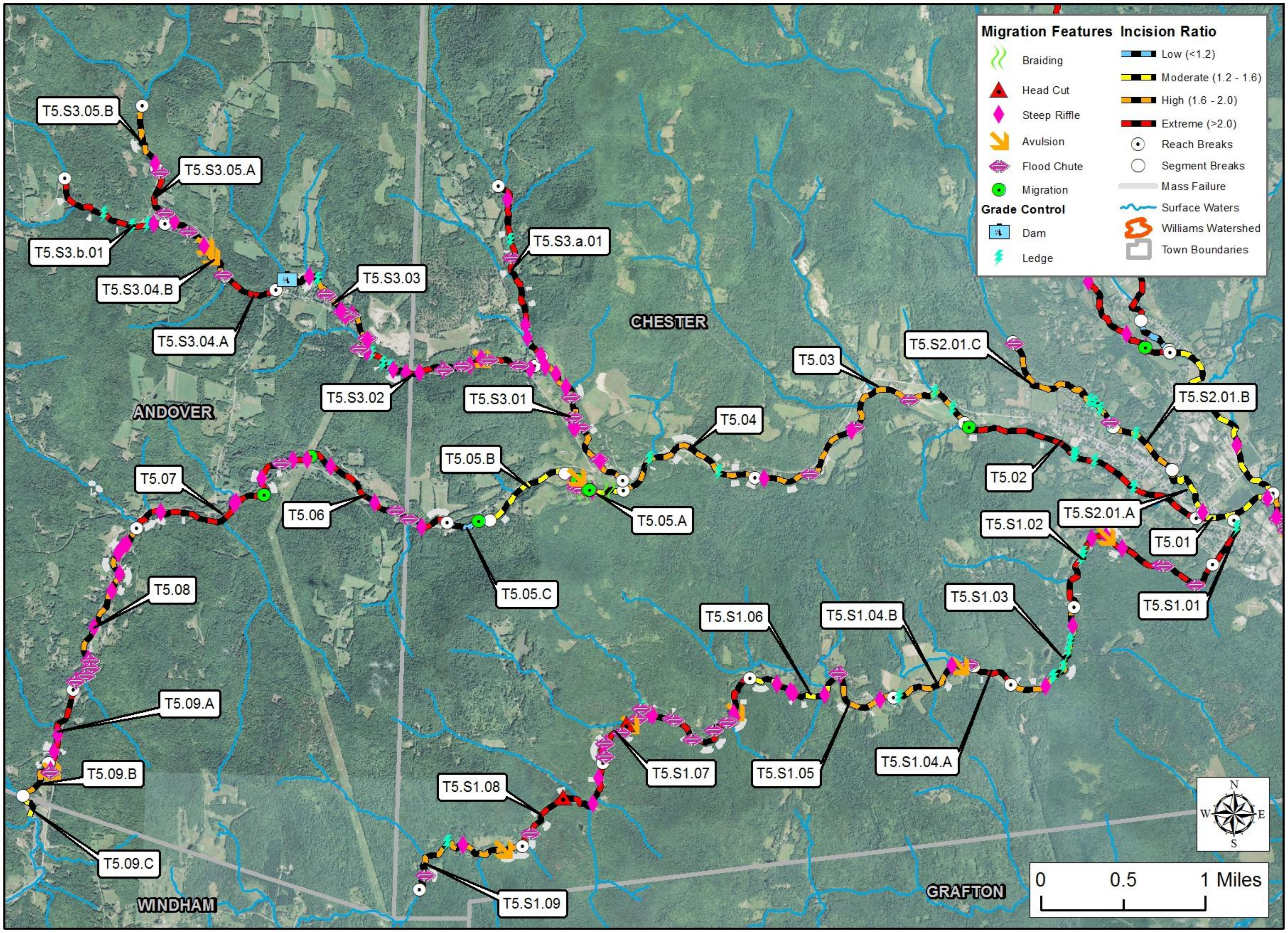


Figure 4.31: Channel adjustment processes for the T5 portion of the Williams River Watershed.

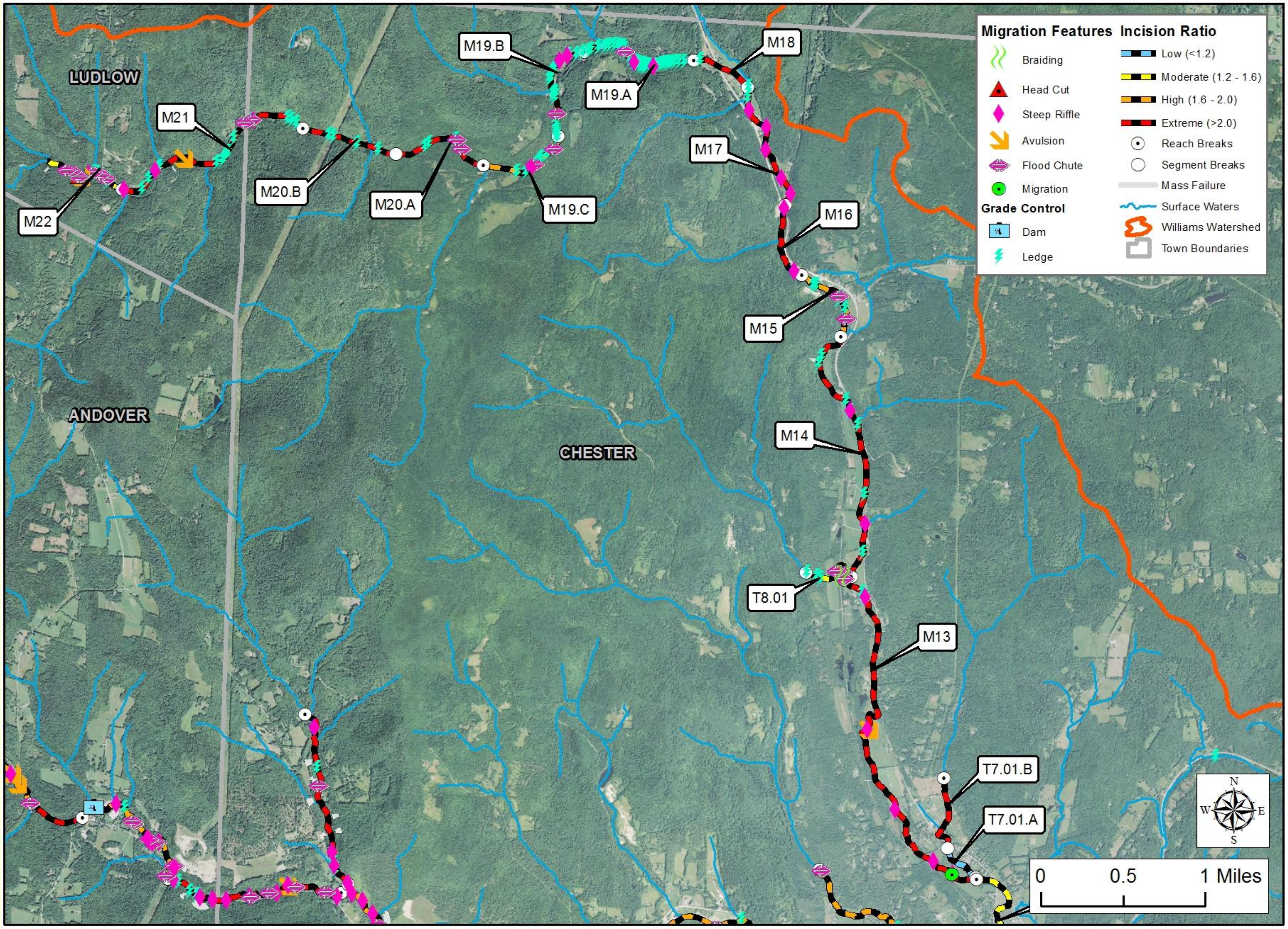


Figure 4.32: Channel adjustment processes for the Upper Williams River Watershed.

4.3.3 Sensitivity Analysis

The methods outlined in the VTANR Corridor Planning Guide have been used to describe the stream sensitivities of the segments in the Williams River study area. Using the stream geometry and substrate data in conjunction with overall geomorphic stability (RGA score) as determined during the Phase 2 surveys, stream sensitivity ratings have been assigned to each segment (Figure 4.33). 35 segments have heightened sensitivities of "Extreme" and 9 segments have heightened sensitivities of "Very High" due to human impacts. The increased stream sensitivity ratings are most often because of stream type departures (STD) (Table 4.5).

Incision due to encroachment, armoring, and/or straightening was the most common driver for heightened sensitivity ratings. Deposition and widening/planform in reaches that are impacted by flood sediments was another important driver for extreme and very high sensitivity ratings.

Incision due to encroachment, armoring, or straightening was the most common scenario for "Extreme" sensitivity in the study area. Areas of major deposition coupled with encroachment also led to "Extreme" sensitivity on some segments. "Very High" sensitivity segments were typically due to incision; however some of the reaches were impacted by major deposition from recent floods leading to widening and aggradation.

Table 4.5: Very High and Extreme sensitivity segments and descriptions of the specific impacts and adjustments

Phase 2 Segment ID	Stream Sensitivity	Description of Impacts
M07.B	Extreme	STD, Encroachment, Bank Armoring
M08.A	Extreme	STD, Encroachment, Straightening
M08.B	Very High	Planform, Aggradation, Widening
M09	Very High	STD, Widening
M10	Very High	Encroachment, Straightening, Widening
M11	Very High	STD, Widening, Planform
M12	Extreme	STD, Encroachment, Straightening
M13	Extreme	STD, Straightening, Bank Armoring
M14	Extreme	STD, Straightening, Bank Armoring
M16	Extreme	STD, Encroachment, Straightening
M17	Extreme	STD, Encroachment, Straightening
M18	Extreme	STD, Encroachment, Straightening
M19.B	Extreme	STD, Encroachment
M20.B	Extreme	STD, Aggradation, Widening
M21	Extreme	STD, Encroachment, Incision
T5.01	Very High	Widening, Aggradation
T5.02	Extreme	STD, Widening
T5.03	Extreme	STD, Widening, Aggradation
T5.05.A	Extreme	STD, Planform, Aggradation

Table 4.5: Very High and Extreme sensitivity segments and descriptions of the specific impacts and adjustments

Phase 2 Segment ID	Stream Sensitivity	Description of Impacts
T5.05.B	Extreme	STD, Widening
T5.06	Extreme	STD, Widening
T5.07	Extreme	STD, Widening, Incision
T5.08	Extreme	STD, Planform, Aggradation
T5.09.A	Extreme	STD, Encroachment, Incision
T5.S1.01	Extreme	STD, Straightening, Encroachment
T5.S1.02	Extreme	STD, Widening, Encroachment
T5.S1.04.A	Extreme	STD, Straightening, Incision
T5.S1.04.B	Extreme	STD, Encroachment, Straightening
T5.S1.05	Extreme	STD, Widening, Straightening
T5.S1.07	Extreme	STD, Incision, Encroachment
T5.S1.08	Extreme	STD, Incision, Encroachment
T5.S1.09	Extreme	STD, Incision, Encroachment
T5.S2.01.A	Extreme	Straightening, Incision
T5.S2.01.C	Extreme	Encroachment, Straightening
T5.S3.01	Extreme	STD, Planform, Aggradation
T5.S3.02	Extreme	STD, Planform, Aggradation
T5.S3.03	Very High	STD, Planform, Aggradation
T5.S3.04.A	Extreme	STD, Encroachment, Straightening
T5.S3.04.B	Very High	Planform
T5.S3.05.A	Very High	STD, Encroachment, Straightening
T5.S3.05.B	Very High	Planform, Aggradation
T5.S3.a.01	Extreme	STD, Incision, Encroachment
T5.S3.b.01	Extreme	STD, Incision, Deposition
T7.01.B	Extreme	STD, Straightening, Bank Armoring

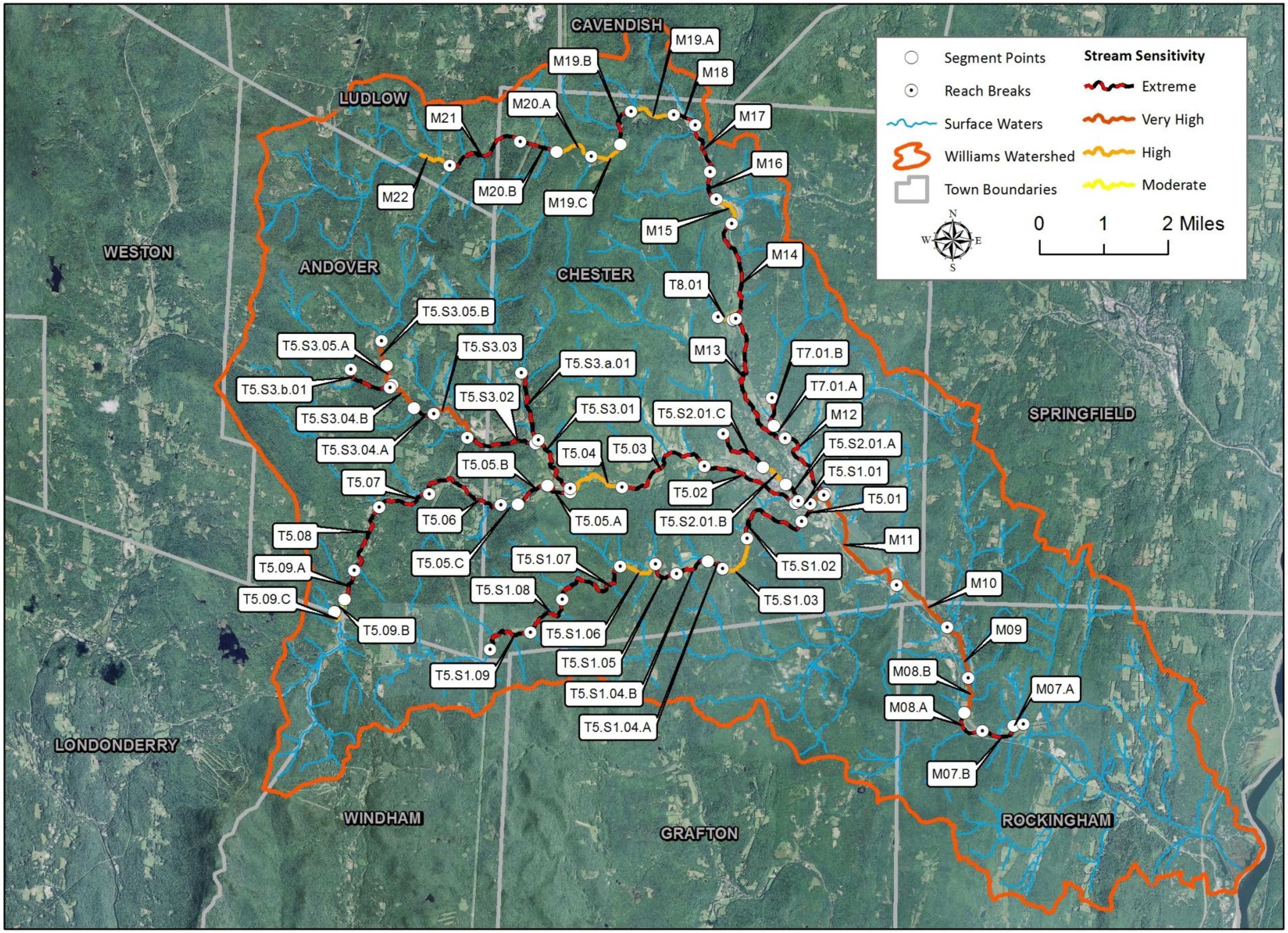


Figure 4.33: Stream Sensitivity Ratings for the Williams River study area.

5.0 Preliminary Project Identification

5.1 Watershed Level Opportunities

5.1.1 Stormwater Runoff

Increased stormwater runoff, even in rural areas of Vermont such as the Williams River watershed, can increase peak flood flows and the erosive power of the streams. Stormwater runoff originating from gravel roads and exposed soil during development, or over farm fields also adds significant sediment inputs to streams. Sediment from roads and driveways can be addressed with improved drainage ditch networks, limiting future driveway lengths in sensitive areas, and other approaches. The Vermont Better Back Roads program provides assistance for towns seeking ways to reduce rural stormwater problems.

The Williams River watershed has limited stormwater impacts because of the largely forested watersheds and low road densities. In the future, if development pressures heighten concerns about impacts from stormwater runoff, the towns in the watershed could consider enacting local standards and guidelines for stormwater treatment. Alternatively, concerns about stormwater management can be raised during local development review as necessary. Some proactive options for reducing stormwater impacts that towns in the watershed could consider include:

- Requiring stormwater controls for development projects which are not large enough in size to fall under state regulatory permits (less than 1 acre impervious cover), but likely have a measurable impact on the conditions of adjacent water bodies (e.g., habitat, water quality).
- Encouraging low impact development and use of green stormwater infrastructure through development density incentives for projects with reduced impervious cover footprints.

Beginning in 2018, VTDEC will begin phasing in the Municipal Roads General Permit (MRGP), and towns in the Williams River watershed will need to begin taking steps to meet the permit's requirements. This MRGP is intended to achieve significant reductions in stormwater-related erosion from municipal roads. Municipalities will be required to develop and implement a multi-year plan to stabilize road drainages to reduce erosion and meet water quality standards.

5.1.2 River Corridors

Many Vermont communities found along rivers large and small have faced significant property losses and risks to public safety during past flood events. Portions of the Williams River watershed are extremely flashy due to steep headwaters and soils with poor infiltration. The National Flood Insurance Program (NFIP) study for the Williams River covers the mainstem from Brockways Mills Dam up to Smokeshire Road, the Chester portion of the Middle Branch, all of the Phase 2 reaches along the South Branch, the Chester portion of Andover Branch and Potash Brook, and Lovers Lane Brook to the athletic fields. Detailed flood studies were not completed on Trebo or Whitmore Brooks; therefore inundation hazards may be underestimated in these drainages. Given the hydrologic characteristics of the watershed, and the severe flood damage witnessed during Tropical Storm Irene and the July 2014 floods, we recommend that all towns in the watershed consider flood hazard ordinances that prevent encroachment in the entire 100-year floodplain (i.e., floodway and floodplain fringe).

While inundation-related flood loss is a significant component of flood disasters, the predominant mode of damage during floods in Vermont is fluvial erosion. Towns can reduce flood recovery and infrastructure maintenance costs and increase public safety by limiting development in areas adjacent to rivers with a high potential for vertical and lateral adjustment. The statewide river corridor developed by VTDEC represents a useful "first-cut" mapping of the area a river or stream requires to redevelop or maintain equilibrium (i.e., least erosive) conditions over the long term. The statewide corridor is generated based on the meander belt width of the channel and includes an additional 50 foot buffer on each side. River corridor mapping can be improved with field survey data of existing channel morphology and valley walls, such as the data compiled for this project. Town zoning regulations based on the statewide or an improved river corridor map should be considered by each town to better map flood and erosion risks for both the safety and protection of their citizens, and the infrastructure controlled by the municipality.

By implementing at least one of the above-mentioned flood hazard zoning recommendations, towns can qualify for increased State aid (from 12.5% to 17.5%) from the Emergency Relief and Assistance Fund (ERAF) to cover future flood damages. Additional ERAF assistance from the State can significantly reduce the financial burden faced by towns during flood recovery; i.e., during a large flood resulting in 2 million dollars in recovery expenses (approximate Irene damages for the Town of Chester), the increased State share of 17.5% would reduce the Town’s match to Federal and State funding by $100,000.

5.1.3 Stream Crossings

Throughout Vermont, undersized and poorly aligned river crossings interrupt flood flows, sediment and woody debris movement downstream, and fish and wildlife migration. These conditions result in: 1) channel instability and/or damage to infrastructure and personal property; 2) increased flooding; and 3) decreased fish and wildlife population health. Many arches, bridges, and culverts in the Williams River study area are currently undersized and causing various problems such as upstream sediment/debris deposition, excessive erosion, and limited aquatic organism passage (Tables 5.1 and 5.2). Debris jams and large sediment deposits formed during T.S. Irene on some of the larger bridges, exacerbating localized flooding and infrastructure damage (Figure 5.1). As improperly sized structures come up for replacement, resizing them to accommodate expected discharge and sediment loads and placing them in proper alignment with stream channels is highly recommended.

Figure 5.1: Floodwaters filling the Route 11 bridge over the Middle Branch in July 2014. Photograph courtesy of M. Burbela and the Chester Telegraph.

Table 5.1: Summary of culvert data in the Williams River watershed.

Map ID	SGA Reach/Segment	Town	SGAID	Location	%Bankfull Width	Geomorphic Compatibility	Aquatic Organism Passage (AOP)*	AOP Retrofit Potential**
Culvert #1	T5.S1.07	Chester	100010000114071	POPPLE DUNGEON RD	53	Fully Incompatible	Red	MML
Culvert #2	T5.S2.01	Chester	700000001714073	Historic Trail	43	Partially Compatible	Gray	MLL
Culvert #3	T5.S2.01	Chester	400004000014071	MAPLE ST	65	Partially Compatible	Green	MML
Culvert #4	T5.S2.01	Chester	700000001814073	Private	26	Mostly Compatible	Gray	LLL
Culvert #5	T5.S2.01	Chester	100043000014071	LOVERS LN	39	Mostly Compatible	Gray	MLL
Culvert #6	T5.S3.02	Chester	100038000014071	POTASH BROOK RD	45	Partially Compatible	Gray	MLL
Culvert #7	T5.S3.a.01	Chester	100038000214071	POTASH BROOK RD	30	Partially Compatible	Red	LLL
Culvert #8	T5.S3.a.01	Chester	100038000314071	POTASH BROOK RD	57	Mostly Incompatible	Gray	MML
Culvert #9	T7.01	Chester	200103000014072	ROUTE 103 N	58	Mostly Compatible	Gray	MML
Culvert #10	T7.01	Chester	700000000614073	Cemetery access	20	Partially Compatible	Gray	LLL
Culvert #11	T8.01	Chester	700000000714073	Farm access	10	Fully Incompatible	Gray	LLL

*Notes on AOP
Green: Full AOP for all aquatic organisms
Gray: Reduced AOP for all aquatic organisms
Orange: No AOP for all aquatic organisms except adult salmonids
Red: No AOP for all aquatic organisms including adult salmonids

** Notes on AOP Retrofit Potential:
H: High probability the existing culvert can be retrofitted
M: Medium probability the existing culvert can be retrofitted
L: Low probability the existing culvert can be retrofitted
Position 1 (left): For strong swimmers
Position 2 (Center): For moderate swimmers
Position 3 (right): For weak swimmers

Table 5.2: Summary of bridge data for the Williams River watershed.

Map ID #	SGA Reach/ Segment	Town	SGAID	Road	Curve Channel Width (ft)	Structure Length (ft)	Structure Height (ft)	Structure Width (ft)	% Bankfull Width
Bridge #1	M07	Rockingham	700000000113143	Railroad	100.2	20	20	120	119.8
Bridge #2	M08	Rockingham	700000000213143	Railroad	99.9	20	16	105	105.1
Bridge #3	M08	Rockingham	100014000013141	WILLIAMS RD	99.9	25	15	65	65.1
Bridge #4	M09	Rockingham	100008000013141	LOWER BARTONSVILLE RD	97.5	90	20	140	143.6
Bridge #5	M10	Chester	700000000014073	Railroad	95.9	18	25	106	110.5
Bridge #6	M11	Chester	100006000014071	MISSING LINK RD	90.5	30	18	88	97.2
Bridge #7	M11	Chester	700000000114073	Railroad	90.5	60	15	150	165.7
Bridge #8	M12	Chester	200011000014072	ROUTE 11 E	59.1	36	13	80	135.4
Bridge #9	M12	Chester	100087000014071	FLAMSTEAD RD	59.1	30	9	33	55.8
Bridge #10	M12	Chester	100001000014071	DEPOT ST	59.1	50	18	90	152.3
Bridge #11	M13	Chester	100005000014071	CHURCH ST	53.5	30	16	110	205.6
Bridge #12	M13	Chester	100050000014071	COLBURN RD	53.5	24	8	56	104.7
Bridge #13	M13	Chester	100118000014071	WILLARD RD	53.5	24	9	36	67.3
Bridge #14	M13	Chester	100017000014071	WYMANS FALL'S RD	53.5	24	12	52	97.2
Bridge #15	M14	Chester	100018000014071	THOMPSON RD	49.6	27	9	29	58.5
Bridge #16	M14	Chester	100078000014071	JEWETT RD	49.6	25	7	40	80.6
Bridge #17	M14	Chester	100077000014071	PALMER RD	49.6	24	7	50	100.8
Bridge #18	M14	Chester	700000000214073	Railroad	49.6	30	14	70	141.1
Bridge #19	M14	Chester	700000000314073	Railroad	49.6	24	8	70	141.1
Bridge #20	M15	Chester	700000000414073	Railroad	46.9	30	9	70	149.3
Bridge #21	M15	Chester	700000000514073	Quarry access	46.9	25	9	45	95.9
Bridge #22	M16	Chester	700000001514073	Railroad	46.6	30	12	80	171.7
Bridge #23	M16	Chester	200103000314072	ROUTE 103 N	46.6	60	42	300	643.8
Bridge #24	M17	Chester	700000001614073	Railroad	45.6	25	5	70	153.5
Bridge #25	M17	Chester	100019000014071	CAVENDISH RD	45.6	25	11	40	87.7

Table 5.2: Summary of bridge data for the Williams River watershed.

Map ID #	SGA Reach/ Segment	Town	SGAID	Road	Curve Channel Width (ft)	Structure Length (ft)	Structure Height (ft)	Structure Width (ft)	% Bankfull Width
Bridge #26	M18	Chester	200103000414072	ROUTE 103 N	43.2	50	11	58	134.3
Bridge #27	M19	Chester	100009000014071	SMOKESHIRE RD	43.1	30	12	36	83.5
Bridge #28	M19	Chester	100009000114071	SMOKESHIRE RD	43.1	30	8	68	157.8
Bridge #29	M19	Chester	100009000214071	SMOKESHIRE RD	43.1	25	10	42	97.4
Bridge #30	M20	Chester	100009000314071	SMOKESHIRE RD	36.4	24	9	44	120.8
Bridge #31	M20	Chester	100009000414071	VAST trail	36.2	16	7	48	132.6
Bridge #32	M21	Chester	700000000014071	Private	33.8	24	8	38	112.4
Bridge #33	M21	Ludlow	100038000014101	LOVEJOY BROOK RD	33.8	24	8	38	112.4
Bridge #34	T5.01	Chester	700000001414073	Railroad	72.0	8	9	88	122.2
Bridge #35	T5.01	Chester	200103000214072	ROUTE 103 S	72.0	36	11	96	133.3
Bridge #36	T5.02	Chester	200035000314072	GRAFTON RD	61.0	26	15	90	147.5
Bridge #37	T5.03	Chester	400057000014071	BLUE HILL RD	61.0	14	15	70	114.8
Bridge #38	T5.03	Chester	100057000014071	SWETT RD	60.4	18	10	40	66.2
Bridge #39	T5.04	Chester	100057000114071	ROUTE 11 W	57.0	42	9	68	119.3
Bridge #40	T5.04	Chester	100057000214071	ROUTE 11 W	57.0	38	13	72	126.3
Bridge #41	T5.05	Chester	100056000014071	KINGSBURY RD	42.8	15	10	24	56.1
Bridge #42	T5.05	Chester	100056000114071	ROUTE 11 W	42.8	45	10	100	233.6
Bridge #43	T5.06	Andover	100029000014011	TROMBLEY RD	41.5	16	10	30	72.3
Bridge #44	T5.06	Andover	200011000014012	SIMONSVILLE RD	41.5	42	11	50	120.5
Bridge #45	T5.07	Andover	100036000014011	HOWARD HILL RD	39.0	30	10	34	87.2
Bridge #46	T5.08	Andover	200011000114012	SIMONSVILLE RD	28.2	50	9	28	99.3
Bridge #47	T5.08	Andover	200011000214012	SIMONSVILLE RD	28.2	60	10	26	92.2
Bridge #48	T5.08	Andover	400011000014012	SIMONSVILLE RD	28.2	30	8	90	319.1
Bridge #49	T5.08	Andover	400011000114012	SIMONSVILLE RD	28.2	45	7	25	88.7
Bridge #50	T5.08	Andover	200011000314012	SIMONSVILLE RD	28.2	50	10	21	74.5

Table 5.2: Summary of bridge data for the Williams River watershed.

Map ID #	SGA Reach/ Segment	Town	SGAID	Road	Curve Channel Width (ft)	Structure Length (ft)	Structure Height (ft)	Structure Width (ft)	% Bankfull Width
Bridge #51	T5.09	Andover	700000000314013	Private	25.6	22	6	30	117.2
Bridge #52	T5.09	Andover	100040000014011	O'S RD	25.6	18	11	22	85.9
Bridge #53	T5.S1.01	Chester	200103000114072	ROUTE 103 S	38.0	36	6	50	131.6
Bridge #54	T5.S1.02	Chester	200035000014072	GRAFTON RD	37.3	26	8	70	187.7
Bridge #55	T5.S1.02	Chester	200035000114072	GRAFTON RD	37.3	26	12	36	96.5
Bridge #56	T5.S1.03	Chester	200035000214072	GRAFTON RD	35.7	24	7	60	168.1
Bridge #57	T5.S1.04	Chester	700000001014073	Private	35.0	20	11	25	71.4
Bridge #58	T5.S1.05	Chester	700000001114073	Private	33.9	8	12	50	147.5
Bridge #59	T5.S1.05	Chester	100010000014071	POPPLE DUNGEON RD	33.9	60	12	28	82.6
Bridge #60	T5.S1.07	Chester	700000001214073	Private	30.9	12	10	36	116.5
Bridge #61	T5.S1.08	Chester	100063000014071	NUDIST CAMP RD	27.5	35	7	42	152.7
Bridge #62	T5.S1.08	Chester	100010000214071	POPPLE DUNGEON RD	27.5	30	7	26	94.5
Bridge #63	T5.S1.09	Chester	700000001314073	Private	23.8	18	8	20	84.0
Bridge #64	T5.S2.01	Chester	200011000214072	PLEASANT ST	23.0	35	10	38	165.2
Bridge #65	T5.S2.01	Chester	100001000114071	DEPOT ST	23.0	15	8	54	234.8
Bridge #66	T5.S2.01	Chester	100005000114071	CHURCH ST	23.0	36	7	15	65.2
Bridge #67	T5.S2.01	Chester	700000001914073	LOVERS LN	23.0	20	5	32	139.1
Bridge #68	T5.S3.01	Chester	200011000314072	ROUTE 11 W	40.1	40	10	38	94.8
Bridge #69	T5.S3.02	Chester	100007000014071	ANDOVER RD	33.3	45	12	70	210.2
Bridge #70	T5.S3.03	Andover	100000000014011	WESTON-ANDOVER RD	32.1	30	10	35	109.0
Bridge #71	T5.S3.03	Andover	100023000014011	PETTENGILL RD	32.1	30	13	22	68.5
Bridge #72	T5.S3.04	Andover	100001000014011	WESTON-ANDOVER RD	28.6	30	7	50	174.8
Bridge #73	T5.S3.04	Andover	700000000014013	private	28.6	18	14	50	174.8
Bridge #74	T5.S3.04	Andover	100001000114011	WESTON-ANDOVER RD	28.6	17	7	32	111.9
Bridge #75	T5.S3.05	Andover	400000000014011	OLD GULF RD S	21.0	22	6	13	61.9

Table 5.2: Summary of bridge data for the Williams River watershed.

Map ID #	SGA Reach/ Segment	Town	SGAID	Road	Curve Channel Width (ft)	Structure Length (ft)	Structure Height (ft)	Structure Width (ft)	% Bankfull Width
Bridge #76	T5.S3.05	Andover	700000000114013	Private	21.0	8	5	14	66.7
Bridge #77	T5.S3.05	Andover	400013000014011	OLD GULF RD S	21.0	20	5	15	69.0
Bridge #78	T5.S3.a.01	Chester	990038000014071	POTASH BROOK RD	23.4	33	7	18	76.9
Bridge #79	T5.S3.b.01	Andover	700000000214013	Private	18.5	25	9	35	189.2
Bridge #80	T5.S3.b.01	Andover	100001000214011	WESTON-ANDOVER RD	18.5	35	10	70	378.4
Bridge #81	T8.01	Chester	700000000814073	Railroad	19.1	30	7	11	57.6
Bridge #82	T8.01	Chester	400017000014071	GOODRICH RD	19.1	15	6	20	104.7
Bridge #83	T8.01	Chester	700000000914073	VAST Trail	19.1	18	7	18	94.2
Bridge #84	T8.01	Chester	400017000114071	WYMANS FALL'S RD	19.1	16	5	17	89.0

5.2 Site-Level Project Opportunities

The site-level projects developed for the Williams River watershed are provided for each portion of the watershed in Tables 5.3 through 5.9. The project strategy, technical feasibility, and priority for each project are listed by project number and reach/segment. A total of 89 projects were identified to promote the restoration or protection of channel stability and aquatic habitat. These tables summarize key information for each project, including the site stressors and constraints, project strategy, priorities for hazard mitigation and ecological benefit, relative costs (i.e., low, moderate, and high), and potential partners and funding sources.

Tables 5.3 to 5.8 include a ranking of project priority, using our best professional judgment (and input from VTDEC, WNCRD, and other local stakeholders), of hazard mitigation and ecological benefits. Many river corridor restoration projects help mitigate flood and erosion hazards **and** improve the ecological conditions of the reach and watershed as a whole (e.g., improved habitat, protection of water quality, etc.). However, some project types provide a greater benefit to one over the other. Table 5.9 describes transportation, residential, and infrastructure resiliency projects within the Williams River watershed. While it is difficult to place a specific value on each project, rankings of “low,” “medium,” and “high” are intended to provide a means to compare the types of benefits each project provides relative to the others. A summary of what is meant by these two priority types is provided below.

> *Hazard Mitigation Priority:* refers to the potential for the project to mitigate flood and erosion hazards for the river corridor in the reach and in downstream areas. For example, replacing an undersized culvert with an appropriately sized structure could reduce flood/erosion hazards around the structure and downstream.
>
> *Ecological Benefits Priority:* refers to the potential for the project to improve aquatic habitat conditions and water quality in the reach and watershed. For example, a riparian buffer planting will improve habitat by increasing shading along the river and reducing long-term bank erosion.

The project locations for the study area are included on the maps provided in Appendix C. The 89 projects are further broken down by category as follows: thirty-four (34) active geomorphic restoration projects, twenty-four (24) passive geomorphic restoration projects, including four (4) conservation projects, and thirty-one (31) infrastructure resiliency projects. Several of the projects are grouped into a single project number based on type and watershed zone (e.g., MBWR-1a-d: four different corridor protection projects along the Middle Branch). Select "high" priority projects within each watershed are described in greater detail in section 5.3. High priority projects for which a project packet was prepared are summarized in Appendix E.

5.2.1 Lower Williams River Site-level Project Opportunities

Table 5.3: Site-Level Project Identification for the Lower Williams River Watershed in the Towns of Rockingham and Chester, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
LWR-1 Rounds Road House Construction Site Segment M07.B 43.2067 N 72.5300 W	**Passive Restoration** Buffer Planting and Erosion Control	All of the woody vegetation was removed from the steep slope extending to the top of the valley wall where a house is being constructed. The slope appears unstable and will be a major source of sediment to the channel.	We recommend working with the private landowner to establish erosion control measures on the slope and to address any gully formation.	Low	Moderate	Reduce sediment loading to the channel	Low	Private Landowner; VTANR ERP
LWR-2a-d Multiple Locations Reach/Segment: M08.A, M08.B, M10, M11	**Passive Restoration** Corridor Protection	Small to large areas of accessible floodplain that provide valuable sediment, debris, and floodwater attenuation during larger events. Most sites have reduced woody buffer vegetation and tall eroding banks. High priority area on segment M08.B.	Protect corridor from future development and plant buffer with native woody vegetation where appropriate.	Varies by Project: Low to **High**	Varies by Project: Low to **High**	Protect floodplain area from future development and increase shading and woody debris inputs to channel. Provide minor to moderate flood water and sediment/debris storage.	Low to Moderate	VTANR ERP; Private landowners; VLT; WCNRCD and ONRCD Trees for Streams
LWR-3 Williams Road Bridge and Railroad Bridge Segment M08.B 43.2115 N 72.5360 W	**Active Restoration** Bridge Replacement	The Williams Road covered bridge is a major channel constriction (65% bankfull width). The railroad bridge immediately downstream is a slight floodprone constriction relative to the upstream and downstream channel widths. The covered bridge constriction likely increased upstream flooding during T.S. Irene.	Reconfigure abutments to increase bankfull width; in the long-term the bridge may need to be replaced to achieve lower flood risks. New structure/configuration would improve sediment transport and floodwater conveyance through the reach.	Moderate	Low	Remove a significant constriction that increased localized flooding during TS Irene.	High	Town of Rockingham; VTrans

Table 5.3: Site-Level Project Identification for the Lower Williams River Watershed in the Towns of Rockingham and Chester, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
LWR-4a-c Multiple Locations Reach/Segment: M08.B, M10, M11	**Passive Restoration** Conservation	Three large floodplain areas that provided critical floodwater and sediment storage during T.S. Irene. The river channel is highly active and is redeveloping a meandering planform. The M08.B and M10 floodplains are undeveloped, the M11 floodplain has houses and structures immediately adjacent.	Work with private land owners to prevent future development or agricultural conversion in river corridor.	**High**	Medium	Large area for sediment and floodwater attenuation, store and slow floodwaters before entering an extending stretch of river with minimal floodplain access.	Low to Moderate	VTANR; VLT; VRC, Private Landowners; Towns of Rockingham and Chester
LWR-6 Missing Link Road Reach M11 43.2398 N 72.5579 W	**Active Restoration** Bridge Retrofit	Missing Link Road bridge was destroyed during T.S. Irene and reconstructed following the storm. The new bridge has an opening that is very close to predicted bankfull width, however the stone armoring along the abutments constricts the channel to approximately 65% bankfull width.	Reconfigure the large stone armor under the bridge to increase bankfull width.	Moderate	Low	Reduce local flooding impacts without increasing scour risk to the bridge abutments.	Low to Moderate	Town of Chester

Table 5.3: Site-Level Project Identification for the Lower Williams River Watershed in the Towns of Rockingham and Chester, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
LWR-8 Railroad Bridge Reach M11 43.2528 N 72.5729 W	**Active Restoration** Bridge Retrofit/ Replacement	The railroad bridge is poorly aligned to the channel and has a wide center pier. The bridge is very wide (165% bankfull) however the alignment and the pier are causing significant sediment deposition under the bridge which is reducing capacity and increasing scour along the center pier footing. The bridge likely plugged with debris during T.S. Irene causing widespread flooding on both floodplains upstream and downstream of the crossing.	It is likely unfeasible to realign the railroad, therefore the bridge should be considered for replacement with a single span structure. Undermining of the center pier should be assessed. Dredging of excess sediment is a short term solution and this could potentially be reduced with the installation of deflector structures upstream to increase flow on both sides of the pier and reduce sediment accumulation.	**High**	Low	Improve floodwater, sediment, and debris transport through the bridge opening and reduce localized flooding of agricultural fields	Moderate to High	Green Mountain Railroad
LWR-10 Flamstead Rd. Bridge Reach M12 43.2715 N 72.5879 W	**Active Restoration** Replace Bridge	The Flamstead Road bridge is a major bankfull width constriction (55%) and is in poor-fair condition. The east abutment projects approximately 15 feet from the steep banks.	Replace with a larger structure that spans the straightened channel and does not further restrict flows.	Moderate	Low	Improve conveyance of floodwaters and sediment during large storms. Reduce the risk of debris catchment which could cause overbank flooding and damage to adjacent roads and houses.	High	Town of Chester, VTrans, VTANR

5.2.2 *Upper Williams River Site-level Project Opportunities*

Table 5.4: Site-Level Project Identification for the Upper Williams River Watershed in the Towns of Chester and Ludlow, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
UWR-1 **Old Abutments for Farm Bridge** Reach M13 43.2728 N 72.5983 W	**Active Restoration** Remove Old Abutments	Stacked stone abutments from a former farm bridge represent a major channel width and bankfull width constriction. The abutments are approximately 28ft wide and the straightened channel upstream/downstream is typically 35-38ft wide	Remove the old abutments on both banks and regrade left bank to reduce short-term erosion.	Low	Moderate	Improve conveyance of floodwaters and sediment during large storms	Low	Private Landowner
UWR-2a-e **Multiple Locations** Reach/Segment: M13, M14, M20.A	**Passive Restoration** Corridor Protection	Small to large areas of accessible floodplain that provide valuable sediment, debris, and floodwater attenuation during larger events. Most sites have reduced woody buffer vegetation and tall eroding banks. High priority areas on reaches M13 and M14.	Protect corridor from future development and plant buffer with native woody vegetation.	Varies by Project: Low to **High**	Varies by Project: Low to **High**	Protect floodplain area from future development and increase shading and woody debris inputs to channel. Provide minor to moderate flood water and sediment/debris storage.	Low to Moderate	VTANR ERP; Private landowners; VLT; ONRCD Trees for Streams
UWR-3 **Colburn Road Bridge Abutment** Reach M13 43.2902 N 72.6041 W	**Active Restoration** Remove Old Bridge Abutments	Stacked stone abutment from previous bridge is a moderate bankfull width constriction (67%). The new bridge and abutments are not a significant constriction.	Remove old bridge abutment on the right (west) bank to increase capacity for floodwater conveyance through the reach.	Moderate	Low	Improve conveyance of floodwaters and sediment during large storms. Reduce the risk of debris catchment which could cause overbank flooding and damage to adjacent roads and houses.	Low	Town of Chester, VTrans; VTANR

Table 5.4: Site-Level Project Identification for the Upper Williams River Watershed in the Towns of Chester and Ludlow, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
UWR-4 **Willard Road Bridge** Reach M13 43.2946 N 72.6036 W	**Active Restoration** Retrofit or Replace Bridge	The Willard Road bridge is a moderate bankfull constriction (67%) due to the right abutment projecting out from the steep banks along this channelized reach. The channel is narrower than curve width, however the constriction resulting from the abutment may increase local flood risk.	Assess whether the bridge abutment can be pushed back to better match the channel width upstream and downstream of the crossing. Otherwise, consider replacing with a larger structure over the long term.	Moderate	Low	Improve conveyance of floodwaters and sediment during large storms. Reduce the risk of debris catchment which could cause overbank flooding and damage to adjacent roads and houses.	High	Town of Chester; VTANR; VTrans
UWR-6 **Thompson Road Bridge** Reach M14 43.3036 N 72.6052 W	**Active Restoration** Retrofit Bridge	Both of the stacked stone abutments for the bridge project ~4-6ft from the steep banks and create a severe bankfull width constriction (58%).	Assess the stability of the bridge deck and girders if the abutments are pushed back.	Moderate	Low	Improve conveyance of floodwaters and sediment during large storms. Reduce the risk of debris catchment which could cause overbank flooding and damage to adjacent roads and houses.	High	Town of Chester, VTrans
UWR-8 **Cota &Cota Gas Property** Reach M16 43.3302 N 72.6154 W	**Active Restoration** Bank Restoration	The channel is highly constricted (20ft) by the railroad embankment to the west and a poured concrete bank on the east. The concrete appears to be undermined in several locations.	Remove the concrete bank and replace with a stacked stone wall keyed in to the channel bottom.	Low	Low	Increase bankfull width through this section to improve floodwater conveyance	Moderate	Private Landowner
UWR-10 **Floodplain along Route 103** Reach M17 43.3374 N 72.6173 W	**Active Restoration** Berm Removal	A 2ft tall by 300ft long berm on the right bank is blocking access to a small floodplain area. Accessible floodplain areas are very limited in this portion the watershed.	Remove berm to restore access to floodplain. Assess road resiliency.	Moderate	Low	Restore access to a small floodplain in a portion of the watershed with very limited floodplain access.	Low to Moderate	VTANR; VTrans; Private Landowner

Table 5.4: Site-Level Project Identification for the Upper Williams River Watershed in the Towns of Chester and Ludlow, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
UWR-11 Smokeshire Road Multiple Locations Reach/Segment M18-M21	**Active Restoration** Roadway Sediment and Runoff Management	Five areas of excessive sediment generation were observed along Smokeshire Road. Due to the close proximity of the road to the channel through most of this section, large volumes of sediment are delivered to the river during storm events.	Improve ditch maintenance, check dam installation, road grading improvements ,etc.	Low	**High**	Reduce sediment inputs to the channel. Potentially increase transportation resiliency with improved surface runoff management	Moderate	Town of Chester, Town of Ludlow, VTANR, Better Backroads
UWR-12 Smokeshire Road Segment M20.A 43.3371 N 72.6603 W	**Active Restoration** Road Resiliency and Berm Removal	The channel appears to have avulsed during T.S. Irene and access to the former channel is blocked by a dredged gravel/cobble berm. The current channel appears stable but is very straight. Existing road embankment armoring may be insufficient if flow returns to the historic channel	Remove the spoils berm to restore access to the former channel as a flood chute. Road embankment armoring should be assessed and increased if necessary to protect the road.	Moderate	Low	Provide access to a floodplain and an overflow channel/flood chute .	Low to Moderate	Town of Chester, VTANR
UWR-14 Smokeshire Road at South Hill Road Reach M22 43.3353 N 72.6992 W	**Passive Restoration** Conservation	The channel extending upstream from Smokeshire Road is highly active and the floodplain shows evidence of major overbank flooding and channel braiding. Several historic berms were observed, including a very tall berm that appears to have been constructed to protect a logging road that is no longer in service.	Work with private land owners to prevent stream corridor from future development or agricultural conversion. Fully or partially remove berms to improve access to floodplain areas	**High**	Medium	Large area for sediment and floodwater attenuation, store and slow floodwaters before entering an extending stretch of river with minimal floodplain access	Low to Moderate	VTANR; VLT; VRC, Private Landowners; Towns of Ludlow

5.2.3 Middle Branch Williams River Site-level Project Opportunities

Table 5.5: Site-Level Project Identification for the Middle Branch Williams River Watershed in the Towns of Chester and Andover, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
MBWR-1a-d Multiple Locations Reach/Segment T5.01, T5.03, T5.05.A, T5.08	**Passive Restoration** Corridor Protection	Small to large areas of accessible floodplain that provide valuable sediment, debris, and floodwater attenuation during larger events. Most sites have reduced woody buffer vegetation and tall eroding banks. The T5.01 project site is high priority for bank stabilization and buffer planting, the T5.05.A site is very high priority for floodplain protection.	Protect corridor from future development and plant buffer with native woody vegetation.	Varies by Project: Low to **High**	Varies by Project: Low to **High**	Protect floodplain area from future development and increase shading and woody debris inputs to channel. Provide minor to moderate flood water and sediment/debris storage.	Low to Moderate	VTANR ERP; Private landowners; VLT; VRC; ONRCD Trees for Streams
MBWR-4 Floodplain near Route 11 and Reservoir Rd Reach T5.03 43.2688 N 72.6218 W	**Active and Passive Restoration** Berm Removal and Floodplain Protection	A 400ft long 4-5ft tall berm was constructed along the south bank following T.S. Irene. This berm blocks access to a large floodplain that provided critical floodwater and sediment attenuation during the 2011 and 2014 floods. This is the last large floodplain before the Middle Branch flows through the Village.	Remove berms and work with the landowner to protect floodplain from future development and plant buffer with native woody vegetation.	**High**	Moderate	Restore and protect access to a large and important floodplain area.	Moderate	VTANR, VRC, Private Landowner
MBWR-5 Kingsbury Road Segment T5.05.A 43.2604 N 72.6583 W	**Active Restoration** Bridge Replacement	The bridge and abutments are a major bankfull width constriction (56%) increasing upstream sediment deposition. Major overbank flooding during T.S. Irene and the 2014 flood seriously damaged the two houses adjacent to the bridge.	Replace bridge with a larger structure to allow for increased capacity of floodwaters and sediment. Special consideration for sediment transport given the very high upstream sediment load.	**High**	Low	Remove a major bankfull width constriction and improve conveyance of floodwaters and sediment during future storm events.	High	Town of Chester

Table 5.5: Site-Level Project Identification for the Middle Branch Williams River Watershed in the Towns of Chester and Andover, Vermont.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
MBWR-6 Route 11 near Hill Top Rd Reach T5.07 43.2601 N 72.7018 W	**Active Restoration** Buyout and Floodplain Restoration	The property located on the bend immediately upstream of the Route 11 bridge was severely impacted by flooding during T.S. Irene. The channel is highly active and depositional through this section. Berms were constructed along the left bank to protect the house following the 2011 and 2014 floods. A flood chute formed along Rt11 during both floods.	The property is in the process of being purchased through a FEMA buyout, no further site work has been completed. Berms should be removed as part of the site work and the stability of the Rt11 embankment should be assessed.	**High**	Low	Remove house and berms to restore access to an important floodplain. Reduce flood risk to Rt 11.	Moderate to High	VTANR, FEMA, Town of Andover

5.2.4 South Branch Williams River Site-level Project Opportunities

Table 5.6: Site-Level Project Identification for the South Branch Williams River Watershed in the Town of Chester

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
SBWR-2 Grafton Road Bridge near Quarry Road Reach T5.S1.02 43.2551 N 72.6019 W	**Active Restoration** Bridge Retrofit	The abutments under the Grafton Road bridge create a moderate channel constriction (66%). The rock riprap left abutment projects well out into the channel.	Replace the riprap left abutment with stacked stone armor to increase bankfull width by approximately 10ft.	Low	Low	Increase floodwater and sediment conveyance through the structure	Low	VTrans
SBWR-3 Grafton Road Reach T5.S1.03 43.2473 N 72.6034 W	**Active Restoration** Remove Old Abutments	A stacked stone abutment on the east bank is a floodprone width constriction and is exacerbating local erosion.	Remove stacked stone abutment to increase channel and floodprone width.	Low	Low	Increase conveyance of floodwaters through the reach and reduce local erosion along the road embankment.	Low	VTrans, VTANR, Private Landowner

Table 5.6: Site-Level Project Identification for the South Branch Williams River Watershed in the Town of Chester

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
SBWR-5 Floodplain South of Popple Dungeon Road Reach T5.S1.06 43.2423 N 72.6349 W	**Active Restoration** Berm Removal	A 300ft long 5 ft tall berm that appears to be from the 1970's flooding is blocking access to a large undeveloped floodplain.	Remove berm and restore access to floodplain during large storm events.	Moderate	Low	Increase floodplain access to attenuate floodwater and sediment during large events.	Low to Moderate	VTANR, Private Landowner
SBWR-6 Floodplain along Popple Dungeon Road (PDR) Reach T5.S1.07 43.2384 N 72.6475 W	**Active Restoration** Berm Removal	Three berms totaling 550ft were observed along the edge of a lawn and along PDR. The two upstream berms do not appear to protect any infrastructure , the downstream berm along PDR is located on top of the bank armor. All of the berms are older than T.S. Irene but don't appear as old as 1970's.	Assess flood risks to the house if either of the upstream berms are removed. If possible, remove berms and reconnect the floodplain during high flows.	Moderate	Low	Restore access to a small floodplain to increase floodwater and sediment storage within the reach.	Low to Moderate	VTANR, Private Landowner
SBWR-7 Popple Dungeon Road near Zezza Rd Reach T5.S1.07 43.2390 N 72.6585 W	**Active Restoration** Culvert Replacement	Major overbank flooding occurred at this crossing during T.S. Irene when the culvert capacity was exceeded, possibly due to debris jamming, and floodwaters came over the road and flowed down the road for several hundred feet. The culvert bottom is rotting and may be an AOP barrier at some flows.	Replace culvert with a larger structure and extend the north wingwall to the valley wall to reduce overbank flooding risk. **Culvert bottom is scheduled for repair in 2017. The Town Highway Department is planning to replace with a bridge in the future.**	**High**	Moderate	Decrease flood risk at a major T.S. Irene damage site and improve AOP through the reach.	High	Town of Chester, VTrans

5.2.5 Lovers Lane Brook, Trebo Brook, and Whitmore Brook Site-level Project Opportunities

Table 5.7: Site-Level Project Identification for Lovers Lane Brook, Trebo Brook, and Whitmore Brook in the Town of Chester

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
LLB-1 **Trail Crossing at Middle Branch Confluence** Reach T5.S2.01.A 43.2582 N 72.5874 W	**Active Restoration** Culvert Replacement/ Removal	A steel culvert under an abandoned road/trail is partially filled with cobbles including a boulder pile at the inlet which may reduce AOP. Large deposits of coarse material and woody debris were observed immediately upstream. This constriction may have increased flooding along Route 103.	Explore removal of the culvert since the historic road/trail is abandoned. Structure removal would require additional excavation to clear the material along the trail and to establish stable slopes.	**High**	**High**	Remove a significant AOP barrier and improve floodwater and sediment conveyance at the mouth of the Brook.	Moderate	VTANR
LLB-2 **Chester Elementary School** Segment T5.S2.01.B 43.2658 N 72.5962 W	**Passive Restoration** Corridor Protection	A large forested floodplain is located along the north bank along the school property and extending upstream. The floodplain elevation is slightly below the south floodplain where the school is located.	Protect corridor from future development and plant buffer with native woody vegetation.	Moderate	Moderate	Protect floodplain area from future development	Low	VTANR ERP; Elementary School; Private landowners; VLT
LLB-3 **Farm Road Crossing** Segment T5.S2.01.C 43.2664 N 72.5987 W	**Active Restoration** Culvert Replacement	A concrete culvert under the farm access road is very small and is a major bankfull constriction (26%). The upstream channel is heavily channelized and aligns with the culvert, however the elevated road grade coupled with the culvert will increase local flooding.	Replace with a larger structure, this project should be considered in concert with LLB-4.	Low	Low	Improve conveyance of floodwaters and sediment through the reach, reduce local flooding.	Moderate	VTANR ERP; Private Landowner

Table 5.7: Site-Level Project Identification for Lovers Lane Brook, Trebo Brook, and Whitmore Brook in the Town of Chester

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
LLB-4 **Farm Field Near Main St and Church St** Segment T5.S2.01.C 43.2668 N 72.5990 W	**Active Restoration** Channel and Floodplain Restoration	Approximately 300ft of channel is deeply channelized and straightened with minimal access to the large floodplains on both banks. The banks are fractured and unstable and dense willow grow in the channel but woody bank and buffer vegetation is absent.	Construct a meandering channel based on predicted curve width and ensure floodplain access. Plant the buffer with native woody vegetation.	Moderate	Moderate	Increase floodplain access to store floodwaters and sediment. Improve habitat through the reach.	Moderate	VTANR ERP; ONRCD Trees for Streams; Private Landowner
TRE-1 **Wetland Complex near White River Confluence** Segment T7.01.A 43.2741 N 72.5934 W	**Passive Restoration** Corridor Protection	Recent dredging and ditching was observed along a farm road across an active beaver wetland.	Work with the landowner to reduce dredging activities and wetland disturbance. May be possible to conserve the entire hayfield to the south which would remove the need for an access road.	Low	Moderate	Remove source of disturbance to wetland complex, reduce sediment inputs to Williams River.	Low	VTANR ERP; Private Landowner; VLT
TRE-2 **Hayfield Upstream of Cemetery** Segment T7.01.B 43.2775 N 72.5956 W	**Passive Restoration** Buffer Planting and Corridor Protection	Woody vegetation is lacking along both banks for most of the segment.	Plant the banks and buffer with native woody vegetation and work with the landowner to protect the corridor from future development or agricultural conversion.	Low	Moderate	Reduce nutrient inputs to channel and increase shading.	Low	ONRCD Trees for Stream; Private Landowner; VTANR
WHB-1 **Farm Road Crossing off of Wymans Falls Road** Reach T8.01 43.2994 N 72.6076 W	**Active Restoration** Culvert Replacement and Channel Stabilization	A 2ft culvert under the farm road is a major constriction and leads to frequent overtopping and severe erosion at the edge of the field.	Recommend removing the culvert and constructing a stone lined tractor crossing with sufficient bankfull width.	Low	**High**	Reduce large inputs of sediment and nutrients during storm events	Low	VTANR ERP; Private Landowner

Table 5.7: Site-Level Project Identification for Lovers Lane Brook, Trebo Brook, and Whitmore Brook in the Town of Chester

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
WHB-2 Floodplain along Railroad near Wyman Falls Rd Reach T8.01 43.3000 N 72.6078 W	**Passive Restoration** Corridor Protection	The river corridor is highly active with multiple flood chutes and debris jams. Large volumes of sediment are stored within the reach. The pasture floodplain to the east is accessible but lacks woody vegetation.	Protect the stream corridor from future development and agricultural conversion; plant native woody vegetation within the floodplain buffer.	Moderate	Moderate	Protect an important section of channel and floodplain for floodwater and sediment attenuation.	Low	VTANR ERP; Private Landowner

5.2.6 *Andover Branch, Potash Brook, and Trout Brook Site-level Project Opportunities*

Table 5.8: Site-Level Project Identification for Andover Branch, Potash Brook, and Trout Brook in the Towns of Chester and Andover

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
AB-2a-b Multiple Locations Reach/ Segment: T5.S3.01, T5.S3.04.B	**Passive Restoration** Corridor Protection	Both of the large floodplain areas are undeveloped and were very important areas of sediment and floodwater attenuation during T.S. Irene and the 2014 flood. Large volumes of flood sediments working through the stream will continue to maintain access to these floodplains during small to moderate floods. The T5.S3.04.B floodplain has active beaver dams creating a braided channel through the densely vegetated floodplain forest.	Protect the stream corridor and floodplains from development	High	Moderate	Maintain two important floodplain areas along highly active sections of Andover Branch	Low	VTANR ERP; VLT; VRC; Private Landowners

Table 5.8: Site-Level Project Identification for Andover Branch, Potash Brook, and Trout Brook in the Towns of Chester and Andover

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
AB-3 **Potash Brook Road** Reach T5.S3.02 43.2714 N 72.6694 W	**Active Restoration** Culvert Replacement, Road Resiliency, Channel Stabilization	The channel upstream of Potash Brook Road is highly active and is splitting flow into a recently formed flood chute. The road was washed out during recent storms at the flood chute. The large culvert appears to have plugged with debris further increasing local flooding. Recently installed riprap in the center of the channel is increasing split flow, increasing risk to the road.	Replace the flood chute culvert with a much larger structure. Remove the channel armoring and install an over flow structure to direct low and moderate flows to the primary channel but allow larger storms to access the flood chute and associated floodplain area. An engineering study is currently in progress and a large secondary culvert will be installed in 2016/2017.	High	Moderate	Reduce the risk of the road washing out during the next large storm and provide access to the flood chute during large flows.	Moderate to High	Town of Chester; VTrans; FEMA
AB-5 **Horseshoe Acres Campground** Segment T5.S3.04.B 43.2832 N 72.7104 W	**Active Restoration** Berm Removal	A gravel spoils berm was constructed post-Irene to block access to a flood chute that formed along the eastern boundary of the campground property. The berm may have been rebuilt following 2014 flooding. The main stream channel is very narrow and may form a headcut or slowly continue to incise.	Remove the berm and restore flow to the flood chute during high flow periods. Bank stability should be assessed and likely improved along the flood chute to reduce erosion risk to the campground.	High	Low	Increase channel capacity for floodwater conveyance and reduce inundation risk for the lower portion of the campground.	Low to Moderate	Private Landowners; VTANR ERP
AB-6 **Horseshoe Acres Campground** Segment T5.S3.04.B 43.2838 N 72.7111 W	**Active Restoration** Berm Removal	A 350 ft long historic berm (likely 1970's vintage) is constructed on the left bank and completely blocks access to a 20-40ft wide floodplain between the channel and Weston Andover Road. Many large trees are growing on or very near the berm.	Remove portions of the berm to minimize tree disturbance and restore access to the floodplain area. Ensure that the road embankment is appropriately protected and install new armor as necessary.	High	Low	Restore access to an important floodplain area immediately downstream of a confluence of two high sediment load streams. Reduce flooding risk to the lower portion of the campground.	Moderate	Private Landowner; VTANR ERP; VTrans

Table 5.8: Site-Level Project Identification for Andover Branch, Potash Brook, and Trout Brook in the Towns of Chester and Andover

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
AB-8 **Horseshoe Acres Campground** Segment T5.S3.05.A 43.2884 N 72.7138 W	**Active Restoration** Berm Removal	Several small gravel berms were observed blocking flood chutes and side channels within a nice forested floodplain. No infrastructure is at risk within the floodplain.	Remove the berms and restore access to side channels and floodplain.	Moderate	Low	Increase floodplain access upstream of main campground area.	Low	Private Landowner; VTANR ERP
TRB-2 **Horseshoe Acres Campground** Reach T5.S3.b.01 43.2838 N 72.7155 W	**Active Restoration** Channel Restoration	A poured concrete stream ford is acting like an elevated grade control and has created a large AOP barrier. The structure is undermined and not safe for vehicles and is fenced off by the campground staff.	Remove the concrete structure and any associated culverts underneath. Install a boulder grade control step to reduce the risk of upstream incision.	Low	High	Restore AOP to Trout Brook	Low to Moderate	VTANR ERP; VTFWS; Private Landowners
PB-2 **Potash Brook Road at Farrar Road** Reach T5.S3.a.01 43.2844 N 72.6718 W	**Active Restoration** Culvert Replacement	The existing CMP culvert is badly deformed, rotted, and very undersized. Significant flooding damage to the road was observed during T.S. Irene and the 2014 floods. The culvert also has a significant outlet drop creating an AOP barrier.	Remove culvert and replace with a bridge designed to the curve width channel or greater given the high sediment and debris load. **Update: the culvert was replaced with a larger structure in 2016.**	**High**	**High**	Remove a major flood constriction and road flooding hazard, restore AOP	High	Town of Chester; VTrans; FEMA

5.2.7 Infrastructure and Utilities Resiliency Project Opportunities within the Williams River Watershed

Table 5.9: Site-Level Project Identification for Infrastructure and Utilities Resiliency in the Towns of Rockingham, Chester, Andover, and Ludlow.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
LWR-5 **Railroad** Reach: M09 43.2285 N 72.5397 W	**Transportation Resiliency**	The channel takes a sharp bend to the east after cascading through a series of bedrock steps. A small floodplain with an active flood chute has formed along the right bank. Floodwaters entering this flood chute have undermined the very large riprap along the tall railroad embankment.	Replace railroad armor and key in the base of the embankment, likely excavating to bedrock. Preserve the small floodplain and flood chute area.	**High**	Low	Protect Green Mountain Railroad embankment from erosion and undermining during large storm events	Moderate	Green Mountain Railroad
LWR-7 **Route 103 near Remington Rd** Reach M11 43.2463 N 72.5712 W	**Infrastructure Resiliency**	The steep valley wall leading up to a house along Route 103 appears unstable. Large trees were recently cut and the slope may be at greater risk as the roots decompose. The slope is covered in dense growth of Japanese Knotweed.	Assess the slope stability during the fall or winter after vegetation has died back. Buffer plantings along the slope may be sufficient to reestablish deep rooting plants.	Moderate	Low	Stabilize slope that may threaten the house in the near future.	Low to High	Private Landowner
LWR-9 **Chester Wastewater Treatment Plant** Reach M11 43.2561 N 72.5764 W	**Relocate or Floodproof Structure**	The Chester WWTP is immediately adjacent to the Williams River and is in a confined valley between the railroad and Green Mountain Turnpike. T.S. Irene resulted in some inundation damage to the WWTP but overall damage was minor/moderate.	Assess options to relocate the WWTP. If this is not feasible then assess options to floodproof the existing plant by increasing floor elevations, installing waterproof barriers, elevating utilities, etc.	**High**	**High**	Reduce the risk of damage or service interruption during floods, reduce the risk of untreated sewage entering channel.	High to Very High	Town of Chester

Table 5.9: Site-Level Project Identification for Infrastructure and Utilities Resiliency in the Towns of Rockingham, Chester, Andover, and Ludlow.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
UWR-5a-d Multiple Locations Route 103 and Smokeshire Road Reach: M14, M18, M21	**Road Resiliency**	Rip-rap is failing along the road embankment. A single line of trees at the lower M14 and the M21 sites are being undermined and if they fall the embankment will be highly vulnerable.	Assess stability of embankment and replace riprap where necessary. New armor should be keyed in to the channel bottom to prevent scour and undermining.	Moderate	Low	Protect roadways from erosion during moderate to large storm events.	Low to Moderate	VTrans, Town of Chester
UWR-7 Near Route 103 and Route 10 Intersection Reach M15 43.3249 N 72.6084 W	**Infrastructure Resiliency**	The channel is actively migrating and eroding the left bank immediately downstream of the railroad bridge. A large cobble bar formed as T.S. Irene sediments worked through the reach. The channel migration appears to be slowing but could rapidly advance in a large storm. Two houses and associated buildings may be at risk as erosion progresses.	Monitor the site bank stability and assess risk to the adjacent houses. Bank stabilization with riprap may be required to arrest channel migration and protect the houses.	Moderate	Low	Protect houses from damage as stream bank erodes.	Moderate	Town of Chester, VTrans, Private Landowners
UWR-9 Railroad Bridge near Newton Rd. Reach M17 43.3341 N 72.6146 W	**Railroad Resiliency**	Deep deposits of gravel have filled the channel through this section of the reach and have significantly reduced the capacity of the railroad bridge. The bridge is a high risk of total loss during a large event.	Assess options for sediment management or bridge retrofits to increase capacity for floodwater and sediment/debris conveyance. Channel dredging may provide short term relief, however the high upstream sediment load will quickly fill the channel back in. Reconfiguring the bridge is the best long term solution.	**High**	Low	Protect the railroad bridge from damage in large storm events.	Low to High	Green Mountain Railroad

Table 5.9: Site-Level Project Identification for Infrastructure and Utilities Resiliency in the Towns of Rockingham, Chester, Andover, and Ludlow.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
UWR-13a-b Smokeshire Road Segments M20.B and M21	**Road Resiliency**	Two stretches of Smokeshire Road are very low relative to the bankfull elevation. The Chester road supervisor stated that these sections rarely flood but are frequently buried in large volumes of ice during spring melt.	Assess the road bed for stability and measures to erosion and sediment loading to channel. Raising road elevation would reduce flooding frequency but may increase ice jamming/damage risk downstream.	Low	Low	Protect road from flood/ice damage and reduce sediment inputs to channel.	Low to Moderate	Town of Chester
MBWR-2 Railroad Bridge Reach T5.01 43.2599 N 72.5811 W	**Railroad Resiliency and Bridge Replacement**	Major sediment accumulation under and near the railroad bridge has significantly reduced the capacity during floods. The railroad bed serves as a large levee across the floodplain which funnels water back to the bridge or directs flow to the south across the athletic fields. The area will continue to be highly depositional for a long time as flood sediments work through the river.	The only viable long term solution is to replace the bridge with a larger structure and increase channel width to provide greater capacity for floodwater and sediment during flood events. The rail bed should be evaluated for possible culverts or other flood overflow features that would increase floodplain connectivity.	**High**	Low	Reduce flooding risks at a known repeat problem area, improve sediment and debris transport through reach during storm events.	High	Green Mountain Railroad, Town of Chester
MBWR-3a-e Multiple Locations Reach: T5.02, T5.03, T5.04, T5.06	**Infrastructure Resiliency**	Failing rip-rap and unstable slopes were observed in many areas along the Middle Branch. The upstream site on T5.06 has an access road threatened by erosion, the other four sites are residential properties where houses are at risk damage due to bank erosion.	Assess options for stabilizing the eroding bank and protecting infrastructure. Sites with existing riprap may only require repairs, other sites may require installation of new bank stabilization features.	Moderate	Low	Protect infrastructure from erosion risk and potential complete loss during flood events. Reduce risk of sediment and debris entering the channel	Low to High	Private Landowners, Towns of Chester and Andover, FEMA

Table 5.9: Site-Level Project Identification for Infrastructure and Utilities Resiliency in the Towns of Rockingham, Chester, Andover, and Ludlow.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
SBWR-1 **Route 103 Bridge** Reach T5.S1.01 43.2570 N 72.5835 W	**Transportation Resiliency**	Moderate accumulation of sand and gravel under the Route 103 bridge has reduced the capacity and is increasing risk of damage to the structure and surrounding properties during flood events. Bridge clearance was measured as 6ft in August 2014.	This bridge should be monitored for sediment deposition and clearance, which may require semi-routine maintenance as there are still large volumes of flood related sediment working through the channel.	Moderate	Low	Reduce risk of flood damage to the bridge and to adjacent properties	Low	VTrans
SBWR-4a-e **Multiple Locations** Reach: T5.S1.03, T5.S1.04.B, T5.S1.08, T5.S1.09	**Transportation Resiliency**	Several areas with failing bank armor that is threatening Grafton Road and Popple Dungeon Road. High priority bank stabilization project on T5.S1.03 where the east embankment along Grafton Road (Route 35) is in very poor condition.	Stabilize eroding banks with stone armor keyed in to the channel bottom. Assess surface runoff issues that might exacerbate slope erosion from above. Route 35 repairs are scheduled for 2017.	**High**	Low	Protect transportation infrastructure from erosion damage.	Moderate	Town of Chester
AB-1a-c **Multiple Locations** Reach: T5.S3.01, T5.S3.03	**Infrastructure Resiliency**	Active bank erosion and failing bank armor are threatening a house and Route 11 along (T5.S3.01) and a quarry access road (T5.S3.01).	Remove the failing armor and install new placed rock armor sufficiently keyed in to channel bottom The T5.S3.01 site may require cutting the slope back to establish a stable grade.	Moderate	Low	Protect vulnerable infrastructure from erosion damage during flood events.	Moderate	Town of Chester; Private Landowners: VTrans
AB-4 **Pettengill Rd** Reach T5.S3.03 43.2787 N 72.6967 W	**Utilities Resiliency**	A utility pole located at the top of the valley wall is immediately threatened by an active mass failure. The mass failure advanced several feet during T.S. Irene and during the 2014 flood.	Move the utility pole to a stable location. It is not feasible to stabilize the mass failure, however buffer planting along the edge of the field may slow advancement.	Moderate	Low	Reduce risk of utility service interruption	Low to Moderate	Green Mountain Power

Table 5.9: Site-Level Project Identification for Infrastructure and Utilities Resiliency in the Towns of Rockingham, Chester, Andover, and Ludlow.

Project ID, Location, Reach, Lat/Long	Type of Project	Site Description Including Stressors and Constraints	Project or Strategy Description	Hazard Mitigation Priority	Ecological Benefits Priority	Project Benefits	Costs	Potential Partners & Funding
AB-7a - b & TRB-1 **Horseshoe Acres Campground** Segment T5.S3.05.A T5.S3.b.01	**Utilities Resiliency**	Three private bridges within the campground have exposed utility lines hanging below the bridge.	Secure the utility lines to the bottom of the bridge	Low	Low	Reduce risk of service interruption within campground.	Low	Private Landowner
PB-1 **Potash Brook Road** Reach T5.S3.a.01 43.2796 N 72.6708 W	**Infrastructure Resiliency**	The bank armor along the east bank downstream of the bridge has failed and the channel is pushing towards a house on the floodplain. The house is increasingly at risk of major flooding damage.	Remove failed armor and install a new stacked stone wall keyed in to the channel bottom and tied in to the upstream bridge opening.	Moderate	Moderate	Protect house from erosion damage, reduce sediment inputs to channel	Moderate	Town of Chester; Private Landowner; FEMA

5.3 High Priority Project Summaries

The corridor planning partners reviewed and commented on the list of preliminary projects during a watershed tour in June, 2016, and via email. A total of 89 projects are described in the River Corridor Plan, a subset of 19 high-priority projects were discussed for further development. Five (5) project "bundles" from the list of high-priority projects were chosen for further development. Project summaries are included in Appendix E for the five highest priority project bundles. Each summary includes:

- A description of the site location and river reach
- A brief technical summary of the stressors on channel stability and aquatic habitat
- A description of channel and floodplain restoration alternatives
- Preliminary cost opinions for restoration alternatives
- A list of current and potential technical partners and funding
- A review of regulatory requirements

The five project bundles chosen for further investigation were:

1. Project LLB-1: Segment T5S2.01.A -Steel culvert under an abandoned access road located at the confluence of Lovers Lane Brook and the Middle Branch Williams River in Chester.
    - *Active Restoration: Culvert Removal*
2. Project WHB-1: Reach T8.01 - A farm access road with an extremely undersized culvert is increasing flooding and erosion of a hayfield at the confluence with the Williams River in Chester.
    - *Active Restoration: Culvert Removal and Installation of Stone Lined Stream Crossing*
3. Projects AB-5, AB-6, AB-8 and TRB-2: Segments T5.S3.04.B, T5.S3.05.A, and T5.S3.b.01- Several projects along Andover Branch and Trout Brook within the Horseshoe Acres Campground in Andover.
    - *Active Restoration: Berm Removal, Stream Crossing Removal*
4. Project MBWR-4: Reach T5.03 on Middle Branch Williams River- River corridor protection and buffer plantings for vulnerable hay fields along VT Route 11 in Chester.
    - *Passive Restoration: Corridor Protection, Berm Removal, and Buffer Plantings*
5. Project MBWR-1c: Segment T5.05.A on Middle Branch Williams River - River corridor protection for vulnerable field and Christmas tree farm on left (north) bank along VT Route 11 and Kingsbury Road.
    - *Passive Restoration: River Corridor Protection*

6.0 Conclusions and Recommendations

The steep terrain draining the Williams River headwaters, in combination with very erodible soil types along the river valley walls, creates significant flood hazards along the valley in Andover, Chester and Rockingham. Major flooding occurred along the Williams River and tributaries during Tropical Storm Irene (August 2011), causing significant damage to transportation infrastructure, residential and commercial properties, and agricultural areas. A localized summer thunderstorm in July 2014 caused major flooding within portions of the Williams watershed, matching or exceeding damages from Tropical Storm Irene in some areas. Roads and bridges were especially hard hit by these floods and the damage to the transportation network slowed recovery efforts and severed main highways (e.g., VT Route 11) and many critical town roads serving dozens of homes in the watershed. In response to the impacts from these floods, and the increasing severity of rainfall and flood events over the last few decades, the towns in the Williams River watershed are wise to take a long-term corridor planning approach to better understand, plan for, and mitigate flood hazards within the watershed.

The 2011 and 2014 floods triggered major channel adjustments in many of the Phase 2 study reaches. The USGS gage on the mainstem of the Williams River in Rockingham indicated the discharge during Tropical Storm Irene exceeded the 500-year flood estimate. Based on the observations that many state highway bridges along the Middle Branch and its tributaries were at or near maximum capacity in the July 2014 flood, this flood was likely near or above the 50-year discharge in this subwatershed. Both floods unleashed an enormous volume of coarse sediment and woody debris into the channel as a result of stream bed and bank erosion and mass failure valley erosion; much of this originated from the steep headwaters zones in the Middle Branch watershed. In some instances, the flood triggered severe channel adjustments even in reaches with limited human impacts in the river corridor.

Overall Phase 2 geomorphic ratings indicate fair to poor river stability along much of the Williams River mainstem in Chester and Rockingham, with the exception of some more stable reaches in the upper watershed along Smokeshire Road. Many reaches of the Middle Branch also had fair to poor stability, with severe channel adjustments found along the lower reaches in Chester, and near the confluence with Andover Branch. Andover Branch and its tributaries, such as Potash Brook, also experienced severe channel adjustments during both floods. The South Branch had fair to poor stability, with the most severe channel adjustments seen in the upper reaches in the southwestern part of Chester.

Key flood resiliency recommendations are summarized below for the watershed and each town representing a significant portion of the study area:

<u>Williams River Watershed</u>

- Based on the flood damage incurred in the 2011 and the 2014 floods, the Williams River watershed is vulnerable to severe flooding during prolonged rainstorms (i.e., Irene) and flashy summer thunderstorms. The National Flood Insurance Program (NFIP) study for the Williams River does not cover the entire floodplain with a detailed study; therefore inundation hazards may be underestimated in the smaller tributaries such as Trebo and Whitmore Brooks, and the upper reaches of the mainstem, Middle Branch, and South Branch. Given the hydrologic characteristics of the watershed, and the severe flood damage witnessed during recent floods, we recommend that all towns in the watershed consider flood hazard ordinances that prevent encroachment in the entire 100-year floodplain (i.e., floodway and floodplain fringe).

- River corridor protection ordinances should be considered by each town to better map flood and erosion risks for both the safety and protection of their citizens, and the infrastructure controlled by the municipality.
- By implementing at least one of the above-mentioned zoning recommendations (either river corridor protection or no new structures in the FEMA flood hazard area), towns can qualify for increased state aid (from 12.5% to 17.5%) from the Emergency Relief and Assistance Fund (ERAF) to cover future flood damages. Additional ERAF assistance from the State can significantly reduce the financial burden faced by towns during flood recovery; i.e., during a large flood resulting in 2 million dollars in recovery expenses (approximate Irene damages for the Town of Chester), the increased State share of 17.5% would reduce the Town's match to Federal and State funding by $100,000.

<u>Town of Rockingham</u>

- River corridor encroachment, historic channel straightening, and bank armoring were common along most of the Williams River mainstem reaches in Rockingham. These historic and ongoing impacts resulted in many stream type departures due to areas of moderate to high incision. Despite these historic alterations some segments maintained elevated floodplains that were accessed in the T.S. Irene flood.
- The floodplain in segment M08.B remains easily accessible due to major aggradation within the segment, which has resulted in planform adjustment. This floodplain, along with another accessible floodplain identified in reach M10, are high priority protection areas to ensure long-term storage of sediment, debris, and floodwaters to reduce flood vulnerability to downstream properties and infrastructure.

<u>Town of Chester</u>

- River corridor encroachment, historic channel straightening, and bank armoring were common along most of the Williams River mainstem reaches in Chester, diminishing somewhat in the upper reaches along Smokeshire Road. These historic and ongoing impacts resulted in many stream type departures due to areas of moderate to high channel incision. Some high priority floodplain and river corridor protection opportunities were noted along the mainstem on agricultural lands west of Route 103, including a large hay field with accessible floodplain (see project labeled UWR-2b on map on page 9 of Appendix C).
- Bedrock grade controls become more prevalent as the valley slope and confinement increase along Smokeshire Road. Bedrock is also present along the banks in many areas and limits the channel's ability to widen. Sediment inputs from stormwater runoff along Smokeshire Road were noted in the headwaters. Due to the close proximity of the road to the channel through most of this section, large volumes of sediment are delivered to the river during storm events. Improved ditch conveyances and maintenance, check dams, and other gravel road best practices are recommended to improve road resiliency and reduce sedimentation to the channel.

- The lower reaches of the Middle Branch along Route 11 are undergoing severe lateral adjustments in response to an enormous flux of coarse sediment and woody debris from the upstream reaches. Given the severe erosion along the banks and valley walls upstream, these downstream reaches will continue to aggrade (i.e., accumulate) sediment over the near term, increasing bank erosion and flood risks as the channel works through this material. These conditions make floodplain and river corridor protections critical for reducing flood risks downstream in Chester Village. Several floodplain protection projects were identified and explored as part of this project, including one important area south of Route 11 and Reservoir Road (project MBWR-4).
- Although infrastructure along South Branch experienced damage during the 2011 flood, it was not impacted to the same degree as the Middle Branch drainages during the 2014 flood. Nonetheless, many reaches of the South Branch are encroached upon by Grafton Road (VT Route 35) and Popple Dungeon Road; this has led to historic channel incision and ongoing widening. There are many areas of road embankment instability that the Town of Chester and VTrans are aware of and plan to address in the near future. Some opportunities for upstream floodplain reconnections and long-term corridor protections were identified in the upper reaches.
- The main tributaries to the Middle Branch – Andover Branch, Potash Brook, Trout Brook – all experienced severe flooding in the 2011 and 2014 storms. In particular, the 2014 flood appeared to hit this area of the watershed the hardest. The channels in these tributaries responded in various ways, leading to conflicts with infrastructure in many locations:
    - Andover Branch: historic encroachment, bank armor, and straightening are highly variable within these segments. Areas that are affected by these impacts exhibit continued incision, while the segments less impacted are widening and adjusting planform. Major bank erosion or scour was seen throughout most segments resulting in deposition of sediment in areas of lower slope and at undersized bridges. The Town of Chester is addressing a channel avulsion which washed out Potash Brook Road in both floods; a larger culvert is planned for installation in 2017 to handle the secondary channel.
    - Potash Brook: this tributary was severely impacted in T.S. Irene and the July 2014 storm washing out the road in multiple locations as the channel incised and widened. A large volume of sediment is still moving through the channel and is being stored by the many debris jams in the channel. The Town of Chester is currently in the process of upgrading a severely undersized culvert along Potash Brook Road.
- Flooding along Lover's Lane Brook in the 2011 flood contributed to damage near the Route 11 and 103 intersection. We identified an undersized culvert under an abandoned road where the brook meets the Middle Branch. There is evidence this culvert constricted floodwaters and exacerbated flooding upstream during 2011. We have explored this opportunity in more detail in the project packets, and the Town of Chester is supportive of a project to remove this structure.

Town of Andover

- There are several good opportunities for floodplain reconnections along the upper reaches of Andover Branch within the Horseshoe Acres campground property. The campground owners have been cooperative and these projects were explored in more detail in the project packets.
- Trout Brook has greater slope than Andover Branch. Both natural valley walls and armoring along Weston-Andover road limit the brook's ability to widen or adjust planform; therefore the reach is very incised. The July 2014 flood scoured the channel bottom and deposited many large boulders in the channel leaving little fine sediment behind. One high priority AOP project was identified within the Horseshoe Acres campground property.

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8.0 Glossary of Terms

Adapted from:

Restoration Terms, by Craig Fischenich, February, 2000, USAE Research and Development Center, Environmental Laboratory, 3909 Halls Ferry Rd., Vicksburg, MS 39180

And

Vermont Stream Geomorphic Assessment Handbook, 2007, Vermont Agency of Natural Resources, Waterbury, VT http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_geoassesspro.htm

Acre -- A measure of area equal to 43,560 ft ^{2} (4,046.87 m^2). One square mile equals 640 acres.

Adjustment process --or type of change, that is underway due to natural causes or human activity that has or will result in a change to the valley, floodplain, and/or channel condition (e.g., vertical, lateral, or channel plan form adjustment processes)

Aggradation -- A progressive buildup or raising of the channel bed and floodplain due to sediment deposition. The geologic process by which streambeds are raised in elevation and floodplains are formed. Aggradation indicates that stream discharge and/or bed-load characteristics are changing. Opposite of degradation.

Algae -- Microscopic plants that grow in sunlit water containing phosphates, nitrates, and other nutrients. Algae, like all aquatic plants, add oxygen to the water and are important in the fish food chain.

Alluvial -- Deposited by running water.

Alluvium -- A general term for detrital deposits make by streams on riverbeds, floodplains, and alluvial fans; esp. a deposit of silt or silty clay laid down during time of flood. The term applies to stream deposits of recent time. It does not include subaqueous sediments of seas or lakes.

Anadromous -- Pertaining to fish that spend a part of their life cycle in the sea and return to freshwater streams to spawn.

Aquatic ecosystem -- Any body of water, such as a stream, lake, or estuary, and all organisms and nonliving components within it, functioning as a natural system.

Armoring -- A natural process where an erosion-resistant layer of relatively large particles is established on the surface of the streambed through removal of finer particles by stream flow. A properly armored streambed generally resists movement of bed material at discharges up to approximately 3/4 bank-full depth. Augmentation (of stream flow) – Increasing flow under normal conditions, by releasing storage water from reservoirs.

Avulsion -- A change in channel course that occurs when a stream suddenly breaks through its banks, typically bisecting an overextended meander arc.

Backwater -- (1) A small, generally shallow body of water attached to the main channel, with little or no current of its own, or (2) A condition in subcritical flow where the water surface elevation is raised by downstream flow impediments.

Backwater pool -- A pool that formed as a result of an obstruction like a large tree, weir, dam, or boulder.

Bank stability -- The ability of a streambank to counteract erosion or gravity forces.

Bankfull channel depth -- The maximum depth of a channel within a riffle segment when flowing at a bank-full discharge.

Bankfull channel width -- The top surface width of a stream channel when flowing at a bank-full discharge.

Bankfull discharge -- The stream discharge corresponding to the water stage that overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years and given its frequency and magnitude is responsible for the shaping of most stream or river channels.

Bankfull width -- The width of a river or stream channel between the highest banks on either side of a stream.

Bar -- An accumulation of alluvium (usually gravel or sand) caused by a decrease in sediment transport capacity on the inside of meander bends or in the center of an overwide channel.

Barrier -- A physical block or impediment to the movement or migration of fish, such as a waterfall (natural barrier) or a dam (man-made barrier).

Base flow -- The sustained portion of stream discharge that is drawn from natural storage sources, and not affected by human activity or regulation.

Bed load -- Sediment moving on or near the streambed and transported by jumping, rolling, or sliding on the bed layer of a stream. See also suspended load.

Bed material -- The sediment mixture that a streambed is composed of.

Bed material load -- That portion of the total sediment load with sediments of a size found in the streambed.

Bed roughness -- A measure of the irregularity of the streambed as it contributes to flow resistance. Commonly expressed as a Manning "n" value.

Bed slope -- The inclination of the channel bottom, measured as the elevation drop per unit length of channel.

Bedform -- Individual patterns which streams follow that characterize the condition of the stream bed into several categories. (*See*: braided, dune-ripple, plane bed, riffle-pool, step-pool, and cascade)

Benthic invertebrates -- Aquatic animals without backbones that dwell on or in the bottom sediments of fresh or salt water. Examples: clams, crayfish, and a wide variety of worms.

Berms -- mounds of dirt, earth, gravel, or other fill built parallel to the stream banks designed to keep flood flows from entering the adjacent floodplain.

Biota -- All living organisms of a region, as in a stream or other body of water.

Boulder -- A large substrate particle that is larger than cobble, between 10 and 160 inches in diameter.

Boundary resistance -- The ability a stream bank has to withstand the erosional forces of the flowing water at varying intensities. Under natural conditions boundary resistance is increased due to stream bank vegetation (roots), cohesive clays, large boulder substrate, etc.

Braided -- A stream channel characterized by flow within several channels, which successively meet and divide. Braiding often occurs when sediment loading is too large to be carried by a single channel.

Braiding (of river channels) -- Successive division and rejoining of riverflow with accompanying islands.

Buffer strip -- A barrier of permanent vegetation, either forest or other vegetation, between waterways and land uses such as agriculture or urban development, designed to intercept and filter out pollution before it reaches the surface water resource.

Canopy -- A layer of foliage in a forest stand. This most often refers to the uppermost layer of foliage, but it can be used to describe lower layers in a multistoried stand. Leaves, branches and vegetation that are above ground and/or water that provide shade and cover for fish and wildlife.

Cascade -- A short, steep drop in streambed elevation often marked by boulders and agitated white water.

Catchment -- (1) The catching or collecting of water, especially rainfall. (2) A reservoir or other basin for catching water. (3) The water thus caught. (4) A watershed.

Channel -- An area that contains continuously or periodically flowing water that is confined by banks and a streambed.

Channelization -- The process of changing (usually straightening) the natural path of a waterway.

Channel evolution model (CEM) -- A series of stages used to describe the erosional or depositional processes that occur within a stream or river in order to regain a dynamic equilibrium following a disturbance.

Clay -- Substrate particles that are smaller than silt and generally less than 0.0001 inches in diameter.

Coarse gravel -- Substrate that is smaller than cobble, but larger than fine gravel. The diameter of this stream-bottom particulate is between 0.63 and 2.5 inches.

Cobble -- Substrate particles that are smaller than boulders and larger than gravels, and are generally between 2.5 and 10 inches in diameter.

Confinement -- *see* Valley confinement

Confluence -- (1) The act of flowing together; the meeting or junction of two or more streams; also, the place where these streams meet. (2) The stream or body of water formed by the junction of two or more streams; a combined flood.

Conifer -- A tree belonging to the order Gymnospermae, comprising a wide range of trees that are mostly evergreens. Conifers bear cones (hence, coniferous) and have needle-shaped or scalelike leaves.

Conservation -- The process or means of achieving recovery of viable populations.

Contiguous habitat -- Habitat suitable to support the life needs of a species that is distributed continuously or nearly continuously across the landscape.

Cover -- “cover” is the general term used to describe any structure that provides refuge for fish, reptiles or amphibians. These animals seek cover to hide from predators, to avoid warm water temperatures, and to rest, by avoiding higher velocity water. These animals come in all sizes, so even cobbles on the stream bottom that are not sedimented in with fine sands and silt can serve as cover for small fish and salamanders. Larger fish and reptiles often use large boulders, undercut banks, submerged logs, and snags for cover.

Critical shear stress -- The minimum amount of shear stress exerted by stream currents required to initiate soil particle motion. Because gravity also contributes to streambank particle movement but not on streambeds, critical shear stress along streambanks is less than for streambeds.]

Cross-section -- A series of measurements, relative to bankfull, that are taken across a stream channel that are representative of the geomorphic condition and stream type of the reach.

Crown -- The upper part of a tree or other woody plant that carries the main system of branches and the foliage.

Crown cover -- The degree to which the crowns of trees are nearing general contact with one another.

Cubic feet per second (cfs) -- A unit used to measure water flow. One cubic foot per second is equal to 449 gallons per minute.

Culvert -- A buried pipe that allows flows to pass under a road.

Debris flow -- A rapidly moving mass of rock fragments, soil, and mud, with more than half of the particles being larger than sand size.

Deciduous -- Trees and plants that shed their leaves at the end of the growing season.

Degradation -- (1) A progressive lowering of the channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation. (2) A decrease in value for a designated use.

Detritus -- is organic material, such as leaves, twigs, and other dead plant matter, that collects on the stream bottom. It may occur in clumps, such as leaf packs at the bottom of a pool, or as single pieces, such as a fallen tree branch.

Dike -- (1) (Engineering) An embankment to confine or control water, especially one built along the banks of a river to prevent overflow of lowlands; a levee. (2) A low wall that can act as a barrier to prevent a spill from spreading. (3) (Geology) A tabular body of igneous (formed by volcanic action) rock that cuts across the structure of adjacent rocks or cuts massive rocks.

Dissolved oxygen (DO) -- The amount of free (not chemically combined) oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation.

Ditch -- A long narrow trench or furrow dug in the ground, as for irrigation, drainage, or a boundary line.

Drainage area -- The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed. The drainage area may include one or more watersheds.

Drainage basin -- The total area of land from which water drains into a specific river.

Dredging -- Removing material (usually sediments) from wetlands or waterways, usually to make them deeper or wider.

Dune-ripple -- A bedform associated with low-gradient, sand-bed channels; the low gradient nature of the channel causes the sand to form a sequence of dunes and small ripples; significant sediment transport typically occurs at most stream stages.

Ecology -- The study of the interrelationships of living organisms to one another and to their surroundings.

Ecosystem -- Recognizable, relatively homogeneous units, including the organisms they contain, their environment, and all the interactions among them.

Embankment -- An artificial deposit of material that is raised above the natural surface of the land and used to contain, divert, or store water, support roads or railways, or for other similar purposes.

Embeddedness -- is a measure of the amount of surface area of cobbles, boulders, snags and other stream bottom structures that is covered with sand and silt. An embedded streambed may be packed hard with sand and silt such that rocks in the stream bottom are difficult or impossible to pick up. The spaces between the rocks are filled with fine sediments, leaving little room for fish, amphibians, and bugs to use the structures for cover, resting, spawning, and feeding. A streambed that is not embedded has loose rocks that are easily removed from the stream bottom, and may even "roll" on one another when you walk on them.

Entrenchment ratio --The width of the flood-prone area divided by the bankfull width.

Epifaunal – "epi" means surface, and "fauna" means animals. Thus, "epifaunal substrate" is structures in the stream (on the stream bed) that provide surfaces on which animals can live. In this case, the animals are aquatic invertebrates (such as aquatic insects and other "bugs"). These bugs live on or under cobbles, boulders, logs, and snags, and the many cracks and crevices found in these structures. In general, older decaying logs are better suited for bugs to live on/in than newly fallen "green" logs and trees.

Ephemeral streams -- Streams that flow only in direct response to precipitation and whose channel is at all times above the water table.

Equilibrium Condition -- The state of a river reach in which the upstream input of energy (flow of water) and materials (sediment and debris) is equal to its output to downstream reaches. Natural river reaches without human impacts tend towards a "stable" state where predictable channel forms are maintained over the long term under varying flow conditions.

Erosion -- Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

Eutrophic -- Usually refers to a nutrient-enriched, highly productive body of water.

Eutrophication -- The process of enrichment of water bodies by nutrients.

Fine gravel -- Is substrate which is larger than sand, but smaller than coarse gravel. It is between 0.08 and 0.63 inches in diameter.

Flash flood -- A sudden flood of great volume, usually caused by a heavy rain. Also, a flood that crests in a short length of time and is often characterized by high velocity flows.

Floodplain -- Land built of fine particulate organic matter and small substrate that is regularly covered with water as a result of the flooding of a nearby stream.

Floodplain (100-year) -- The area adjacent to a stream that is on average inundated once a century.

Floodplain Function – Flood water access of floodplain which effects the velocity, depth, and slope (stream power) of the flood flow thereby influencing the sediment transport characteristics of the flood (i.e., loss of floodplain access and function may lead to higher stream power and erosion during flood).

Flow -- The amount of water passing a particular point in a stream or river, usually expressed in cubic feet per second (cfs).

Fluvial -- Migrating between main rivers and tributaries. Of or pertaining to streams or rivers.

Fluvial Geomorphology—The study of how rivers and their landforms interact over time through different climatic conditions.

Ford -- A shallow place in a body of water, such as a river, where one can cross by walking or riding on an animal or in a vehicle.

Fry -- A recently hatched fish.

Gabion -- A wire basket or cage that is filled with gravel or cobble and generally used to stabilize streambanks.

Gaging station -- A particular site in a stream, lake, reservoir, etc., where hydrologic data are obtained.

Gallons per minute (gpm) -- A unit used to measure water flow.

Geographic information system (GIS) -- A computer system capable of storing and manipulating spatial data.

Geomorphology -- A branch of both physiography and geology that deals with the form of the earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and the buildup of erosional debris.

Glide -- A section of stream that has little or no turbulence.

Grade control -- A fixed feature on the streambed that controls the bed elevation at that point, effectively fixing the bed elevation from potential incision; typically bedrock, dams. or culverts.

Gradient -- Vertical drop per unit of horizontal distance.

Grass/forb -- Herbaceous vegetation.

Gravel -- An unconsolidated natural accumulation of rounded rock fragments, mostly of particles larger than sand (diameter greater than 2 mm), such as boulders, cobbles, pebbles, granules, or any combination of these.

Groundwater -- Subsurface water and underground streams that can be collected with wells, or that flow naturally to the earth's surface through springs.

Groundwater basin -- A groundwater reservoir, defined by an overlying land surface and the underlying aquifers that contain water stored in the reservoir. In some cases, the boundaries of successively deeper aquifers may differ and make it difficult to define the limits of the basin.

Groundwater recharge -- Increases in groundwater storage by natural conditions or by human activity. See also artificial recharge.

Groundwater Table -- The upper surface of the zone of saturation, except where the surface is formed by an impermeable body.

Habitat -- The local environment in which organisms normally live and grow.

Habitat diversity -- The number of different types of habitat within a given area.

Habitat fragmentation -- The breaking up of habitat into discrete islands through modification or conversion of habitat by management activities.

Headcut -- A sharp change in slope, almost vertical, where the streambed is being eroded from downstream to upstream.

Headwater -- Referring to the source of a stream or river.

High gradient streams -- typically appear as steep cascading streams, step/pool streams, or streams that exhibit riffle/pool sequences. Most of the streams in Vermont are high gradient streams.

Hydraulic gradient -- The slope of the water surface. See also streambed gradient.

Hydraulic radius -- The cross-sectional area of a stream divided by the wetted perimeter.

Hydric -- oil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper horizon.

Hydrograph -- A curve showing stream discharge over time.

Hydrologic balance -- An accounting of all water inflow to, water outflow from, and changes in water storage within a hydrologic unit over a specified period of time. Hydrologic region -- A study area, consisting of one or more planning subareas, that has a common hydrologic character.

Hydrologic unit Code (HUC) -- A distinct watershed or river basin defined by an 8-digit code.

Hydrology -- The scientific study of the water of the earth, its occurrence, circulation and distribution, its chemical and physical properties, and its interaction with its environment, including its relationship to living things.

Hyporheic zone -- The area under the stream channel and floodplain where groundwater and the surface waters of the stream are exchanged freely.

Impoundment -- An area where the natural flow of the river has been disrupted by the presence of human-made or natural structure (e.g. weir or beaver dam). The impoundment backwater extends upstream causing sediment to be deposited on the stream bottom.

Improved paths – Paths that are maintained and typically involve paved, gravel or macadam surfaces.

Incised river -- A river that erodes its channel by the process of degradation to a lower base level than existed previously or is consistent with the current hydrology.

Incision ratio -- The low bank height divided by the bankfull maximum depth.

Infiltration (soil) -- The movement of water through the soil surface into the soil.

Inflow -- Water that flows into a stream, lake,

Instream cover -- The layers of vegetation, like trees, shrubs, and overhanging vegetation, that are in the stream or immediately adjacent to the wetted channel.

Instream flows -- (1) Portion of a flood flow that is contained by the channel. (2) A minimum flow requirement to maintain ecological health in a stream.

Instream use -- Use of water that does not require diversion from its natural watercourse. For example, the use of water for navigation, recreation, fish and wildlife, aesthetics, and scenic enjoyment.

Intermittent stream -- Any nonpermanent flowing drainage feature having a definable channel and evidence of scour or deposition. This includes what are sometimes referred to as ephemeral streams if they meet these two criteria.

Irrigation diversion -- Generally, a ditch or channel that deflects water from a stream channel for irrigation purposes.

Islands -- mid-channel bars that are above the average water level and have established woody vegetation.

Kame – a deposit of stratified glacial drift in isolated mounds or steep-sided hills.

Lake -- An inland body of standing water deeper than a pond, an expanded part of a river, a reservoir behind a dam

Landslide -- A movement of earth mass down a steep slope.

Large woody debris (LWD) -- Pieces of wood at least 6 ft. long and 1 ft. in diameter (at the large end) contained, at least partially, within the bankfull area of a channel.

Levee -- An embankment constructed to prevent a river from overflowing (flooding).

Limiting factor -- A requirement such as food, cover, or another physical, chemical, or biological factor that is in shortest supply with respect to all resources necessary to sustain life and thus "limits" the size or retards production of a population.

Low gradient -- streams typically appear slow moving and winding, and have poorly defined riffles and pools.

Macroinvertebrate -- Invertebrates visible to the naked eye, such as insect larvae and crayfish.

Macrophytes -- Aquatic plants that are large enough to be seen with the naked eye.

Mainstem -- The principal channel of a drainage system into which other smaller streams or rivers flow.

Mass movement -- The downslope movement of earth caused by gravity. Includes but is not limited to landslides, rock falls, debris avalanches, and creep. It does not however, include surface erosion by running water. It may be caused by natural erosional processes, or by natural disturbances (e.g., earthquakes or fire events) or human disturbances (e.g., mining or road construction).

Mean annual discharge -- Daily mean discharge averaged over a period of years. Mean annual discharge generally fills a channel to about one-third of its bank-full depth.

Mean velocity -- The average cross-sectional velocity of water in a stream channel. Surface values typically are much higher than bottom velocities. May be approximated in the field by multiplying the surface velocity, as determined with a float, times 0.8.

Meander -- The winding of a stream channel, usually in an erodible alluvial valley. A series of sine-generated curves characterized by curved flow and alternating banks and shoals.

Meander amplitude -- The distance between points of maximum curvature of successive meanders of opposite phase in a direction normal to the general course of the meander belt, measured between center lines of channels.

Meander belt width -- the distance between lines drawn tangential to the extreme limits of fully developed meanders. Not to be confused with meander amplitude.

Meander length -- The lineal distance down valley between two corresponding points of successive meanders of the same phase.

Mid-channel Bars – bars located in the channel away from the banks, generally found in areas where the channel runs straight. Mid-channel bars caused by recent channel instability are unvegetated.

Milligrams per liter (mg/l) -- The weight in milligrams of any substance dissolved in 1 liter of liquid; nearly the same as parts per million by weight.

Moraine – a mass of till either carried by an active glacier or deposited on the land after a glacier recedes.

Natural flow -- The flow past a specified point on a natural stream that is unaffected by stream diversion, storage, import, export, return flow, or change in use caused by modifications in land use.

Neck cutoff -- A channel migration feature where the land that separates a meander bend is cut off by the lateral migration of the channel. This process may be part of the equilibrium regime or associated with channel instability.

Outfall -- The mouth or outlet of a river, stream, lake, drain or sewer.

Outwash – water-transported material carried away from the ablation zone of a melting glacier.

Oxbow -- An abandoned meander in a river or stream, caused by cutoff. Used to describe the U-shaped bend in the river or the land within such a bend of a river.

Peat -- Partially decomposed plants and other organic material that build up in poorly drained wetland habitats.

Perched groundwater -- Groundwater supported by a zone of material of low permeability located above an underlying main body of groundwater with which it is not hydrostatically connected.

Perennial streams -- Streams that flow continuously.

Permeability -- The capability of soil or other geologic formations to transmit water.

pH -- The negative logarithm of the molar concentration of the hydrogen ion, or, more simply acidity.

Planform -- The channel shape as if observed from the air. Changes in planform often involve shifts in large amount of sediment, bank erosion, or the migration of the channel. A channel straightened for agricultural purposes has a highly impacted planform.

Point bar -- The convex side of a meander bend that is built up due to sediment deposition.

Pond -- A body of water smaller than a lake, often artificially formed.

Pool -- A reach of stream that is characterized by deep, low-velocity water and a smooth surface.

Potential plant height -- the height to which a plant, shrub or tree would grow if undisturbed.

Probability of exceedance -- The probability that a random flood will exceed a specified magnitude in a given period of time.

Railroads – Used or unused railroad infrastructure.

Rapids -- A reach of stream that is characterized by small falls and turbulent, high-velocity water.

Reach -- A section of stream having relatively uniform physical attributes, such as valley confinement, valley slope, sinuosity, dominant bed material, and bed form, as determined in the Phase 1 assessment.

Rearing habitat -- Areas in rivers or streams where juvenile fish find food and shelter to live and grow.

Reference stream type --Uses preliminary observations to determine the natural channel form and process that would be present in the absence of anthropogenic impacts to the channel and the surrounding watershed.

Refuge area -- An area within a stream that provides protection to aquatic species during very low and/or high flows.

Regime theory -- A theory of channel formation that applies to streams that make a part of their boundaries from their transported sediment load and a portion of their transported sediment load from their boundaries. Channels are considered in regime or equilibrium when bank erosion and bank formation are equal.

Restoration -- The return of an ecosystem to a close approximation of its condition prior to disturbance.

Riffle -- A reach of stream that is characterized by shallow, fast-moving water broken by the presence of rocks and boulders.

Riffle-pool ratio -- The ratio of surface area or length of pools to the surface area or length of riffles in a given stream reach; frequently expressed as the relative percentage of each category. Used to describe fish habitat rearing quality.

Riffle-step ratio-- ratio of the distance between riffles to the stream width.

Riparian area -- An area of land and vegetation adjacent to a stream that has a direct effect on the stream. This includes woodlands, vegetation, and floodplains. Riparian buffer is the width of naturally vegetated land adjacent to the stream between the top of the bank (or top of slope, depending on site characteristics) and the edge of other land uses. A buffer is largely undisturbed and consists of the trees, shrubs, groundcover plants, duff layer, and naturally uneven ground surface. The buffer serves to protect the water body from the impacts of adjacent land uses. Riparian corridor includes lands defined by the lateral extent of a stream's meanders necessary to maintain a stable stream dimension, pattern, profile, and sediment regime. For instance, in stable pool-riffle streams, riparian corridors may be as wide as 10-12 times the channel's bankfull width. In addition the riparian corridor typically corresponds to the land area surrounding and including the stream that supports (or could support if unimpacted) a distinct ecosystem, generally with abundant and diverse plant and animal communities (as compared with upland communities).

Riparian habitat -- The aquatic and terrestrial habitat adjacent to streams, lakes, estuaries, or other waterways.

Riparian -- Located on the banks of a stream or other body of water.

Riparian vegetation -- The plants that grow adjacent to a wetland area such as a river, stream, reservoir, pond, spring, marsh, bog, meadow, etc., and that rely upon the hydrology of the associated water body.

Ripple -- (1) A specific undulated bed form found in sand bed streams. (2) Undulations or waves on the surface of flowing water.

Riprap -- Rock or other material with a specific mixture of sizes referred to as a "gradation," used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.

River channels --Large natural or artificial open streams that continuously or periodically contain moving water, or which form a connection between two bodies of water.

River miles --Generally, miles from the mouth of a river to a specific destination or, for upstream tributaries, from the confluence with the main river to a specific destination.

River reach -- Any defined length of a river.

River stage -- The elevation of the water surface at a specified station above some arbitrary zero datum (level).

Riverine -- Relating to, formed by, or resembling a river including tributaries, streams, brooks, etc.

Riverine habitat -- The aquatic habitat within streams and rivers.

Roads -- Transportation infrastructure. Includes private, town, state roads, and roads that are dirt, gravel, or paved.

Rock -- A naturally formed mass of minerals.

Rootwad -- The mass of roots associated with a tree adjacent to or in a stream that provides refuge for fish and other aquatic life.

Run (in stream or river) -- A reach of stream characterized by fast-flowing, low-turbulence water.

Runoff -- Water that flows over the ground and reaches a stream as a result of rainfall or snowmelt.

Sand -- Small substrate particles, generally from 0.002 to 0.08 in diameter. Sand is larger than silt and smaller than gravel.

Scour -- The erosive action of running water in streams, which excavates and carries away material from the bed and banks. Scour may occur in both earth and solid rock material and can be classed as general, contraction, or local scour.

Sediment -- Soil or mineral material transported by water or wind and deposited in streams or other bodies of water.

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

Seepage -- The gradual movement of a fluid into, through, or from a porous medium. Segment: A relatively homogenous section of stream contained within a reach that has the same reference stream characteristics but is distinct from other segments in the reach in one or more of the following parameters: degree of floodplain encroachment, presence/absence of grade controls, bankfull channel dimensions (W/D ratio, entrenchment), channel sinuosity and slope, riparian buffer and corridor conditions, abundance of springs/seeps/adjacent wetlands/stormwater inputs, and degree of channel alterations.

Sensitivity -- of the valley, floodplain, and/or channel condition to change due to natural causes and/or anticipated human activity.

Shoals -- unvegetated deposits of gravels and cobbles adjacent to the banks that have a height less than the average water level. In channels that are over-widened, the stream does not have the power to transport these larger sediments, and thus they are deposited throughout the channel as shoals.

Silt -- Substrate particles smaller than sand and larger than clay; between 0.0001 and 0.002 inches in diameter.

Siltation -- The deposition or accumulation of fine soil particles.

Sinuosity -- The ratio of channel length to direct down-valley distance. Also may be expressed as the ratio of down-valley slope to channel slope.

Slope -- The ratio of the change in elevation over distance.

Slope stability -- The resistance of a natural or artificial slope or other inclined surface to failure by mass movement.

Snag -- Any standing dead, partially dead, or defective (cull) tree at least 10 in. in diameter at breast height and at least 6 ft tall. Snags are important riparian habitat features.

Spawning -- The depositing and fertilizing of eggs (or roe) by fish and other aquatic life.

Spillway -- A channel for reservoir overflow.

Stable channel -- A stream channel with the right balance of slope, planform, and cross section to transport both the water and sediment load without net long-term bed or bank sediment deposition or erosion throughout the stream segment.

Stone -- Rock or rock fragments used for construction.

Straightening -- the removal of meander bends, often done in towns and along roadways, railroads, and agricultural fields.

Stream -- A general term for a body of water flowing by gravity; natural watercourse containing water at least part of the year. In hydrology, the term is generally applied to the water flowing in a natural narrow channel as distinct from a canal. Stream banks are features that define the channel sides and contain stream flow within the channel; this is the portion of the channel bank that is between the toe of the bank slope and the bankfull elevation. The banks are distinct from the streambed, which is normally wetted and provides a substrate that supports aquatic organisms. The top of bank is the point where an abrupt change in slope is evident, and where the stream is generally able to overflow the banks and enter the adjacent floodplain during flows at or exceeding the average annual high water.

Stream channel -- A long narrow depression shaped by the concentrated flow of a stream and covered continuously or periodically by water.

Stream condition -- Given the land use, channel and floodplain modifications documented at the assessment sites, the current degree of change in the channel and floodplain from the reference condition for parameters such as dimension, pattern, profile, sediment regime, and vegetation.

Stream gradient -- A general slope or rate of change in vertical elevation per unit of horizontal distance of the bed, water surface, or energy grade of a stream.

Stream morphology -- The form and structure of streams.

Stream order -- A hydrologic system of stream classification. Each small unbranched tributary is a first-order stream. Two first-order streams join to make a second-order stream. A third-order stream has only first-and second-order tributaries, and so forth.

Stream reach -- An individual segment of stream that has beginning and ending points defined by identifiable features such as where a tributary confluence changes the channel character or order.

Stream type -- Gives the overall physical characteristics of the channel and helps predict the reference or stable condition of the reach.

Stream type departure -- When the current stream type differs from the reference stream type as a response to anthropogenic or severe natural disturbances. These departures are often characterized by large-scale incision, deposition, or changes in planform.

Streambank armoring – The installation of concrete walls, gabions, stone riprap, and other large erosion resistant material along stream banks.

Streambank erosion -- The removal of soil from streambanks by flowing water.

Streambank stabilization -- The lining of streambanks with riprap, matting, etc., or other measures intended to control erosion.

Streambed -- (1) The unvegetated portion of a channel boundary below the baseflow level. (2) The channel through which a natural stream of water runs or used to run, as a dry streambed.

Streamflow -- The rate at which water passes a given point in a stream or river, usually expressed in cubic feet per second (cfs).

Step (in a river system) --A step is a steep, step-like feature in a high gradient stream (> 2%). Steps are composed of large boulders lines across the stream. Steps are important for providing grade-control, and for dissipating energy. As fast-shallow water flows over the steps it takes various flow paths thus dissipating energy during high flow events.

Substrate -- (1) The composition of a streambed, including either mineral or organic materials. (2) Material that forms an attachment medium for organisms.

Surface erosion -- The detachment and transport of soil particles by wind, water, or gravity. Or a group of processes whereby soil materials are removed by running water, waves and currents, moving ice, or wind.

Surface water -- All waters whose surface is naturally exposed to the atmosphere, for example, rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc., and all springs, wells, or other collectors directly influenced by surface water.

Suspended sediment -- Sediment suspended in a fluid by the upward components of turbulent currents, moving ice, or wind.

Suspended sediment load -- That portion of a stream's total sediment load that is transported within the body of water and has very little contact with the streambed.

Tailwater -- (1) The area immediately downstream of a spillway. (2) Applied irrigation water that runs off the end of a field.

Thalweg -- (1) The lowest thread along the axial part of a valley or stream channel. (2) A subsurface, groundwater stream percolating beneath and in the general direction of a surface stream course or valley. (3) The middle, chief, or deepest part of a navigable channel or waterway.

Tractive Force --The drag on a streambed or bank caused by passing water, which tends to pull soil particles along with the streamflow.

Transpiration -- An essential physiological process in which plant tissues give off water vapor to the atmosphere.

Tributary -- A stream that flows into another stream, river, or lake.

Turbidity -- A measure of the content of suspended matter that interferes with the passage of light through the water or in which visual depth is restricted. Suspended sediments are only one component of turbidity.

Urban runoff -- Storm water from city streets and gutters that usually carries a great deal of litter and organic and bacterial wastes into the sewer systems and receiving waters.

Valley confinement -- Referring to the ratio of valley width to channel width. Unconfined channels (confinement of 4 or greater) flow through broader valleys and typically have higher sinuosity and area for floodplain. Confined channels (confinement of less than 4) typically flow through narrower valleys.

Valley wall -- The side slope of a valley, which begins where the topography transitions from the gentle-sloped valley floor. The distance between valley walls is used to calculate the valley confinement.

Variable-stage stream -- Stream flows perennially but water level rises and falls significantly with storm and runoff events.

Velocity -- In this concept, the speed of water flowing in a watercourse, such as a river.

Washout -- (1) Erosion of a relatively soft surface, such as a roadbed, by a sudden gush of water, as from a downpour or floods. (2) A channel produced by such erosion.

Water quality -- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Waterfall -- A sudden, nearly vertical drop in a stream, as it flows over rock.

Watershed -- An area of land whose total surface drainage flows to a single point in a stream.

Watershed management -- The analysis, protection, development, operation, or maintenance of the land, vegetation, and water resources of a drainage basin for the conservation of all its resources for the benefit of its residents.

Watershed project -- A comprehensive program of structural and nonstructural measures to preserve or restore a watershed to good hydrologic condition. These measures may include detention reservoirs, dikes, channels, contour trenches, terraces, furrows, gully plugs, revegetation, and possibly other practices to reduce flood peaks and sediment production.

Watershed restoration -- Improving current conditions of watersheds to restore degraded habitat and provide long-term protection to aquatic and riparian resources.

Weir -- A structure to control water levels in a stream. Depending upon the configuration, weirs can provide a specific "rating" for discharge as a function of the upstream water level.

Wetland -- Areas adjacent to, or within the stream, with sufficient surface/groundwater influence to have present hydric soils and aquatic vegetation (e.g. cattails, sedges, rushes, willows or alders).

Width/depth ratio -- The ratio of channel bankfull width to the average bankfull depth. An indicator of channel widening or aggradation, and used for stream type classification.