Upper Winooski River Corridor Plan
Town of Marshfield

January 2008

Prepared for:
Friends of the Winooski River
PO Box 777
Montpelier, VT 05602

EXECUTIVE SUMMARY

The Winooski River is the largest tributary watershed to Lake Champlain, draining more than 1,000 square miles. The River corridor extends from its mouth in Lake Champlain just north of Burlington east towards the Green Mountains and its watershed drains nearly 10% of all the land in the State. The upper Winooski River watershed comprises approximately 396 square miles and flows west from its headwaters in the town of Cabot through Marshfield, Plainfield, East Montpelier, and Montpelier where it becomes part of the larger, overall watershed. This River Corridor Plan focuses on the seven mainstem Winooski River reaches which flow through the town of Marshfield. The project study area is shown on Figure 1 and includes reaches R28, R29, R30, R31, R32, R33, and R34.

Development of this Plan was a collaborative effort between The Johnson Company, Friends of the Winooski River (FWR), and the Vermont Agency of Natural Resources Rivers Management Program (RMP). The Corridor Planning Process involves the integration of fluvial geomorphic data and the goals and objectives of the local community in order to formulate scientifically sound and ecologically beneficial river restoration and conservation projects. The main goal of RMP is to manage toward, protect, and restore fluvial geomorphic equilibrium condition of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner (VT ANR 2007). The overall objectives are to improve water quality and the community's relationship with the river by reducing fluvial erosion hazards, increasing sediment and nutrient attenuation assets, and improving aquatic and riparian habitats.

Phase 1 and 2 fluvial geomorphic assessments were conducted on all seven reaches in the town of Marshfield in 2005 and 2006. Fluvial geomorphology is the study of physical river processes that occur in different landforms and geologic settings. It utilizes the collection of physical data such as channel width and depth, floodplain characteristics, and bed and bank conditions to evaluate how streams are adjusting from their expected norms (or equilibrium condition) and predict what sorts of adjustments are likely to occur in the future. The Phase 1 assessments were performed by the Central Vermont Regional Planning Commission and Winooski Natural Resource Conservation District. The Phase 2 assessments were performed by The Johnson Company. All of the assessments were performed in accordance with the most recent version of the Vermont Agency of Natural Resources (VT ANR) Stream Geomorphic Assessment Protocols (VT ANR 2007). The results of the Phase 2 assessments were documented in the March 2007 Phase 2 Geomorphic Assessment Report prepared by The Johnson Company and available through FWR. The Phase 2 assessment results indicated a great deal of stream channel adjustment occurring in the seven reaches studied as part of this plan. A significant amount of historic channel alterations including straightening, dredging, and armoring were noted. These channel alterations have caused most of the assessed reaches to undergo some degree of channel incision, or downcutting, where the stream erodes into its bed and the stream no longer has complete access to it floodplain during high flow events. The incision, coupled with a lack of adequate woody riparian vegetation has led to widening and planform adjustments which are likely to continue as the river attempts to re-connect to its floodplain and return to equilibrium conditions.

Watershed and reach scale stressors were evaluated for each reach including hydrologic alterations, land use and land cover changes, sediment regime stressors, channel slope and depth modifiers, boundary conditions and riparian modifiers. Changes to sediment regime and reach sensitivity to future adjustments were also evaluated. Figures and Tables were created to allow for in-depth evaluation of how each of these stressors have contributed to the current condition of the study reaches, and how that differs from the expected reference (or equilibrium) condition. Appropriate restoration and conservation techniques were developed for each reach, and a comprehensive Project and Practices Summary Table was created to prioritize the identified restoration and conservation strategies.

In summary, the findings of this Corridor Plan are as follows:

- Historically, most of the Upper Winooski watershed acted as a sediment and nutrient attenuation zone, where incoming fine sediments from upstream were stored on the floodplain, and inputs of coarse sediment were equal to outputs of coarse sediment.
- Due to the historic and ongoing adjustment processes and stressors documented in the Upper Winooski, it has largely been transformed into a sediment and nutrient source and transport zone where floodplain access is limited and sediment and nutrients are funneled through the system to downstream receiving waters.
- The highest priority projects for the watershed are those that attempt to restore the sediment and nutrient attenuation assets which once dominated the system.
- Other recommended project types include riparian buffer enhancement to filter out excess nutrients, help stabilize streambanks, and provide shade and cover to improve aquatic habitat; replacement of undersized bridges and culverts to reduce channel constrictions, and restore normal flow patterns; and removal of berms, dams, or other encroachments which limit floodplain access.

The Upper Winooski watershed is fairly unique in that it is still largely undeveloped so that many opportunities for river corridor restoration exist. Obviously, there is a large amount of human investment within the river corridor in homes, businesses, and agricultural lands, but the goals of this and other river corridor plans is to find areas within the watershed where a balance can be reached between these human investments and the health and wellbeing of river systems. A complete list of recommended projects for the study area is included in Table 12 at the end of this report along with maps showing the various project areas which are included as Figures 15 through 21.

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1.0 INTRODUCTION AND PROJECT OVERVIEW

The Winooski River is the largest tributary watershed to Lake Champlain, draining more than 1,000 square miles. The River corridor extends from its mouth in Lake Champlain just north of Burlington east towards the Green Mountains and its watershed drains nearly 10% of all the land in the State. The upper Winooski River watershed comprises approximately 396 square miles and flows west from its headwaters in the town of Cabot through Marshfield, Plainfield, East Montpelier, and Montpelier where it becomes part of the larger, overall watershed. This River Corridor Plan focuses on the seven mainstem Winooski River reaches which flow through the town of Marshfield. The project study area is shown of Figure 1 and includes reaches R28, R29, R30, R31, R32, R33, and R34.

Development of this Plan was a collaborative effort between The Johnson Company, Friends of the Winooski River (FWR), and Vermont Rivers Management Program (RMP). Funding for the project was provided through a grant from RMP to FWR. The Corridor Planning Process involves the integration of fluvial geomorphic assessment data, and the goals and objectives of the local community to formulate scientifically sound and ecologically beneficial river restoration and conservation projects that will not only improve water quality, but also improve the community's relationship with the river. To facilitate these goals, RMP has developed a River Corridor Planning Guide to aid in the identification and development of river restoration and conservation projects. References to this guide will be made throughout this report, and a complete copy is available online at http://www.anr.state.vt.us/dec/waterq/rivers/htm/rv_restoration.htm.

The main goal of the Vermont River Management 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 (VT ANR 2007). The objectives are fluvial erosion hazard mitigation, sediment and nutrient load reduction and attenuation, and aquatic and riparian habitat protection and restoration. Similarly, the main goal of FWR is to "reduce pollution in the rivers of the Winooski watershed, and promote wildlife habitat, scenic values, and recreational amenities (http://www.winooskiriver.org/).

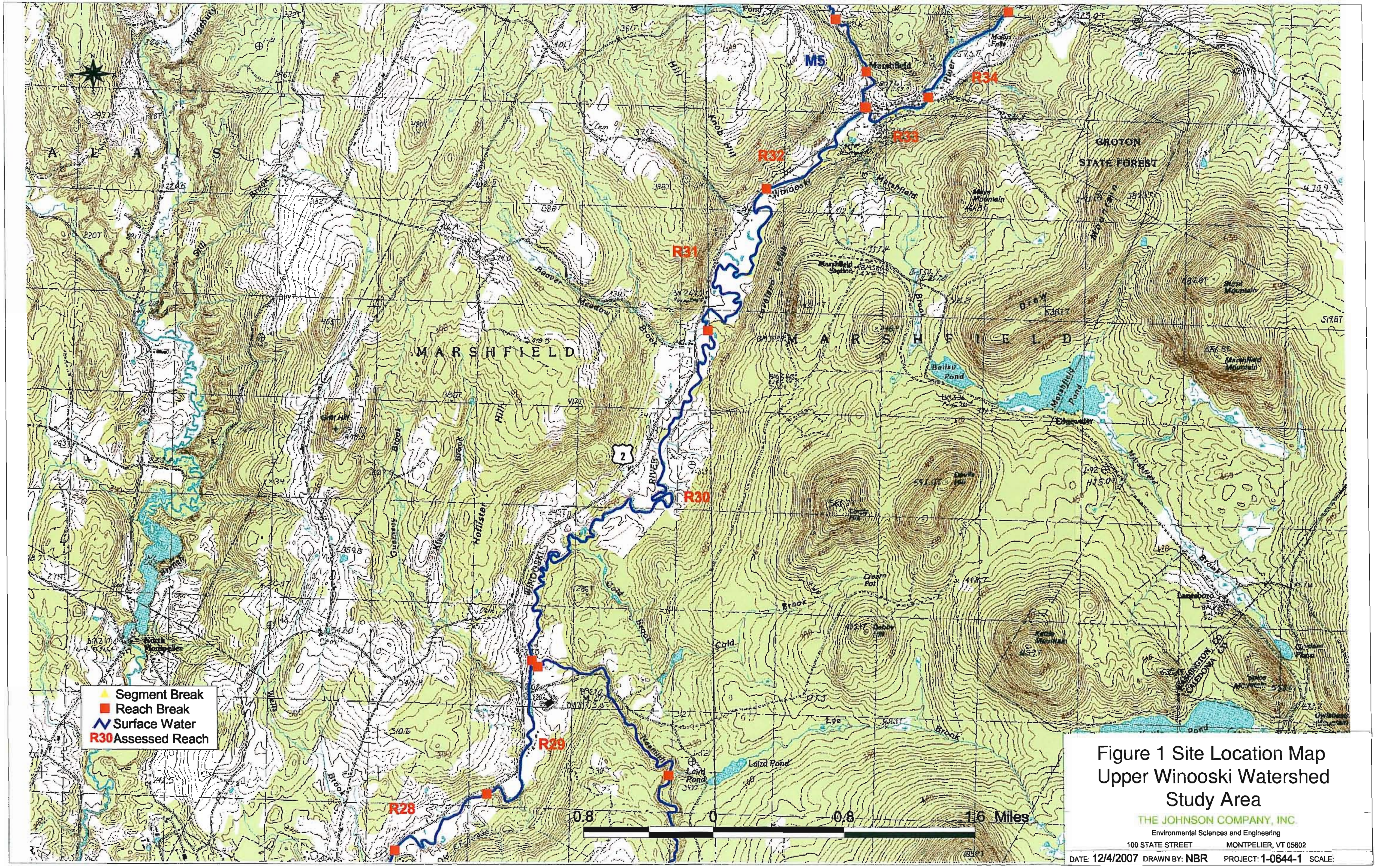


Figure 1 Site Location Map
Upper Winooski Watershed
Study Area

THE JOHNSON COMPANY, INC.
Environmental Sciences and Engineering
100 STATE STREET MONTPELIER, VT 05602

DATE: 12/4/2007 DRAWN BY: NBR PROJECT: 1-0644-1 SCALE:

2.0 BACKGROUND INFORMATION

2.1 GEOGRAPHIC SETTING

2.1.1 Watershed Description

The Upper Winooski watershed lies within the towns of Cabot, Marshfield, Plainfield, East Montpelier, Barre, and the City of Montpelier. Watershed elevation ranges from approximately 507 feet above mean sea level at downtown Montpelier to more than 859 feet at Molly's Falls Reservoir. Seven complete river reaches (approximately 10.2 linear miles) are located within the Town of Marshfield, which is near the upper portion of the watershed, and are the focus of this Plan. Figure 1 shows the Reach locations within Marshfield.

2.1.2 Political Jurisdictions

The entire study area lies within the Town of Marshfield in Washington County, Vermont. A majority of the river lands are privately owned with approximately 75 different landowners lying within the river corridor. There are also several parcels of municipally owned property.

2.1.3 Land Use History and Current General Characteristics

The first inhabitants of Marshfield were Native Americans who utilized the Winooski River valley for hundreds of years before the first European settlers arrived in the late 1700s. The town was officially chartered in 1790 and there were 172 inhabitants in 1800 when the first Town Meeting was held (Johnson, 2005). This population quickly grew to nearly 1,300 by the mid 1800s. Much of this population boom was attributable to the rapid deforestation of most of the hillsides, and the agricultural activities that followed. These landscape changes spurred the dramatic change in hydrology that increased peak flows and sediment inputs. These changes are still playing a role in the current evolution of the Winooski River. In the early to mid 1900s agriculture gradually declined and the forestland slowly returned, reducing some of the higher flows and sediment inputs into the watershed. Currently agricultural activities are still the dominant land use within the Winooski River Corridor, though some portions, such as Reach 33 within Marshfield village, are heavily developed with both residential and commercial uses. The primary agricultural land uses include dairy farming, pasture, hay, and crop lands, recently abandoned meadows not currently in production, as well as smaller vegetable and tree farms. Residential development is concentrated within the village of Marshfield, though rural housing within the town has increased over the last few decades, particularly within the Winooski River Corridor. The Winooski River valley also serves as the major transportation corridor for the region with Vermont Route 2 running near the river channel throughout the study area.

2.2 GEOLOGIC SETTING

The upper Winooski watershed is located to the east of the Green Mountains. Bedrock in the study area is dominated by a combination of the Moretown and Barton River Members (Waits River Formation), Gile Mountain and Northfield Formations and Knox Mountain Granite, which are comprised of various types of quartzite, phyllite, schist, slate, limestone, greenstones and granite (Doll 1961) (Konig 1961). The study area, like all of Vermont, was covered by glaciers at recently as 10,000 years ago. These glaciers left exposed bedrock along the ridge tops and deposited glacial till at lower elevations. Bedrock and till comprise a majority of the valley walls within the watershed, while a majority of the river corridor is comprised of less cohesive, silts, clays, sands and other fluvial material deposited over time as the river meandered through the valley. The surficial geology reflects this and is comprised of lake bottom deposits of silt, silty clay and clay, and recent alluvium as fluvial sand, gravels and silt (Stewart and MacClintock 1970) (Larsen 1999). Soils in the study area are dominated by sandy loam, silt loam, fine sand, fine sandy loam, silt loam, and sand predominantly associated with the following series: Salmon very fine sandy loam, Waitsfield silt loam, Sunny silt loam, Sunday fine sand, Buxton silt loam, Rumney fine sandy loam, Dummerston fine sandy loam, Nicholville silt loam, Vershire-Dummerston Complex, Buckland silt loam, and Adams loamy fine sand (USDA SCS 1979).

2.3 GEOMORPHIC SETTING

The study area within Marshfield includes seven complete river reaches, approximately 10.2 linear miles of the Winooski River mainstem. Each reach is delineated based on physical characteristics such as valley width and slope, bed materials, and hydrologic characteristics. The locations of the assessed reaches are shown on Figure 1. A complete description of the Phase 1 and 2 Geomorphic Results may be found in the Phase 2 Stream Geomorphic Report produced by The Johnson Company in April 2007 and available through FWR or RMP. Below is a summary of the Phase 1 Geomorphic results which describes the expected, or reference, condition for the study area. These data describe what one would expect the river system to look like in its natural state with no anthropogenic influences.

Based on the Phase 1 data, all seven reaches within the study have C, B and E reference stream types characterized by slopes of less than 2% with substrate ranging from sand to boulder. The valley types for all assessed reaches range from broad to very broad with the exception of reach R33 which is located within a narrow valley. Valley widths range from approximately 587 feet in R33 to nearly 1,614 feet in R19. All of these characteristics are common for Vermont watersheds with their steep, relatively narrow valley walls and geologic material primarily comprised of glacial till. Figure 2 below shows the characteristics of various stream types (A through G) and how they appear in plan and cross section views (US EPA 2004).

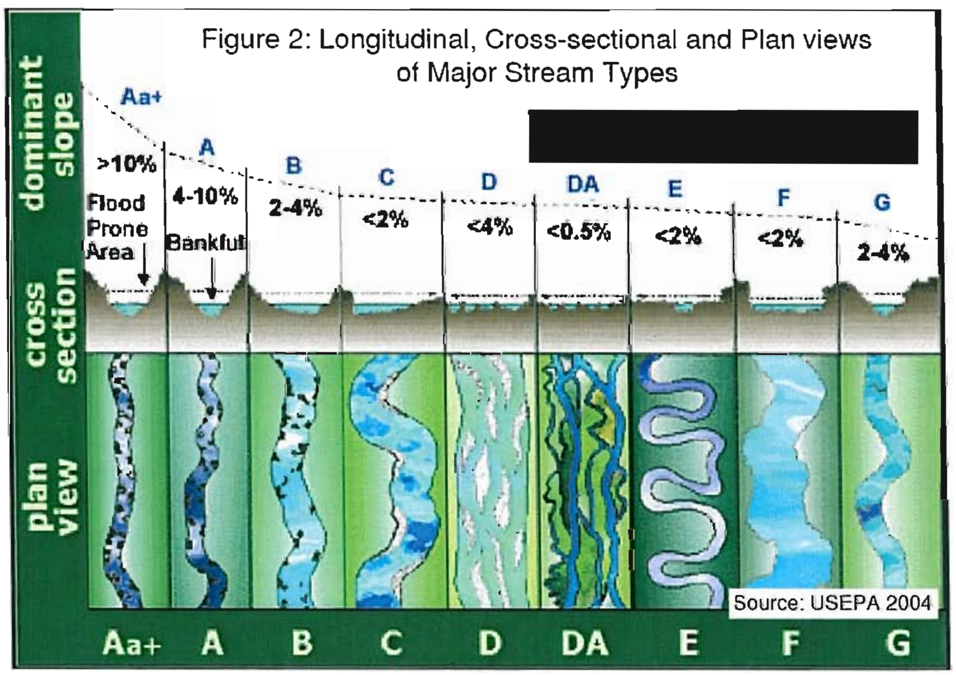
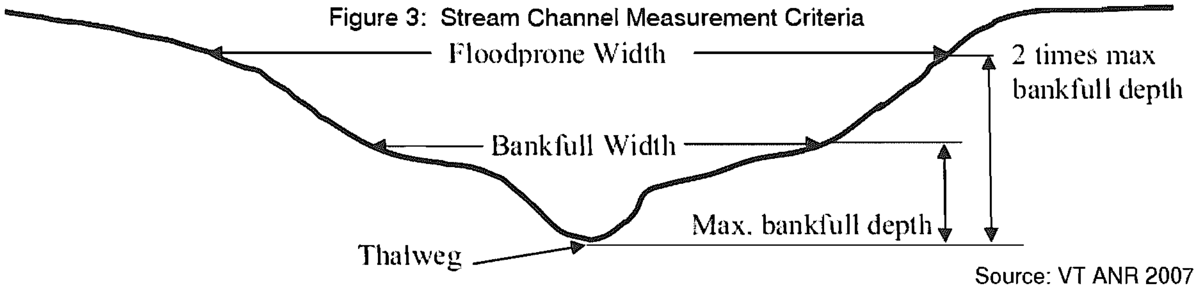


Figure 2: Longitudinal, Cross-sectional and Plan views of Major Stream Types

Stream typing involves classifying reaches based on combinations of physical parameters such as valley landform, channel dimensions, slope, sediment supply, and bed forms, which indicate the fluvial processes at work in a river reach. Streams are placed into different stream types based on their entrenchment, width to depth ratio, sinuosity, channel slope, substrate size, and bed features (VT ANR 2007). The first stream type descriptor is a capital letter (A through G) that describes the entrenchment ratio (equal to floodprone width divided by bankfull width) and width to depth ratio (equal to bankfull width divided by average depth). Figure 3 below shows how each of these ratios is measured (VT ANR 2007).

Figure 3: Stream Channel Measurement Criteria



Source: VT ANR 2007

The second descriptor is a number (1 through 6) used to describe the dominant bed substrate in decreasing order: 1 – bedrock; 2 – boulder; 3 – cobble; 4 – gravel; 5 – sand; and 6 - silt. The third descriptor is a lower case letter which describes the channel slope: a = slope >4%; b = slope 2-4%; and C = slope <2%, though this descriptor is only used if the channel slope falls outside the normal range typically found for that stream type (shown in the Figure 2 above). The fourth and final descriptor describes the bedform of the reach. The most common of these is riffle-pool, but other bedforms include step-pool, plane bed, dune-ripple, and braided. When combined these four descriptors convey a great deal of information about what the stream reach looks like. A common stream type often found in Vermont is C4 riffle-pool. Table 1 below summarizes the Phase 1 data for the seven reaches. All of the study area reaches were classified as C, B, or E stream types, which are common in Vermont. It is important to note that these stream types are the reference, or expected, ones for the study area, and may not reflect the current conditions. The objective of the Phase 2 and corridor planning processes is to identify what types of stressors are impacting each reach; how these stressors change the existing stream type and other parameters; and use this information to identify restoration and conservation projects that can aid in returning the river system to its equilibrium state. More detailed descriptions and maps of the study area are located in Section 6 of this report.

Table 1: Upper Winooski Phase 1 Reference Stream Data

Reach ID	Reach Length (miles)	Valley Type	Valley Width (ft)	Channel Width (ft)	Channel Slope (%)	Sinuosity	Reference Stream Type	Bedform
R28	0.9	Broad	800	96.0	0.04	1.2	C4	Dune-Ripple
R29	1.2	Broad	666	95.8	0.31	1.1	B4	Plane-Bed
R30	3.9	Very-Broad	1149	87.6	0.06	1.5	E5	Dune-Ripple
R31	2.0	Very-Broad	1175	83.6	0.03	2.0	E5	Dune-Ripple
R32	0.8	Broad	678	82.6	0.28	1.2	C4	Riffle-Pool
R33	0.6	Broad	587	74.4	1.8	1.3	C4	Plane-Bed
R34	0.8	Very-Broad	802	74.3	0.45	1.1	C4	Plane-Bed

2.4 HYDROLOGY

The United States Geological Survey (USGS) maintains a Vermont Streamstats website, that computes flow and basin characteristics for Sites without permanent gauges (http://water.usgs.gov/osw/streamstats/Vermont.html). A copy of the USGS Streamstats printout for the Study Area (upper Winooski River Watershed area upstream of Reach 28) is presented in Figure 4 as an example.

Figure 4:
Streamflow Statistics Report

Date: Mon Oct 1 2007 11:26:45
Site Location: Vermont
Latitude: 44.2858
Longitude: -72.4091
Drainage Area: 92.7 mi2

Peak Flow Basin Characteristics			
100% Statewide Peak Flow (92.7 mi2)			
Parameter	**Value**	**Min**	**Max**
Drainage Area (square miles)	92.7	0.211	850
Percent Lakes and Ponds (percent)	1.91	0	6.86
Percentage of Basin Above 1200 ft (percent)	80.9	0	100
Geographic Factor (dimensionless)	206008.0	-87	296194

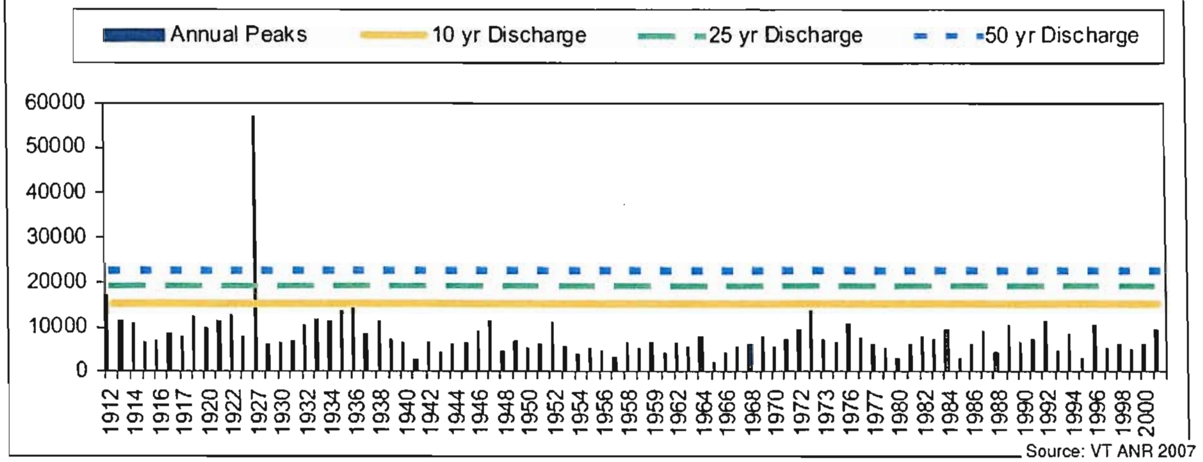
Streamflow Statistics					
Statistic	**Flow (ft^3/s)**	**Prediction Error (percent)**	**Equivalent years of record**	**90-Percent Prediction Interval**	
				Minimum	**Maximum**
Q2	2010	42	1.4	1040	3870
Q5	2920	40	2.3	1530	5550
Q10	3560	41	3.2	1860	6830
Q25	4440	42	4.6	2300	8560
Q50	5110	43	5.5	2650	9870
Q100	5810	44	6.3	2900	11600
Q500	7560	49	7.6	3520	16200

Source: USGS 2007

The Basin Characteristics Table shows the drainage area (92.7 square miles) as well as other hydrologic data. The Streamflow Statistics Table shows the water flow in cubic feet per second (one cubic foot is equal to 7.5 gallons) for different streamflow events. Q2 refers to a 2-year flow event while Q100 refers to a 100-year flood event. The flood event numbers equal the statistical likelihood that the event will happen in any given year (for example on average there is a 1 in 2 chance that a Q2 flow event will occur in any year, while there is a 1 in 100 chance of a Q100 flow event occurring). While not directly used at this stage in the corridor planning process, this USGS flow information can be useful in a variety of ways from delineating floodplains to designing proper bridge widths.

The nearest USGS gage for the study area is on the upper Winooski just downstream from the confluence of the North Branch with the Winooski in Montpelier in Reach 18, approximately 15 miles downstream of Marshfield village (USGS Gauge Number 04286000). A summary of annual peak flows for the Winooski River at Montpelier is shown in Figure 5 below (VT ANR, 2007). The flow values along the Y-axis are shown in cubic feet per second (the same units as the Streamstats Table above). Floods in Marshfield historically have occurred along the Winooski River, but tributaries have also exhibited flash flooding that has caused property damage. Flooding most frequently occurs in the late spring as a result of snow melt and ice jams, but has occurred in all seasons (Marshfield Town Plan, 2006). The largest documented flood of the Winooski River in Marshfield occurred in November, 1927, after extremely heavy rainfall in the region (Johnson, 2005). Several flood events have occurred in the region over the last 45 years including 1964, 1973, 1978, 1981, and 1992 (Montpelier Flood and Hazard Mitigation Plan, 1998). Despite the relatively frequent flooding within the city, no flows in excess of a 10 year discharge have been recorded since the 1927 flood. The dam located near the gauge likely has an effect on the magnitude of those flow events. Currently, there are nine dams located within the upper Winooski watershed which have a large effect on the regions hydrology, however only one of these, in Reach 33, is located in Marshfield. The dam which provides the most impacts to Marshfield is the Molly's Falls Reservoir and power generating station located just upstream from the village. Further discussion of these dams is provided in Section 4.1.1.

Figure 5: Historical Flow Data
Winooski River at Montpelier, VT



2.5 ECOLOGICAL SETTING

The study area includes a variety of aquatic and upland habitat types which include forest, agricultural crop and pasture land, riparian wetland complexes, and beaver ponds. The primary aquatic habitat is a riffle-pool community with sand and gravel substrate. Much of this habitat has been adversely affected by geomorphic processees including historic and active degradation and aggradation which leads to filling of pools, embedding of riffle substrates, bank instability, and loss of shade and cover. The impoundments along the stream also have an impact on the aquatic habitat by altering the natural flow patterns and preventing fish migration (Montpelier Flood and Hazard Mitigation Plan, 1998).

3.0 METHODOLOGY

3.1 FLUVIAL GEOMORPHIC ASSESSMENTS

Phase 1 and 2 fluvial geomorphic assessments were conducted on all seven reaches in the town of Marshfield in 2005 and 2006. Phase 1 assessments utilize remote sensing data such as topographic maps, aerial photographs, and GIS databases to assess the overall condition of the river. Phase 2 assessments involve a field based approach where each reach is walked in its entirety and physical measurements are collected to determine what stream adjustment processes are taking place and to predict how the system will continue to evolve. The Phase 1 assessments were performed by the Central Vermont Regional Planning Commission and Winooski Natural

Resource Conservation District. The Phase 2 assessments were performed by The Johnson Company. All of the assessments were performed in accordance with the most recent version of the Vermont Agency of Natural Resources (VT ANR) Stream Geomorphic Assessment Protocols (VT ANR 2007). The results of the Phase 2 assessments are documented in the March 2007 Phase 2 Geomorphic Assessment Report prepared by The Johnson Company. A copy of this report is available from RMP or FWR. In addition, all of the collected data is available to the public through RMP's Data Management System (DMS) located at https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm, username: public, password: public.

The Phase 2 assessment results indicated a large degree of stream adjustment occurring within the upper Winooski watershed, including the seven reaches studied as part of this plan. Significant historic channel alterations including straightening, dredging, and armoring were noted. These channel alterations have caused most of the assessed reaches to undergo some degree of channel incision, or downcutting, where the stream erodes into its bed and the stream no longer has complete access to it floodplain during high flow events. The incision, coupled with a lack of adequate woody riparian vegetation has led to widening and planform adjustments which are likely to continue as the river attempts to re-connect to its floodplain and return to equilibrium conditions. The causes and consequences of these adjustment processes are discussed in more detail in Section 5 of this Corridor Plan.

3.2 QUALITY ASSURANCE AND QUALITY CONTROL

Thorough QA reviews were performed by The Johnson Company in November 2006 and VT ANR in January 2007 and the Phase 1 and 2 Data Management Systems (DMS) were updated on January 31, 2007. All of the collected data are stored in the DMS and original copies of the Phase 2 data sheets may be found at The Johnson Company's office in Montpelier, VT.

4.0 DEPARTURE ANALYSIS AND STRESSOR IDENTIFICATION

Section 4 describes the results of the Phase 1 and 2 assessments for the Upper Winooski study area. A variety of maps and tables including Stressor, Departure and Sensitivity Maps are included to show watershed and reach scale stressors and how they interact and affect the watershed as a whole. The data, tables, and maps described in Section 4 will be used to identify restoration and conservation techniques on a reach scale basis (described in Section 5) that meet the goals and objectives of reducing fluvial erosion hazards, increasing sediment and nutrient attenuation sites, and improving aquatic and riparian habitat.

4.1 DEPARTURE ANALYSIS

4.1.1 Hydrologic Regime Stressors

The hydrologic regime may be defined as the timing, volume, and duration of flow events throughout the year, and over time it may be influenced by many factors including climate, soils, geology, groundwater inputs, watershed land cover and use, connectivity of the stream to riparian and floodplain networks, and valley and stream morphology (VT ANR 2007). Hydrologic regime is characterized by the input and manipulation of water at the watershed scale (i.e. dams, large land use changes, ect.) and should not be confused with channel hydraulics which deals with the energy and flows on a smaller, reach-wide scale (i.e. bridges, culverts). When the hydrologic regime of a watershed is impacted the stream will often undergo a series of predictable adjustments which can result in significant changes in sediment loading and flow patterns downstream (VT ANR 2007). An example of this is a large dam which impounds water and periodically releases it into the river system. The large pulses of water released from the dam will affect the stream channel and surrounding riparian lands differently than the more constant flow changes which occur in a natural system. Because dams are typically managed in a way that results in high flows occurring more frequently than they would naturally, the stream bed and banks are subjected to highly erosive energy more frequently than they would otherwise be. The River Stressor ID Table, Table 2, summarizes the stressors that were identified in the Upper Winooski – Marshfield Watershed. These stressors and conditions are contributing to increased or decreased flow, sediment load, channel slope, power, and boundary resistance at both the watershed and reach scales. The red descriptor in each cell describes the overall stressor while the parameters listed below show which factors are contributing to or indicative of that stressor. For example, buffer widths less than 25 feet contribute to decreased boundary resistance while widths greater that 25 feet help resist erosion and contribute to increased boundary resistance. More detailed descriptions of these stressors and contributing factors are provided in each appropriate Section below. Figure 2 depicts the major hydrologic stressors identified within the study area.

Table 2: River Stressor ID Table - Upper Winooski, Marshfield

River Segment ID	Watershed Scale Stressors		Reach Scale Stressors	
	Hydrologic	Sediment Load	Stream Power	Boundary Resistance
R28	**Increased Flows** Stormwater Inputs = >2<5/mile (moderate) Urban land use = 5.6% (moderate) Roads (Rt. 2 within corridor)	**Increased Load** Crop land use = watershed = >5<10% (moderate) dominant land use = pasture # of Deposition Features = Moderate - High # of Erosion Features = High Rejuvenating tribs = yes	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) Encroachments = High **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high) Stormwater outfalls = >=2<5/mile (moderate)	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Grade Controls = None Bed = smaller than coarse gravel Bank erosion = Left = >20%, R = >20% Bank armoring = L = high, R = high
R29	**Increased Flows** Urban land use = watershed = >=5<10% (moderate) Roads and Ditching dominant land use = Hay Route 2 within corridor	**Increased Load** Crop land use = watershed = >5<10% (moderate) dominant land use = Hay # of Deposition Features = High # of Erosion Features = Low - Moderate	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) Encroachments = High **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high) **Decreased Stream Power - Depth** Depth Decreases # of Delta/Backwater Deposits = Moderate # of Deposition Features = High	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Bank armoring = L = moderate, R = moderate **Increased Boundary Resistance** Bed = coarse gravel
R30A	**Increased Flows** Urban land use = watershed = >=5<10% (moderate)	**Increased Load** Crop land use = watershed = >5<10% (moderate) # of Deposition Features = Moderate # of Erosion Features = Moderate - High Mass wasting Sites = Multiple Rejuvenating tribs = yes	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) **Decreased Stream Power - Depth** Depth Decreases Delta/Backwater Deposits = Low-Moderate # of Deposition Features = High	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Bed = smaller than coarse gravel Bank erosion = L = >20%, R = >5<20%
R30B	**Increased Flows** Urban land use = Watershed = >=5<10% (moderate) Roads and Ditching dominant land use = Crop/Pasture	**Increased Load** Crop land use = watershed = >5<10% (moderate) dominant land use = Crop/Pasture # of Deposition Features = Moderate # of Erosion Features = High Mass wasting Sites = Multiple Rejuvenating tribs = yes	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high)	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Grade Controls = None Bed = smaller than coarse gravel Bank armoring = L = moderate, R = moderate Bank erosion = L = >20%, R = >20%

Red Text: describes the overall stressor. Parameters listed below describe factors contributing to or indicative of that stressor (i.e. reduced buffer widths cause decreased boundary resistance).
L and R refers to left and right side of channel when looking downstream

Table 2: River Stressor ID Table - Upper Winooski, Marshfield

River Segment ID	Watershed Scale Stressors		Reach Scale Stressors	
	Hydrologic	Sediment Load	Stream Power	Boundary Resistance
R31A	**Increased Flows** Urban land use = watershed = >=5<10% (moderate)	**Increased Load** Crop land use = watershed = >5<10% (moderate) Dominant land use = pasture # of Deposition Features = Moderate # of Erosion Features = High Rejuvenating tribs = yes	**Increased Stream Power - Slope** Slope Increases Straightening = >=5<20% (moderate) **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high)	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Grade Controls = None Bed = Smaller than coarse gravel Bank erosion = L = >20%, R = >20%
R31B	**Increased Flows** Stormwater Inputs = >5/mile (high) Urban land use = Watershed = >=5 <10% (moderate) Roads and Ditching	**Increased Load** Crop land use = watershed = >5<10% (moderate) # of Deposition Features = High # of Erosion Features = High Rejuvenating tribs = yes	**Increased Stream Power - Slope** Slope Increases Straightening = >=5<20% (moderate) **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high) Stormwater outfalls = >5/mile (high)	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness R Buffer dominant= <25ft Bank Cohesive = No Bed = Smaller than coarse gravel Bank erosion = L = >20%, R = >20%
R32A	**Increased Flows** Dams = Store and release upstream Urban land use = Watershed = >=5 <10% (moderate) Roads and Ditching dominant land use = L = forest, R = Hay Route 2 in Corridor	**Increased Load** Crop land use = watershed = >5<10% (moderate) dominant land use L = forest, R=Hay # of Deposition Features = Moderate # of Erosion Features = Low-Moderate	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) # of Encroachments = High **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high)	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness R Buffer dominant= <25ft Bank Cohesive = No Grade Controls = none Bed = Smaller than coarse gravel
R32B	**Increased Flows** Stormwater Inputs = >2<=5/mile (moderate) Dams = store and release upstream Urban land use = Watershed = >=5 <10% (moderate) Roads and Development dominant land use = L = residential, R = Hay	**Increased Load** Crop land use = watershed = >5<10% (moderate) dominant land use L = residential, R=Hay # of Deposition Features = High # of Erosion Features = moderate	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) # of Encroachments = High **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high) Stormwater outfalls = >=2<5/mile (moderate) **Decreased Stream Power - Depth** Depth Decreases # of Delta/Backwater Deposits = Moderate # of Deposition Features = High	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Grade Controls = none Bank erosion = L = >20%, R = <5% Bank armoring = L = moderate R = moderate **Increased Boundary Resistance** Bed = Larger than coarse gravel

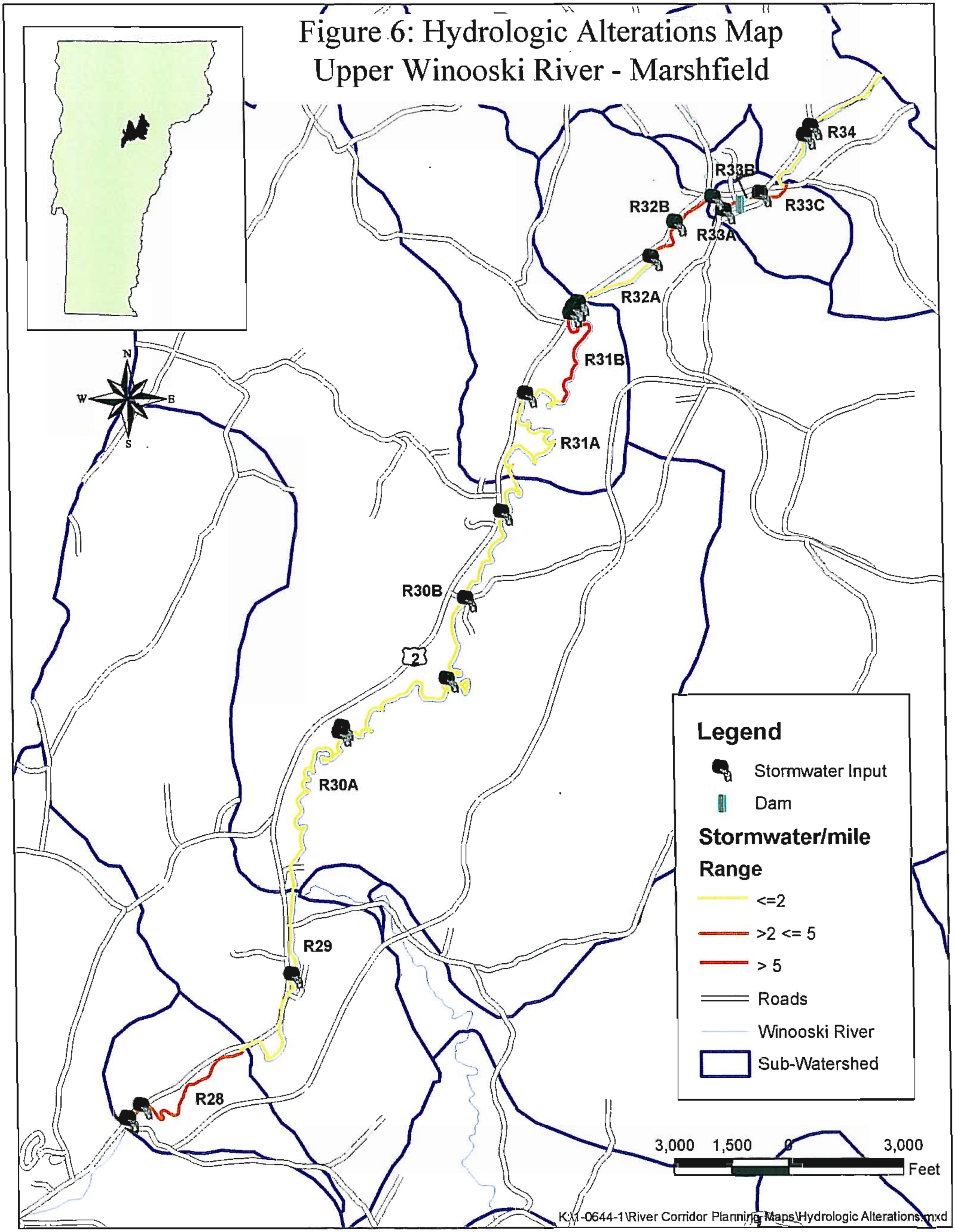
Red Text: describes the overall stressor. Parameters listed below describe factors contributing to or indicative of that stressor (i.e. reduced buffer widths cause decreased boundary resistance).
L and R refers to left and right side of channel when looking downstream

Table 2: River Stressor ID Table - Upper Winooski, Marshfield

River Segment ID	Watershed Scale Stressors		Reach Scale Stressors	
	Hydrologic	Sediment Load	Stream Power	Boundary Resistance
R33A	**Increased Flows** Stormwater Inputs = >5/mile (high) Dams = store and release upstream Urban land use = Watershed = >=5 <10% (moderate) Roads and Development dominant land use = residential	**Increased Load** Crop land use = watershed = >5<10% (moderate) # of Deposition Features = Moderate-High	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) # of Encroachments = High **Decreased Stream Power - Slope** Slope Decreases Grade Controls & Constrictions = >5 (high) **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high) Stormwater outfalls = >5/mile (high)	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Bank armoring = L = high R = high **Increased Boundary Resistance** Bed = Larger than coarse gravel Grade Controls = Dam mid-seg, weir upstream
R33B	Impounded water from Dam in Marshfield Village			
R33C	**Increased Flows** Stormwater Inputs = >2<=5/mile (moderate) Dams = store and release upstream Urban land use = Watershed = >=5 <10% (moderate) Roads and development dominant land use = L = forest, R = residential	**Increased Load** Crop land use = watershed = >5<10% (moderate) # of Deposition Features = High # of Erosion Features = low	**Increased Stream Power - Slope** Slope Increases Straightening = >20% (high) # of Encroachments = High **Decreased Stream Power - Slope** Slope Decreases Grade Controls & Constrictions = >5 (high) **Increased Stream Power - Depth** Depth Increases Berms/roads = >20% (high) Stormwater outfalls = >2<=5/mile (moderate) **Decreased Stream Power - Depth** Depth Decreases # of Delta/Backwater Deposits = high # of Deposition Features = High	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness R Buffer dominant= <25ft Bank Cohesive = No Bank armoring = L = high R = high **Increased Boundary Resistance** Grade Controls = multiple Bed = Larger than coarse gravel
R34	**Increased Flows** Dams = Store and release upstream Urban land use = Watershed = >=5 <10% (moderate) Roads and ditching dominant land use = L = forest, R = hay	**Increased Load** Crop land use = watershed = >5<10% (moderate) dominant land use L= forest, R = hay # of Deposition Features = High # of Erosion Features = low	**Increased Channel Power - Slope** Slope Increases Straightening = >20% (high) # of Encroachments = High **Decreased Channel Power - Slope** Slope Decreases Grade Controls & Constrictions = >2<=5 (mod) **Increased Channel Power - Depth** Depth Increases Berms/roads = >20% (high)	**Decreased Boundary Resistance** Riparian Veg./bank cohesiveness L Buffer dominant= <25ft R Buffer dominant= <25ft Bank Cohesive = No Bank armoring = L = high R = high **Increased Boundary Resistance** Grade Controls = multiple downstream Bed = Larger than coarse gravel

Red Text: describes the overall stressor. Parameters listed below describe factors contributing to or indicative of that stressor (i.e. reduced buffer widths cause decreased boundary resistance).
L and R refers to left and right side of channel when looking downstream

Figure 6: Hydrologic Alterations Map
Upper Winooski River - Marshfield



One of the most significant hydrologic stressors for the upper Winooski watershed, and the majority of Vermont, is the large scale deforestation that occurred in the 19th century. As the state was settled much of the forest was cut for timber and the land cleared for agriculture. Where today Vermont is approximately 80% forestland and 20% open, in the late 19th and early 20th century it was only 20% forested and 80% open. The effect of those land use changes are still being seen today. With much of the land cleared higher intensity flash floods were more common and carried with them a tremendous amount of sediment down into the valleys. This sediment built up in the river systems and raised the bed elevation of many streams. The Winooski River is now eroding down through the built-up sediment and losing access to its floodplain. This process is increased through channel management techniques such as channelization, dredging, and ditching (VT ANR 2007).

Stormwater inputs affect the hydrologic regime by increasing the peak flow during high flow events. In addition, impervious surfaces such as roads and buildings reduce the attenuation of rainfall through infiltration and increase the rate and volume of precipitation that reaches the stream channel. The River Stressor ID Table breaks stormwater impacts down into three categories based on the number of stormwater inputs identified per mile of assessed stream (<=2 (low), >2<=5 (moderate), and >5 (high)). The upper Winooski watershed in Marshfield is dominated by agricultural and forest land except for residential development in R33 within Marshfield village and along Route 2. As such, stormwater impacts in the area are generally low to moderate with the exception of R33 within the village and R31 where more stormwater inputs were noted from road and ditch networks. Figure 6 shows the stormwater impacts for each reach quantified as number of stormwater inputs per mile of stream.

Dams change the hydrologic regime of a watershed by altering the timing, duration, and volume of large flow events. The Winooski River is impacted by several dams, though only one of these is located in the study area in Reach 33A. The dam in R33A is not a large store-and – release structure so therefore its effect is limited to the areas immediately upstream and downstream of the structure. While it is not located within the study area, the large power generating station located just upstream of Reach 34 does have a rather significant impact on the hydrology of the region. One effect of the dam is the reduction of sediment entering the watershed from upstream. In equilibrium conditions, without the dam's presence, sediment would continually move through the watershed, reducing the stream power during flood events as some of the river's energy would be required to move the sediment. With the dam in place, material remains trapped upstream of the dam reducing the movement of sediment through the system. The store-and-release of water from the structure also affects the river's flow regime. During periods of normally high flood events, some of the water is held behind the dam, reducing the magnitude of these events. This water is released at a later date, increasing the flow of water during normal periods of reduced flow. In effect, the structure reduces the maximum and minimum flow downstream of it. Without regulation, these hydrologic effects could cause significant adjustments downstream of the dam, however current water release regulations limit the timing and duration of water discharges and thereby reduce the severity of hydrologic impacts caused by the structure. There is no doubt however that historically the construction and operation of the power generating station played a role in many of the channel adjustments currently observed within the study area.

As described above, land use and land cover have a significant impact on the hydrologic regime of a watershed. Figures 7 and 8 show the current land use and cover for the study area. Though forestland is the dominant land use in Marshfield, agricultural and residential land uses are significant influences in some reaches and are concentrated within the river corridor. Table 2 shows the percent urbanization for each reach. Altered hydrology may be a significant stressor once urban land use reaches greater then 5% of the watershed (VT ANR 2007). While Marshfield is a rather rural community, the urban land use within the study area is still slightly greater than 5%, and likely alters the hydrologic regime of the region. This urban and agricultural land use has caused an increase in the magnitude and duration of large flow events through increased runoff and decreased infiltration capacity. This is particularly true in agricultural lands that were converted from wetlands. As is shown in Figure 7, some historic wetlands (i.e. hydric soils) have been converted through subsurface drainage and other means into agricultural lands. In addition, these land uses increase the sediment inputs into the system. These and other sediment load stressors are discussed below.

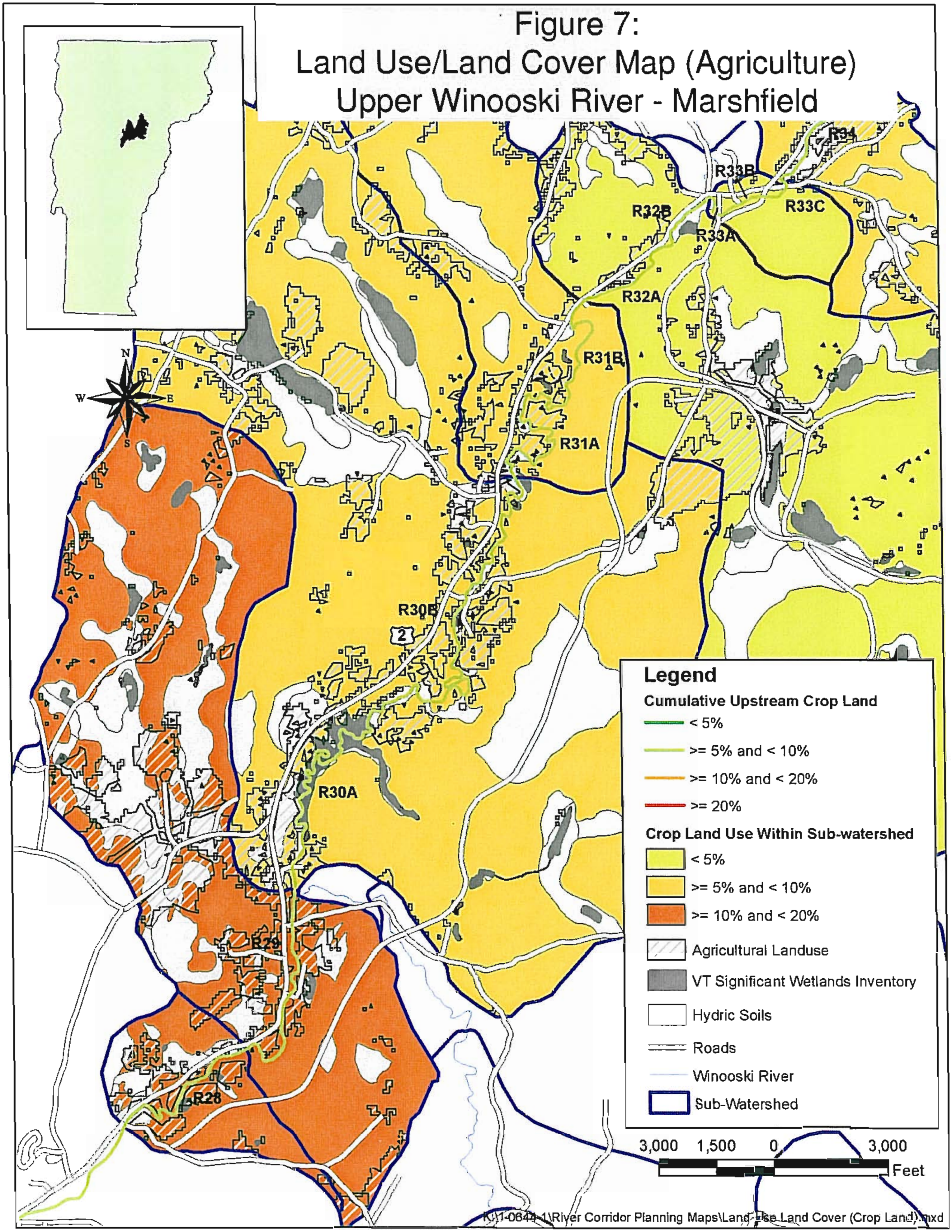


Figure 7:
Land Use/Land Cover Map (Agriculture)
Upper Winooski River - Marshfield
R34
R33B
R33C
R32B
R33A
R32A
R31B
R31A
R30B
2
R30A
R29
R28
N
W
E
S
Legend
Cumulative Upstream Crop Land
< 5%
>= 5% and < 10%
>= 10% and < 20%
>= 20%
Crop Land Use Within Sub-watershed
< 5%
>= 5% and < 10%
>= 10% and < 20%
Agricultural Landuse
VT Significant Wetlands Inventory
Hydric Soils
Roads
Winooski River
Sub-Watershed
3,000 1,500 0 3,000
Feet
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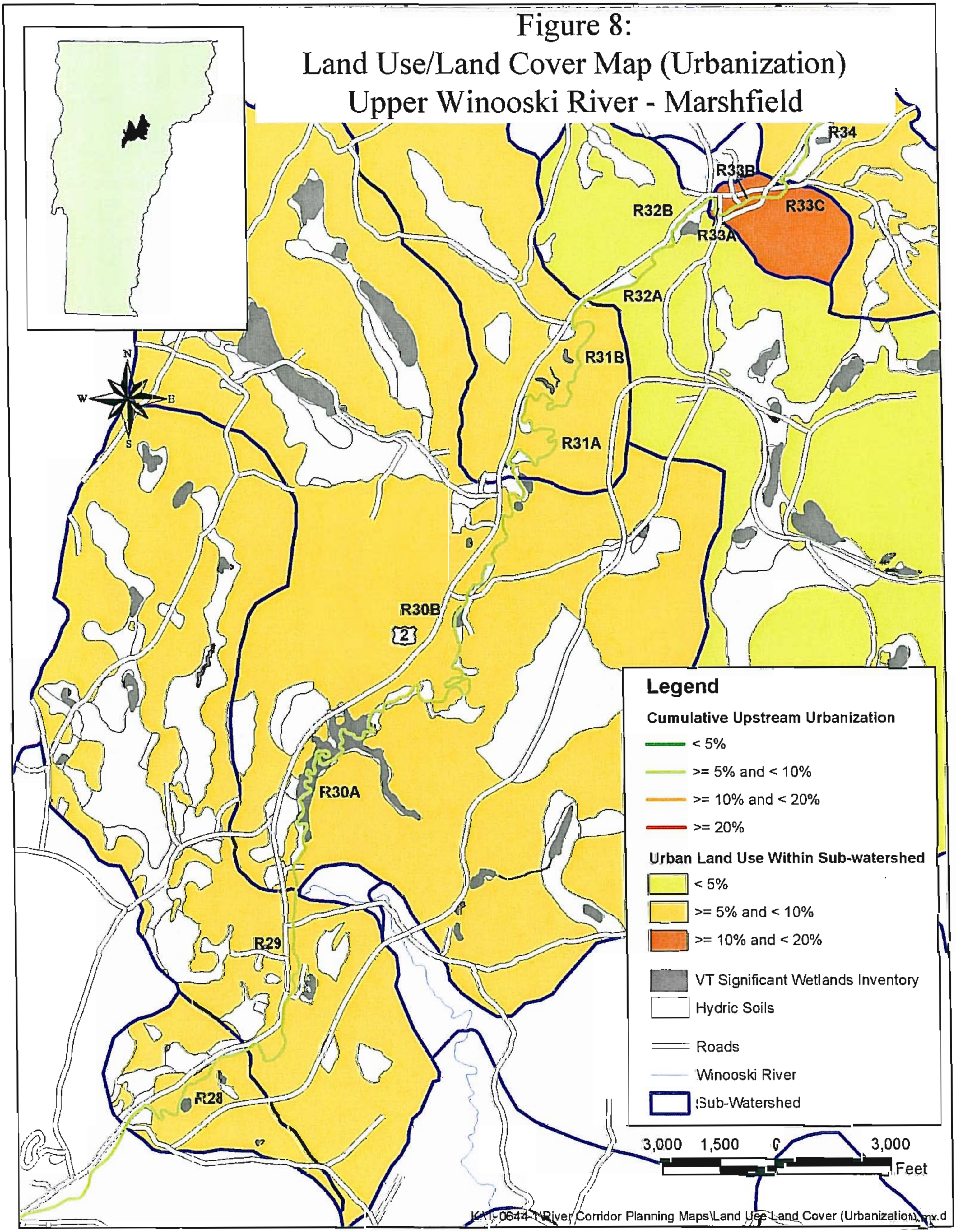
Figure 8:
Land Use/Land Cover Map (Urbanization)
Upper Winooski River - Marshfield



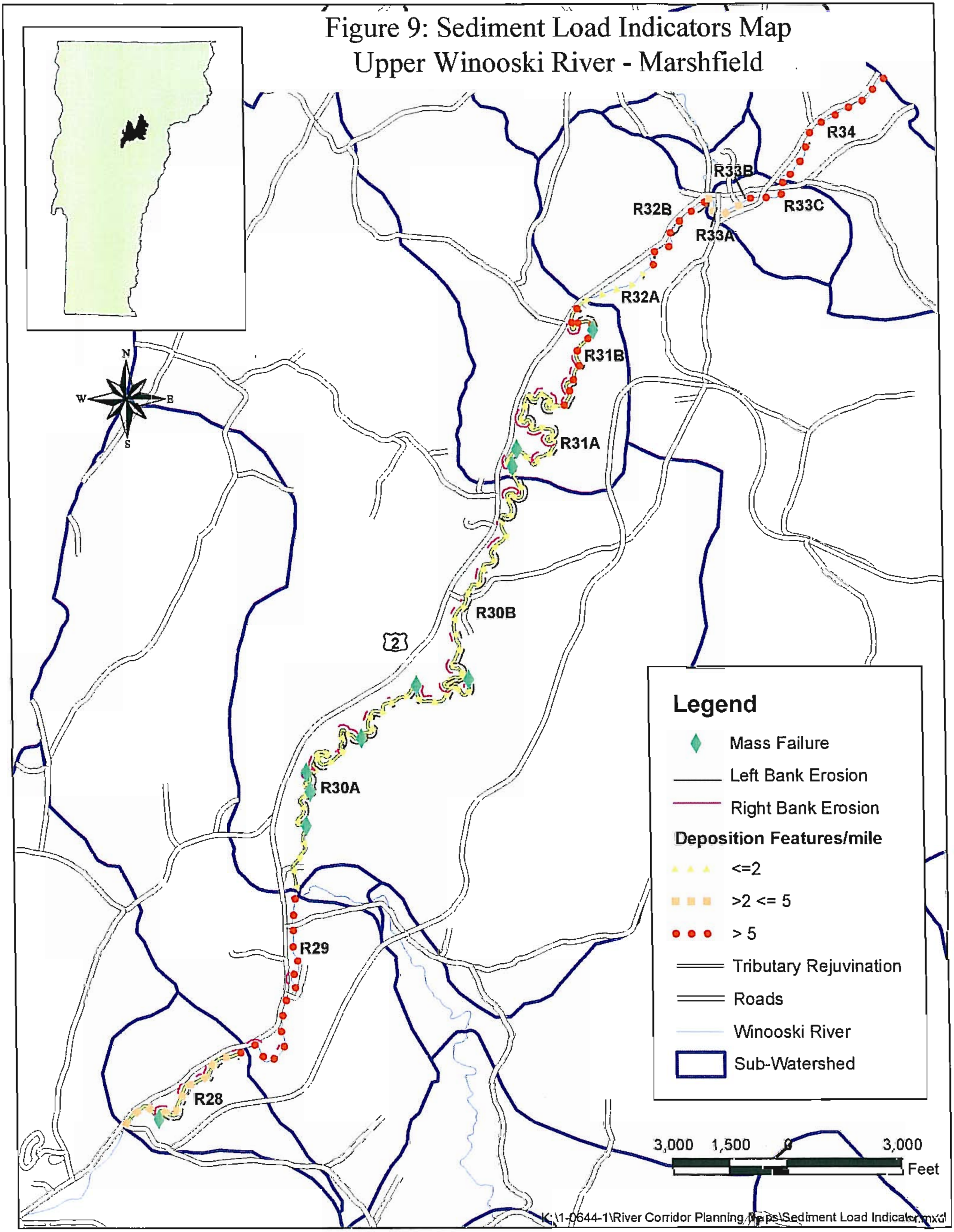
4.1.2 Sediment Regime Stressors

The sediment regime is defined as the quantity, size, transport, sorting, and distribution of sediments which are influenced by the proximity of sediment sources, the hydrologic regime, as well as the valley, stream, and floodplain characteristics (VT ANR 2007). The sediment regime may be split into two types of sediment: wash load and bed load. Wash load refers to finer grained materials which become suspended in the water column at higher flows and eventually settle out under lower flows and velocity, typically on floodplains and the inside of meander bends as flood waters recede. When these features are absent from a watershed, wash load sediments may remain suspended in the water column until they reach a larger receiving body of water. Bed load sediments are comprised of coarser materials that move during high flow events by rolling along the stream bed until they encounter areas of lesser energy. A watershed in equilibrium has a consistent pattern and movement of wash and bed loads. When this pattern is disrupted, aquatic habitat, water quality, and stream morphology are affected. (VT ANR 2007).

4.1.2.1 Watershed Scale Sediment Regime Stressors

Because the sediment regime is closely linked to a stream's hydrologic characteristics, many of the same stressors discussed above will have an impact on the watershed-wide sediment regime. Many of the existing hydrologic stressors such as stormwater inputs, increased runoff from agricultural fields, and urbanization not only cause increased flows, but also increased bed and wash loads due to lack of sediment attenuation sites and increased surface runoff. In addition, the increased flows can cause production of in-stream sediment from erosion of the stream banks and bed. As shown in Table 2 above, nearly all of the assessed reaches have increased sediment load caused by one or more of these hydrologic stressors. Figure 9 shows the sediment load indicators for the study area. The increased sediment load is evident in the number of mass failures and deposition features, such as gravel bars, present, particularly in Reaches 29, 31B, 32B, and 34.

Figure 9: Sediment Load Indicators Map
Upper Winooski River - Marshfield



4.1.2.2 Reach Scale Sediment Regime Stressors

Just as hydrologic alterations can affect the watershed wide sediment regime, modifications to the valley, channel, floodplain, and boundary conditions at the reach scale can change the hydrology and sediment transport capacity. Reach scale stressors can affect either stream power (increase or decrease in stream channel slope or depth) or the resistance to stream power known as boundary conditions (VT ANR 2007). Examples of human related activities which can increase stream power through slope and depth changes are channel straightening, dredging, berming, and undersized bridges and culverts. Structures such as dams and weirs can lead to a decrease in stream power. Boundary resistance is increased through armoring and placement of grade controls or decreased by removal of riparian vegetation and dredging. A summary of these reach scale stressors is shown on Table 2 above.

Reach scale channel slope modifiers are summarized on Figure 10. Nearly all of the assessed reaches within Marshfield exhibit stressors related to channel slope increases including extensive straightening and encroachment. Reach scale channel depth modifiers are shown on Figure 11. The main stressor associated with increased channel depth is river corridor encroachments from residential development and Route 2. The cumulative effect of these slope and depth increases has been an increase in stream power which has led to widespread channel incision (or downcutting) and bank erosion and ultimately a decreased sediment and nutrient attenuation capacity as the Winooski has lost access to its historic floodplain through much of the study area.

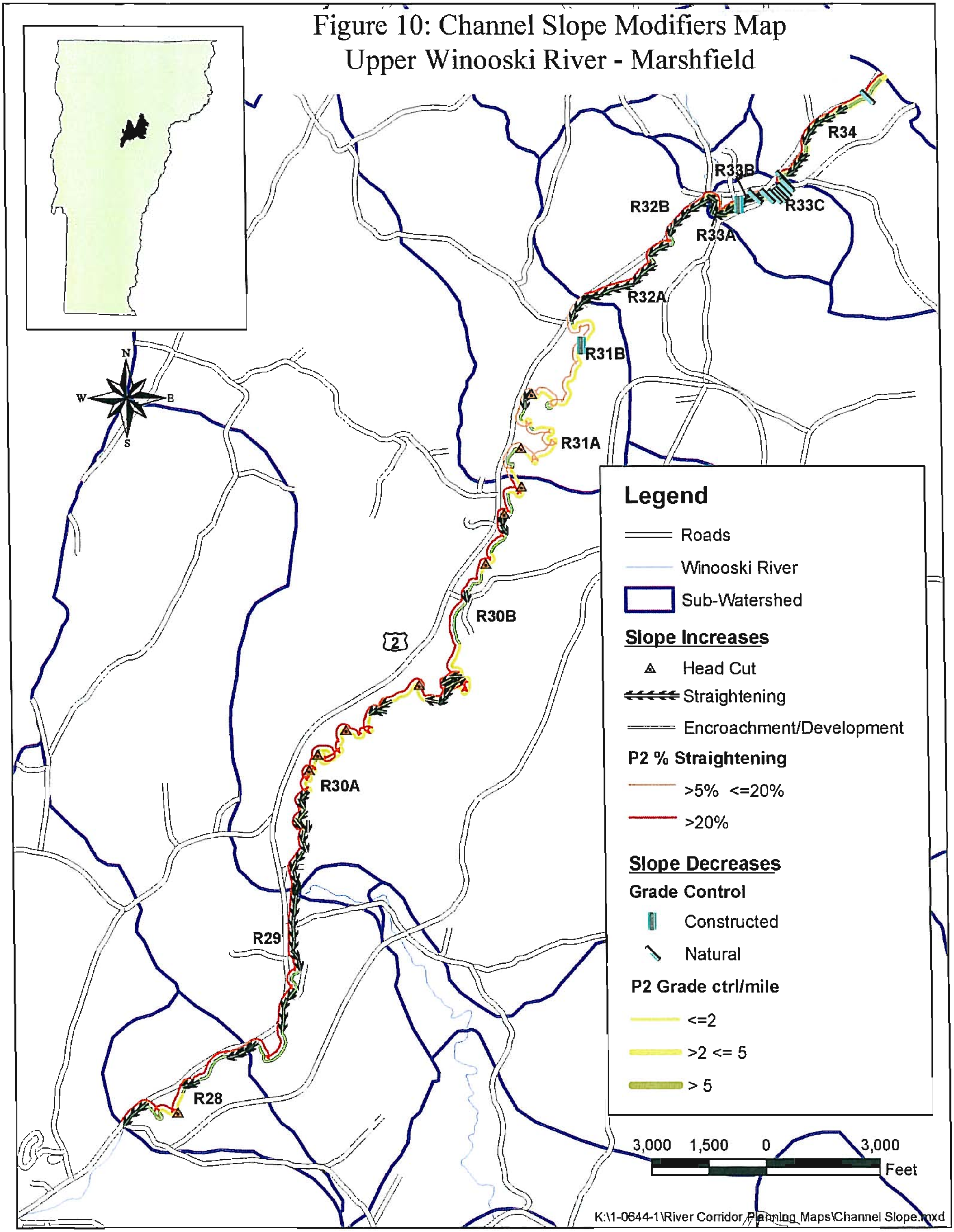
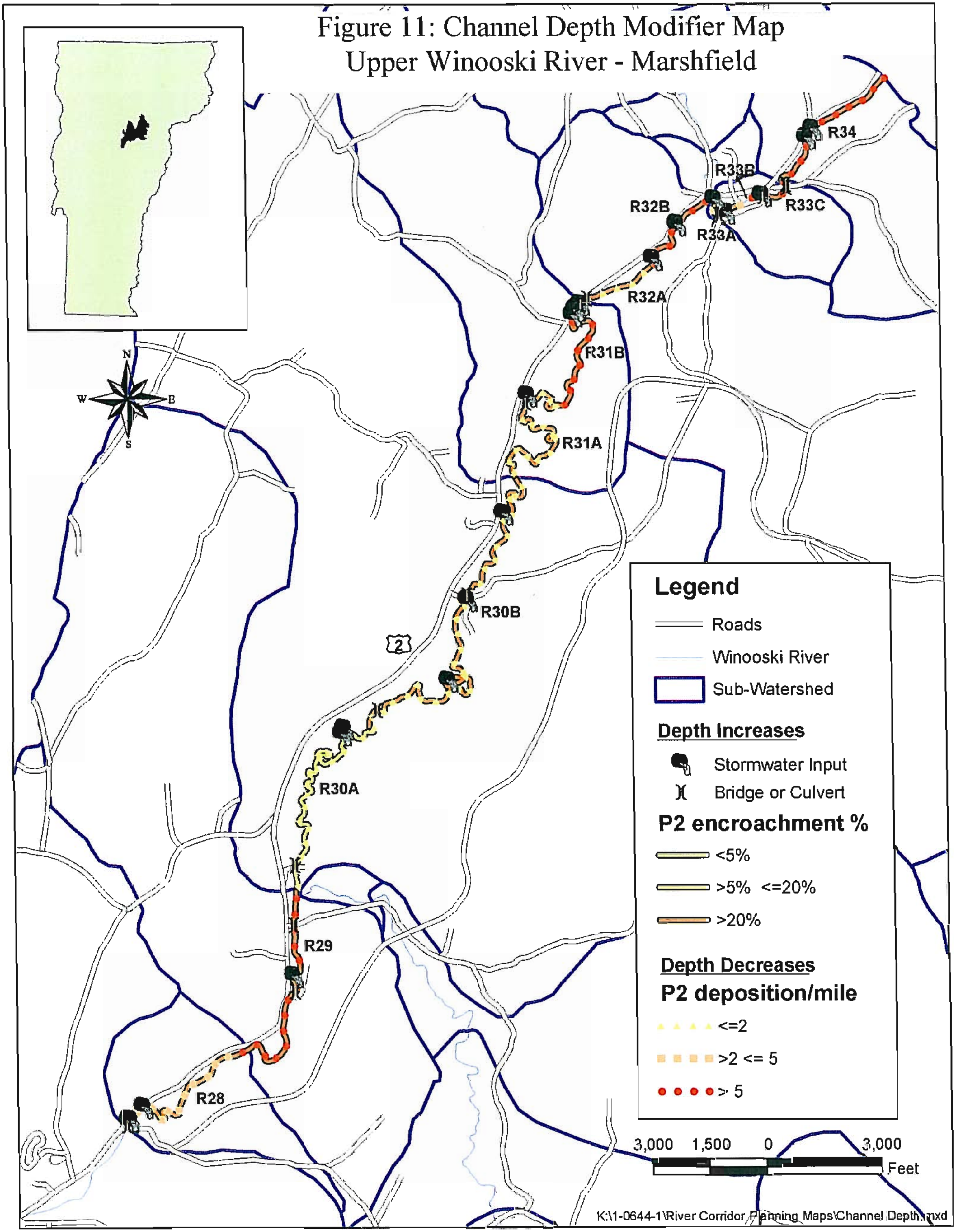


Figure 10: Channel Slope Modifiers Map
Upper Winooski River - Marshfield
N
S
E
W
R34
R33B
R32B
R33C
R33A
R32A
R31B
R31A
R30B
2
R30A
R29
R28
Legend
Roads
Winooski River
Sub-Watershed
Slope Increases
Head Cut
Straightening
Encroachment/Development
P2 % Straightening
>5% <=20%
>20%
Slope Decreases
Grade Control
Constructed
Natural
P2 Grade ctrl/mile
<=2
>2 <= 5
> 5
3,000 1,500 0 3,000
Feet
K:\1-0644-1\River Corridor Planning Maps\Channel Slope.mxd

Figure 11: Channel Depth Modifier Map
Upper Winooski River - Marshfield



In addition to the increased channel slope and depth, a significant reduction in the channel boundary resistance has occurred through a reduction in bank vegetation and buffers. Normally woody vegetation located along the stream channel will withstand some of the stream energy produced during flood events and help prevent excessive erosion and channel migration. In addition, woody buffer vegetation is beneficial for filtering out sediment and nutrients before they reach the channel, and enhances aquatic habitat by moderating water temperatures and providing food and habitat structure for aquatic organisms. A Boundary Conditions and Riparian Modifiers Map is shown as Figure 12. The decreased boundary resistance in the Upper Winooski is caused by the lack of woody buffer present along most reaches combined with the lack of cohesive bank soils such as silts and clays which naturally provide some resistance to erosion. The extensive amount of bank armoring present along exposed stream banks is also evidence of decreased boundary resistance, as landowners attempt to arrest erosion using hard engineering techniques.

It is also important to note that the study area lacks any permanent grade controls with the exception of the bedrock located in Reach 33. This lack of bed resistance means that any vertical channel adjustments, such as the incision processes described above, will move upstream without any permanent structures to arrest it. The Phase 2 data indicates that historic incision has occurred in nearly every reach and has reduced the amount of floodplain connection still available during high flow events.

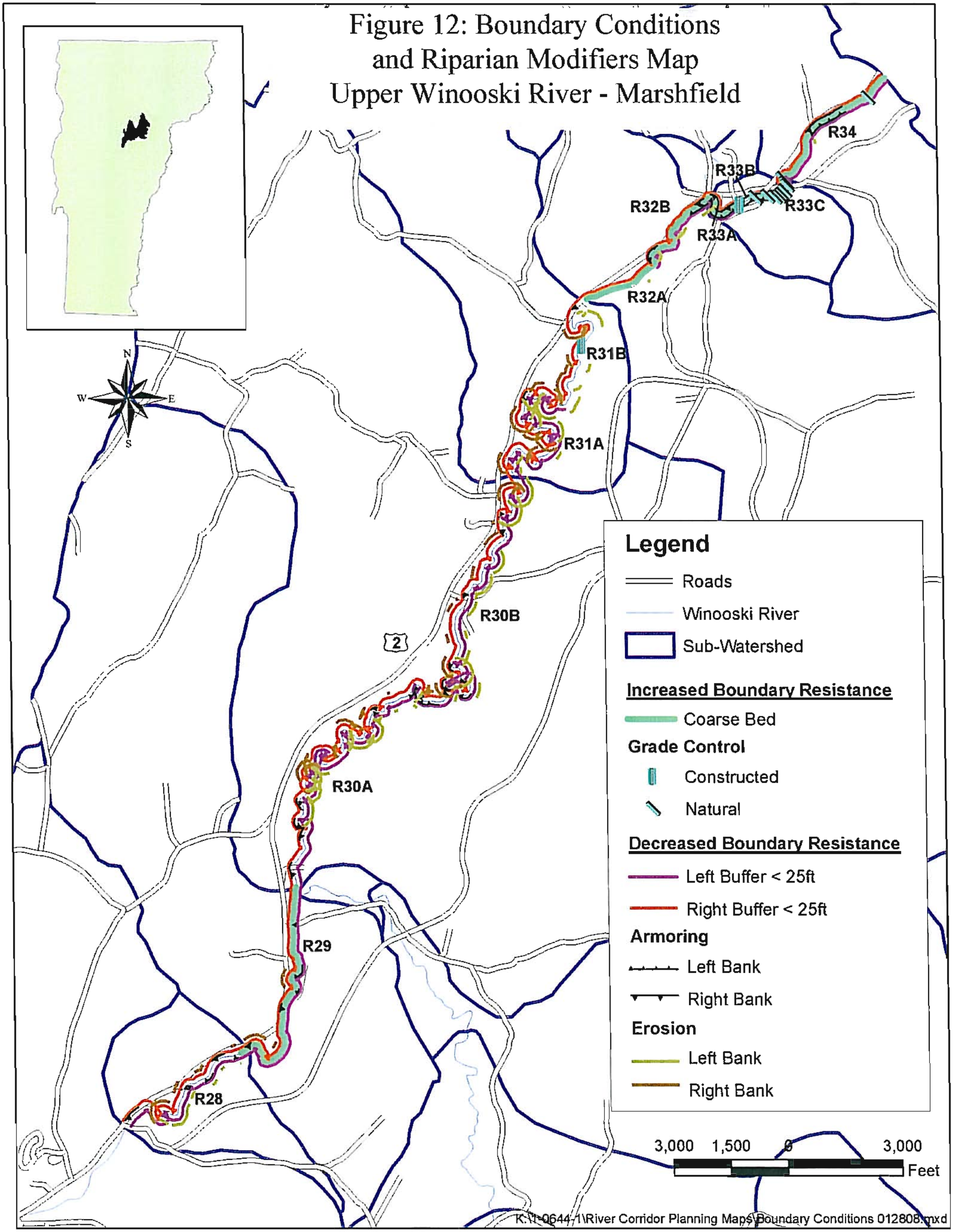


Figure 12: Boundary Conditions
and Riparian Modifiers Map
Upper Winooski River - Marshfield
N
W
E
S
R34
R33B
R32B
R33C
R33A
R32A
R31B
R31A
R30B
2
R30A
R29
R28
Legend
Roads
Winooski River
Sub-Watershed
Increased Boundary Resistance
Coarse Bed
Grade Control
Constructed
Natural
Decreased Boundary Resistance
Left Buffer < 25ft
Right Buffer < 25ft
Armoring
Left Bank
Right Bank
Erosion
Left Bank
Right Bank
3,000 1,500 0 3,000
Feet
K:\1-0644-1\River Corridor Planning Maps\Boundary Conditions 012808.mxd

4.1.3 Constraints to Sediment Transport and Attenuation

Streams in equilibrium are continuously moving sediment through the watershed from upstream to downstream. The type and amount of sediment are dictated by the size and overall slope of the watershed, and the type of geologic material the stream flows through. Understanding the transport and storage of sediment within a watershed is one of the most important aspects of river corridor restoration. Changes or modifications to watershed inputs and hydraulic geometry create disequilibrium and lead to an uneven distribution of stream power and sediment. This disequilibrium is manifested through large and small scale channel adjustments such as excessive erosion and deposition. These adjustments will continue until the stream returns itself to an equilibrium state where a balance between flow and sediment transport and attenuation are achieved (VT ANR 2007).

Table 3, Departure Analysis Table, presents data on sediment transport and Table 4, shows the sediment regime for the study area and how it has changed from its reference regime. This information is presented graphically in Figure 13. Historically, nearly the entire study area, except for R29, had a coarse equilibrium and fine deposition sediment regime. This means that the stream was in balance, and the sediment inputs essentially equaled the sediment outputs. Fine sediments and nutrients were stored on the floodplain during high flow events, and generally the system was in equilibrium. Currently, much of the study area has been converted to a fine source and transport regime where little sediment and nutrient attenuation is occurring because the channel has lost much of its historic floodplain access. This means that sediment and nutrients are no longer stored in the watershed, but carried downstream to other reaches and receiving bodies of water. In addition, the incision which has limited floodplain access also is causing excessive erosion which has converted these reaches from historic sediment and nutrient sinks to sediment and nutrient sources. The exception to this are reaches 29, 32B, and 34, which still have limited floodplain access and retain their fine sediment storage capacity. As shown in Table 3, many of the fine source and transport reaches have opportunities for increased sediment storage through floodplain restoration given the limited number of constraints from roads, bridges, homes and other development (Figure 13). More information about how these altered sediment regimes play into river corridor restoration and conservation projects for the area are described in Section 5.

Table 3: Departure Analysis Table - Upper Winooski River - Marshfield

	Existing Constraints Which May Limit Restoration Opportunities		Transport[1]	Attenuation (sediment/nutrient storage)[2]		
River Segment	Vertical	Lateral		Natural	Increased	Asset
R28		Roads and Agriculture	Converted	X		X
R29		Roads, Agriculture, Berms and Houses	Natural		X	Limited
R30A		Agriculture	Converted	X		X
R30B		Roads Agriculture, and Houses	Converted	X		X
R31A		Roads, Agriculture, and Houses	Converted	X		X
R31B		Roads, Agriculture, and Houses	Converted	X	X	X
R32A		Roads and Agriculture	Converted	X		X
R32B		Roads, Agriculture and Houses		X	X	Limited
R33A	Weir upstream	Roads, Berms, and Houses	Converted			None
R33B	Not Evaluated - Ponded water behind Marshfield dam					None
R33C	Natural Grade Controls Weir downstream	Roads, Berms, and Houses			X	None
R34	Natural Grade Controls Dam upstream	Roads and Agriculture		X	X	X

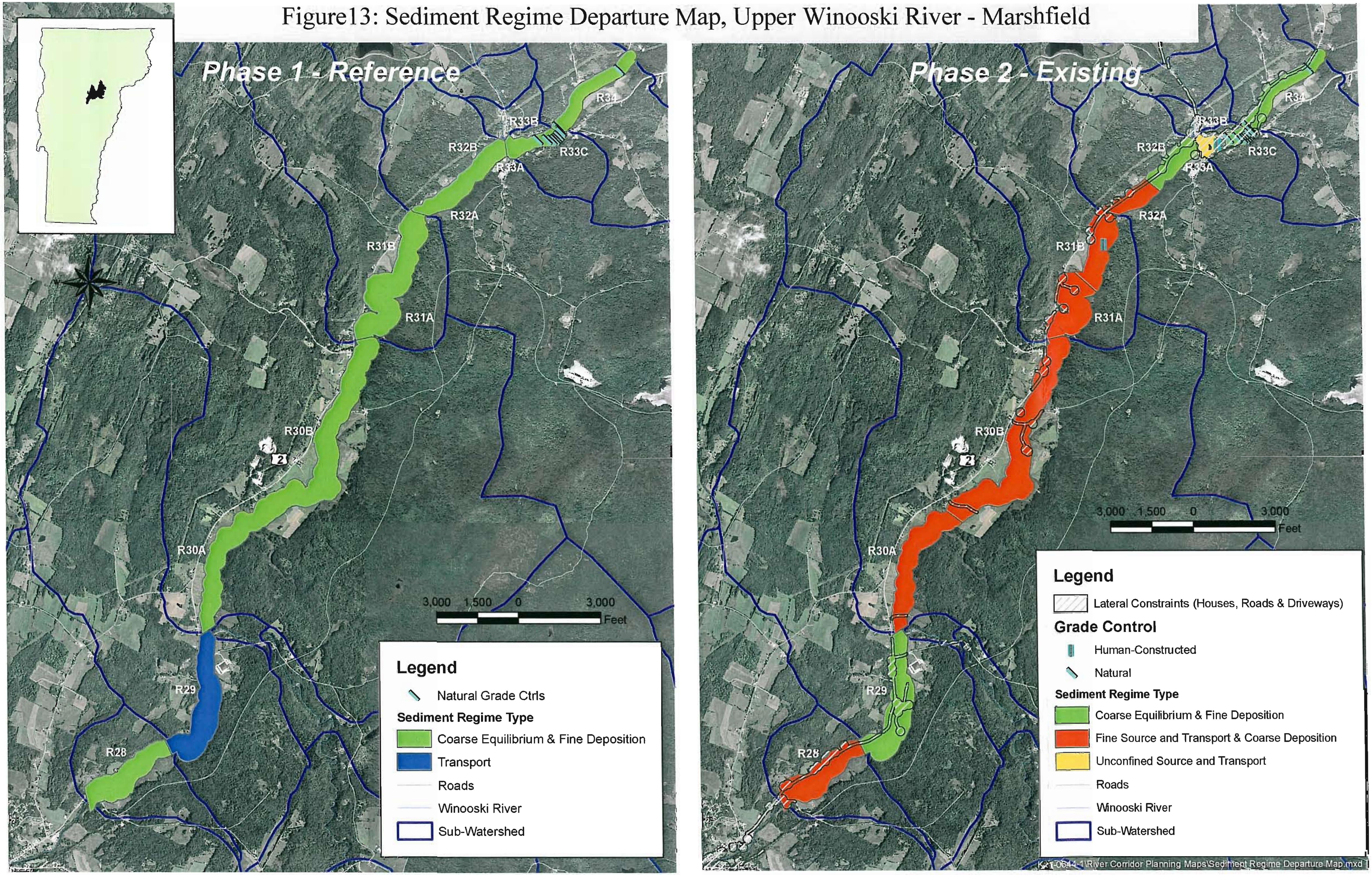
Notes:
[1]. Converted - converted from sediment storage to sediment transport, Natural - natural sediment transport reach
[2]. Natural - naturally l to allow future deposition to occur

Table 4: Sediment Regime Table - Upper Winooski, Marshfield

Reach ID	Reference Sediment Regime	Reference Stream Type	Stage of Channel Evolution/Geomorphic Condition	Criteria related to Sediment Supply, Transport and Storage	Existing Stream Type	Existing Sediment Regime
R28	Coarse Equilibrium & Fine Deposition	C5 - Dune-ripple	III (widening)/ Fair	Incision Ratio = 2.0 Valley Type[1] = BD Bank Armoring = <50% Straightening = <50% W/D Ratio = <30	C5 - Plane bed	Fine Source & Transport and Coarse Deposition
R29	Transport	B4-Plane Bed	IV (widening and aggrading)/ Fair	Incision Ratio = 1.0 Valley Type = BD Bank Armoring = <50% Straightening = >50% W/D Ratio = 17	C4 - Plane bed	Coarse Equilibrium & Fine Deposition
R30A	Coarse Equilibrium & Fine Deposition	E3-Dune-ripple	III (widening)/ Fair	Incision Ratio = 1.6 Valley Type = BD Bank Armoring = <50% Straightening = <50% W/D Ratio = 22	C5 - Dune-ripple	Fine Source & Transport and Coarse Deposition
R30B	Coarse Equilibrium & Fine Deposition	E3-Dune-ripple	III (widening)/ Fair	Incision Ratio = 1.8 Valley Type = VB Bank Armoring = <50% Straightening = <50% W/D Ratio = 17	C5 - Dune-ripple	Fine Source & Transport and Coarse Deposition
R31A	Coarse Equilibrium & Fine Deposition	E3-Dune-ripple	III (widening)/ Poor	Incision Ratio = 2.3 Valley Type = VB Bank Armoring = <50% Straightening = <50% W/D Ratio = 23	F5 - Dune-ripple	Fine Source & Transport and Coarse Deposition
R31B	Coarse Equilibrium & Fine Deposition	E3-Dune-ripple	III (widening)/ Poor	Incision Ratio = 2.2 Valley Type = BD Bank Armoring = <50% Straightening = <50% W/D Ratio = 20	F5 - Dune-ripple	Fine Source & Transport and Coarse Deposition
R32A	Coarse Equilibrium & Fine Deposition	C3-Riffle-pool	II (degrading)/ Fair	Incision Ratio = 1.8 Valley Type = NW Bank Armoring = <50% Straightening = >50% W/D Ratio = 19	B4c - Plane bed	Fine Source & Transport and Coarse Deposition
R32B	Coarse Equilibrium & Fine Deposition	C3-Riffle-pool	III (widening)/ Fair	Incision Ratio = 1.25 Valley Type = NW Bank Armoring = <50% Straightening = >50% W/D Ratio = 16	C3 - Riffle-pool	Coarse Equilibrium & Fine Deposition
R33A	Coarse Equilibrium & Fine Deposition	C2-Plane bed	II (degrading)/ Fair	Incision Ratio = 1.4 Valley Type = NW Bank Armoring = >50% Straightening = >50% W/D Ratio = 22	C3 - Plane bed	Unconfined Source and Transport
R33B	Coarse Equilibrium & Fine Deposition	C2-Plane bed	Not Evaluated - Ponded water behind dam in Marshfield Village			
R33C	Coarse Equilibrium & Fine Deposition	C2-Plane bed	II (degrading)/ Fair	Incision Ratio = 1.3 Valley Type = SC Bank Armoring = >50% Straightening = >50% W/D Ratio = 17	F2 - Step-pool	Coarse Equilibrium & Fine Deposition
R34	Coarse Equilibrium & Fine Deposition	C3-Plane bed	IIc (degrading)/ Fair	Incision Ratio = 1.0 Valley Type = BD Bank Armoring = <50% Straightening = <50% W/D Ratio = 14	C4 - Plane bed	Coarse Equilibrium & Fine Deposition

Notes: [1]: BD - broad, VB - very broad, NW - narrow, SC - semi-confined

Figure13: Sediment Regime Departure Map, Upper Winooski River - Marshfield



4.2 SENSITIVITY ANALYSIS

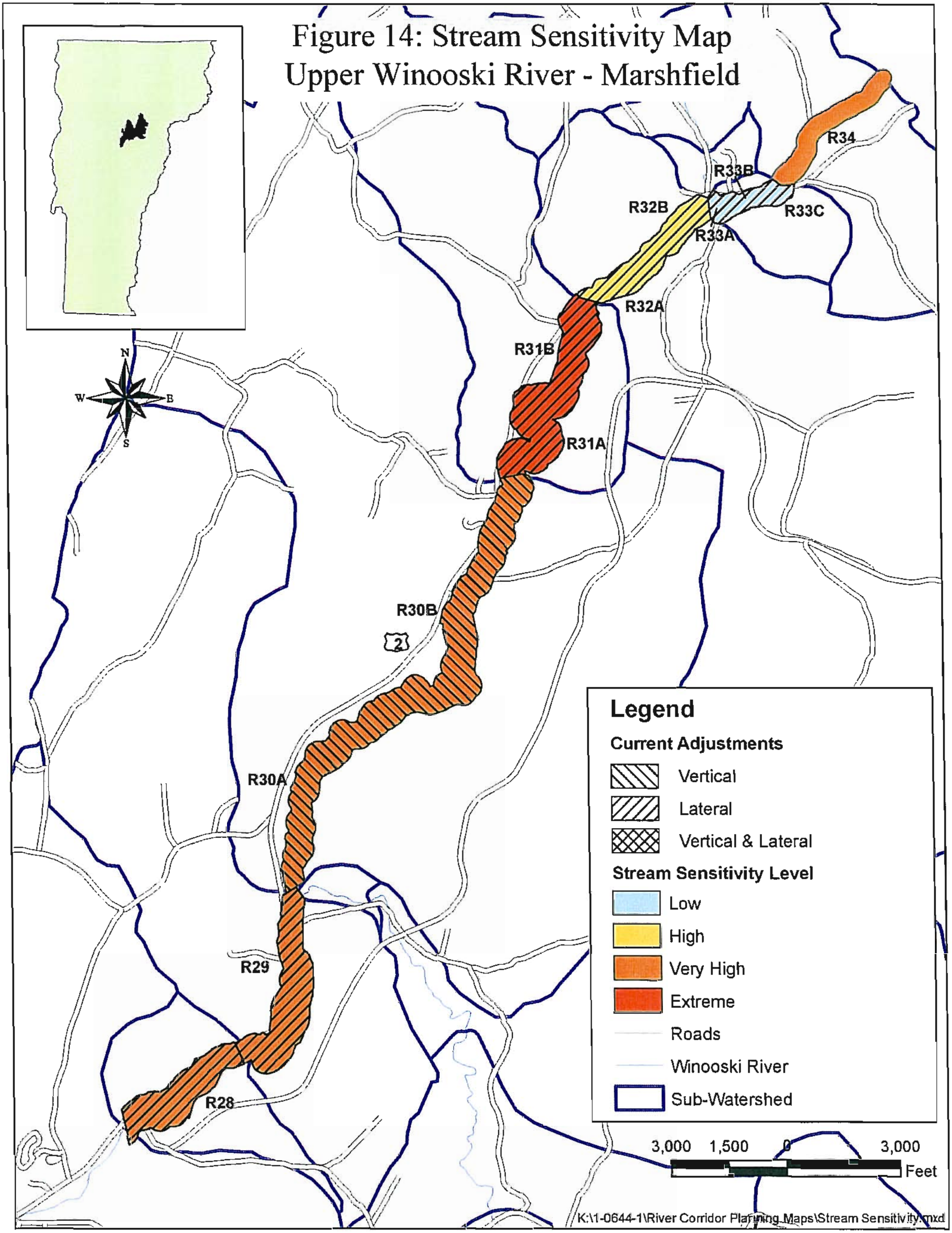
Figure 14 shows the predicted stream sensitivity for each reach in the study area. Stream sensitivity is defined as the likelihood that future vertical and lateral adjustments will occur including channel migration, widening, degradation, and aggradation. This sensitivity rating is based on the documented current and historic adjustment processes combined with known reference information for each reach. As is shown on Figure 14, five of the seven reaches have a very high or extreme sensitivity, meaning it is very likely that further vertical and lateral adjustments will occur. Every reach with the exception of R34 is currently experiencing vertical and/or lateral adjustments, which based on the high sensitivity will continue and likely increase if nothing is done to mitigate the stressors affecting the watershed.

5.0 PRELIMINARY PROJECT IDENTIFICATION

The preceding Section 4 described the underlying stressors and described how each reach within the study area has departed from its reference conditions. Utilizing the Tables, Figures and data above along with the step-wise procedure for identification of river corridor restoration and conservation projects developed by VT ANR (2007) the following Section will identify appropriate types of projects for each reach in the study area. Appropriate projects were broken down into the following eight project types:

1. Protect River Corridors
2. Plant Stream Buffers
3. Stabilize Stream Banks
4. Arrest Head Cuts
5. Remove Berms
6. Remove or Replace Structures
7. Restore Incised Reach
8. Restore Aggraged Reach

Figure 14: Stream Sensitivity Map
Upper Winooski River - Marshfield



For each of the seven assessed reaches, a Project and Practices Summary Table was created describing the types of projects which would best aid in restoring sediment and nutrient attenuation and restoring the reach to equilibrium conditions. Section 6.2 takes all of the identified project techniques identified at the Reach scale and prioritizes them at the watershed scale to identify which projects may be technically feasible and achieve the greatest possible benefit.

5.1 REACH BASED PROJECT IDENTIFICATION

5.1.1 Reach 28 Description and Project Identification

Reach 28 is the furthest downstream reach in the study area and extends from the John Fowler Bridge upstream for approximately ½ mile. Route 2 runs within the river corridor for the entire reach. This reach was found to be highly incised (has historically cut down into its bed) due to historic straightening and other channel management techniques, and only has access to the floodplain during high flow events. One head cut was noted during the Phase 2 Assessment, indicating that some incision is still ongoing. Extensive bank erosion was noted along large portions of the reach as the channel widens in an attempt to re-create new floodplain and dissipate flood related energy. The reach was found to be in Evolution Stage III (widening and plan form adjustments) as it attempts to re-establish a more stable meander pattern and connection to its floodplain. The riparian corridor is dominated by hay fields and pasture on both sides with a narrow buffer of less than 5 feet. The habitat assessment showed relatively poor aquatic habitat with a lack of woody cover, and very few favorable sediment types and flow patterns.

Given the current condition of R28, the recommended remedial strategies are to re-establish floodplain connection to enhance the sediment and nutrient storage potential of the Reach, and improve aquatic habitat. There are both passive and active remedial techniques which could be utilized. The passive approach involves protecting the river corridor and limiting channel management to allow the current evolution of the channel to continue. Over time the stream will re-establish a more stable meander pattern, create greater floodplain connection and return to a more stable equilibrium state. The active approach would involve physical manipulation of the channel and adjacent corridor to construct a more stable meander pattern and accessible floodplain. In conjunction with either technique, woody buffer vegetation planting should be conducted to improve aquatic habitat. Initial planting should be concentrated on more stable sections of streambank to ensure that future erosion and/or channel migration does not affect the plantings. Other instream aquatic habitat improvement techniques, such as introduction of woody debris for cover, should also be considered once greater channel stability has been reached. The head cut identified on Figure 15 should also be halted through construction of a grade control structure to prevent further incision. One other additional remedial action to be considered for R28 is the widening or removal of the bridge abutments for the historic Martin's Covered Bridge. The abutments are currently undersized and act as a channel constriction. Correctly sized abutments will help facilitate channel restoration, improve aquatic habitat, and reduce potential future flood damage. A large portion of this reach is located on land owned by the Town of Marshfield, which makes the potential for corridor protection much more feasible. Current plans call for the creation of a park and recreational area on this land. This could provide a good opportunity for a demonstration project on publicly owned land to show the value and benefit of river corridor protection and buffer planting.

Table 5: Projects and Practices Table - Upper Winooski Watershed
Reach 28

River Segment	Restoration/Conservation Technique	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps/Project Notes
R28	Protect River Corridor - potential project within town owned land near covered bridge. Corridor currently undeveloped and not in production	High	High	Yes	Landowner (Town of Marshfield) cooperation, Road encroachments along right bank, Martin's covered bridge mid-reach has undersized abutments
R28	Plant Stream Buffer - majority of reach has little to no riparian buffer	High	High	Yes	Reach highly incised with active widening/erosion, planting efforts should be concentrated along more stable sections of reach or placed to accommodate for future widening
R28	Restore incised reach - active or combination active and passive restoration on Town owned land	High	High	No	Need additional information prior to design - survey, phase III assessment, town approval, potential permitting issues, high cost
R28	Arrest Head Cut - head cut identified mid-reach, weir or other grade control structure needed to prevent head cut migration and further incision	High	High	Yes	Selection and design of preferred structure type
R28	Replace or remove undersized structure - remove or widen Martin's covered bridge abutments	High	Low	Yes	Current abutments undersized, survey and phase III assessment needed prior to redesign, if current covered bridge is to be used it may have to be retrofitted to accommodate wider abutments

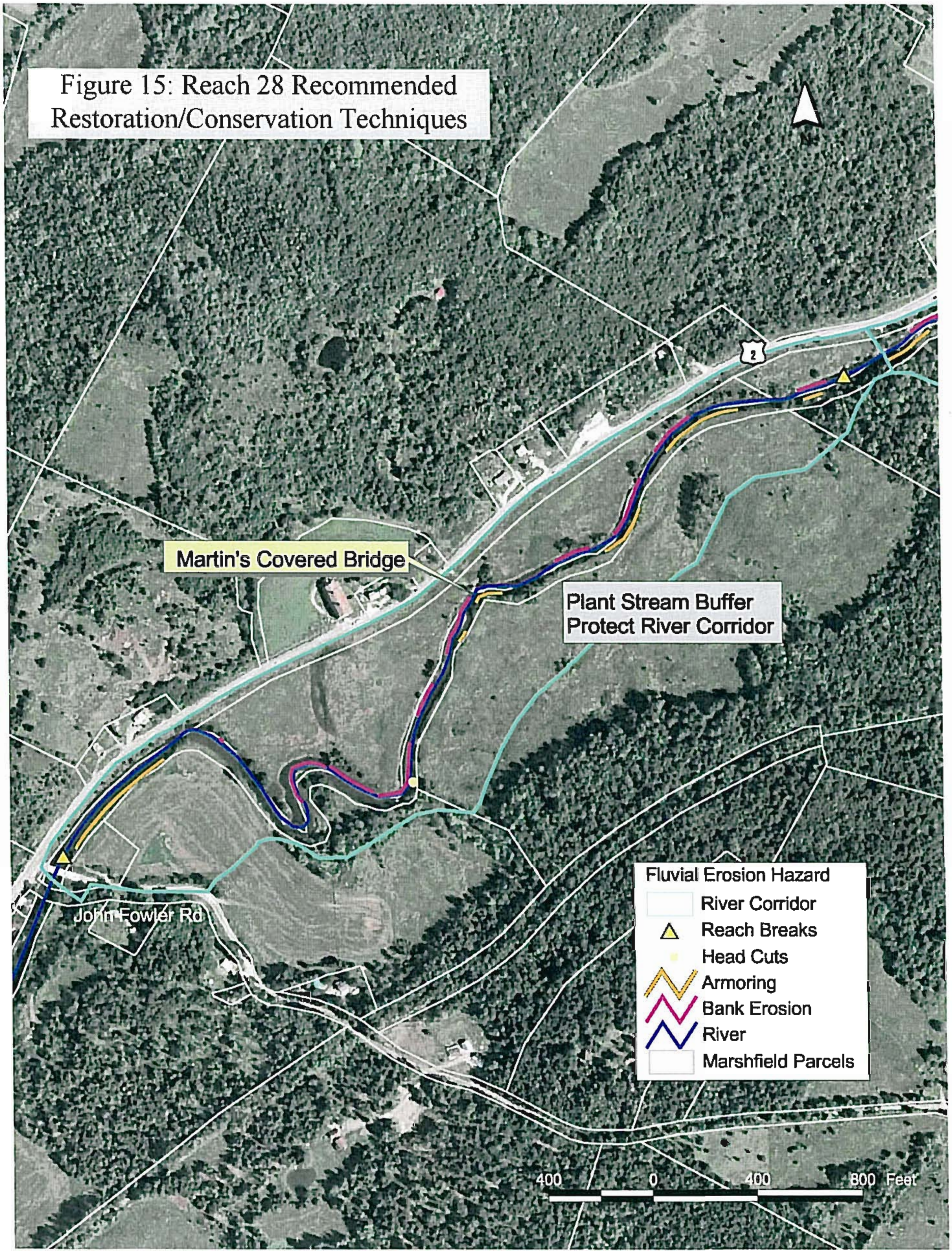


Figure 15: Reach 28 Recommended Restoration/Conservation Techniques
Martin's Covered Bridge
Plant Stream Buffer
Protect River Corridor
John Fowler Rd
2
Fluvial Erosion Hazard
River Corridor
Reach Breaks
Head Cuts
Armoring
Bank Erosion
River
Marshfield Parcels
400
0
400
800 Feet

5.1.2 Reach 29 Description and Project Identification

Reach 29 extends upstream from the end of Reach 28 for approximately ¾ mile to the confluence with Nasmith Brook, near Twinfield Union School. This reach has been extensively straightened in the past. Several encroachments run throughout the river corridor, including Route 2, and several homes and businesses. The reach is in evolution stage IV, meaning that it has widened and is currently aggrading as is evident by the large number of bars and other depositional features shown on Figure 9. Moderate bank erosion was noted in several places throughout the reach as it responds to the active and historic channel management. The habitat and geomorphic scores were both fair for this reach which had a very high sensitivity rating.

Given the large number of human investments located within the river corridor and adjacent to the stream channel, the opportunities for conservation and restoration projects are quite limited for Reach 29. Table 6 and Figure 16 below summarize the recommended restoration techniques. In order to protect Route 2, the two eroding streambanks close to the road will need to be stabilized. A large portion of the river corridor is already developed, but efforts should be made to limit further development within the corridor, particularly in the downstream portion of the reach where a few undeveloped fields still exist. Stream bank buffer plantings are needed in the reach, particularly in the northern portion near Twinfield Union School, where little buffer is currently present. As it is on Town owned land, this portion of the reach could provide a good educational opportunity for the students to participate in restoration projects and learn the value of riparian buffers.

Table 6: Projects and Practices Table - Upper Winooski Watershed
Reach 29

River Segment	Restoration/Conservation Technique	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps/Project Notes
R29	Protect River Corridor - limit further development within corridor	High	Low	Yes	Corridor largely developed with multiple constraints (houses, roads, etc.) so options for gaining sediment and nutrient attenuation are limited. Priority for this reach should be limiting future development to retain existing floodplains and limit future erosion hazards
R29	Plant Stream Buffer - majority of reach has little riparian buffer, particularly north of Twinfield School	High	High	Yes	Reach historically straightened and armored with multiple constraints - woody buffers should be established to reduce erosion, improve habitat, and filter excess nutrients
R29	Stabilize eroding streambanks (2) along Route 2	High	Low	Yes	Two eroding banks are threatening Route 2, one near downstream end of reach, one just north of campground entrance. These banks should be stabilized to protect infrastructure

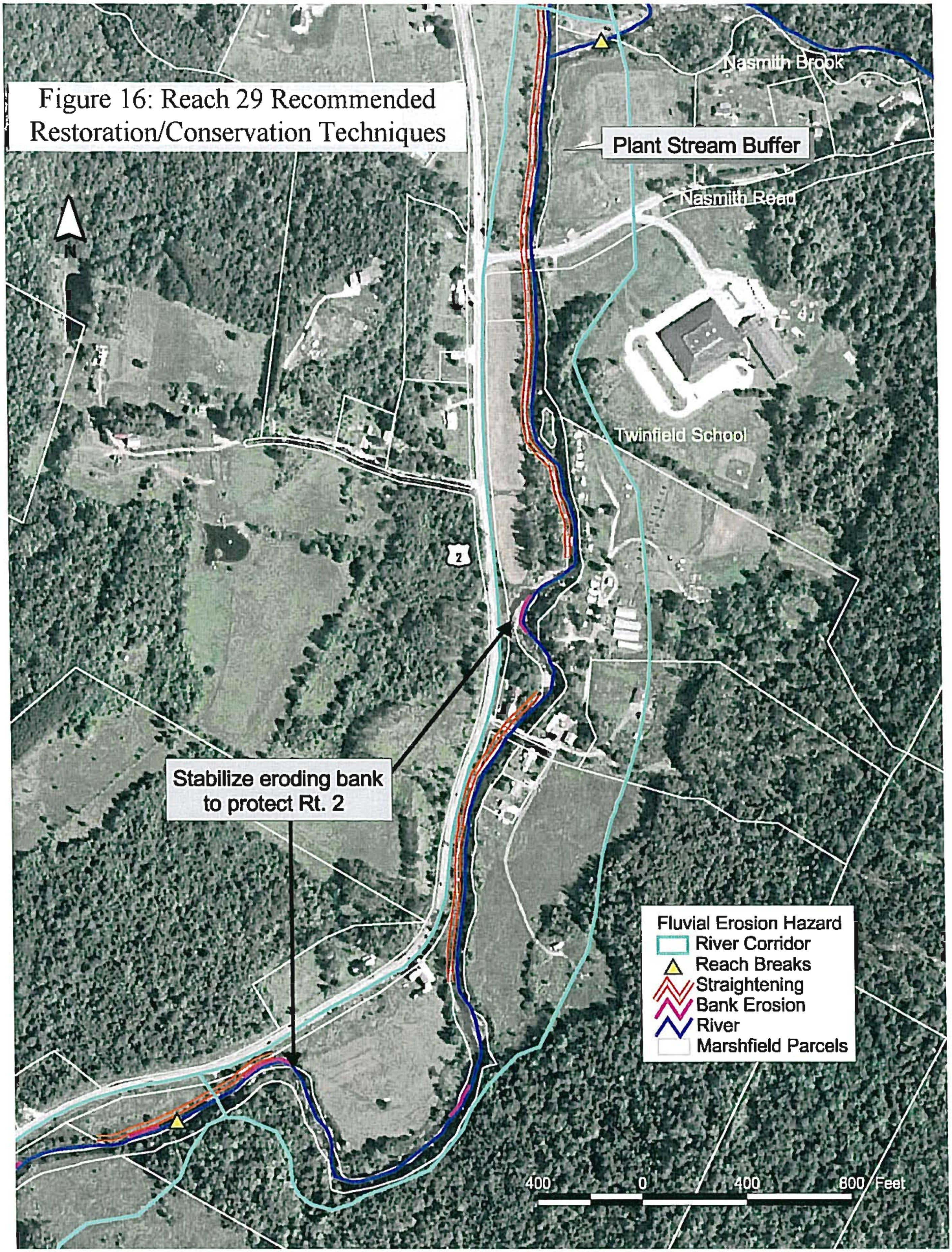


Figure 16: Reach 29 Recommended Restoration/Conservation Techniques

5.1.3 Reach 30 Description and Project Identification

Reach 30 extends from the confluence with Naismith Brook upstream for approximately 1.5 miles to the confluence with Beaver Meadow Brook. The reach was segmented into two parts, 30A and 30B, due to land use differences. Segment A is primarily forested with recently abandoned agricultural fields, while Segment B is dominated by active hay and corn fields and pasture. Similar adjustment processes were noted in each segment, mainly historic and active degradation and widening caused by historic channel management such as straightening and dredging. The reach was found to be in evolution stage III, as it widens and attempts to re-create floodplain access lost through the incision process. Large portions of the reach lack adequate riparian buffers. Overall, relatively poor aquatic habitat was observed.

Table 7 and Figure 17 below summarize the preferred restoration and conservation techniques for both Segments A and B. Given the active and historic incision which dominates both segments, the main priority for this reach is to re-establish floodplain connection to restore the historic sediment and nutrient attenuation assets which were present here. A large portion of the reach is undeveloped agricultural land so opportunities to protect the river corridor are still available. As of the date of this report, two landowners in Segment A, and one in Segment B are in the process of working with FWR to establish river corridor easements to protect a large portion of the reach. Active floodplain creation could be a valid technique in either segment, though with incision ratios of 1.6 and 1.8, both segments still have limited access to their current floodplain, and therefore could receive a large benefit from less expensive passive restoration techniques. This involves simply protecting the river corridor from development and limiting channel management to allow the stream to continue its evolutionary process, and over time, re-create floodplain at a lower elevation. This technique is much less expensive than active approaches which are typically reserved for more highly incised reaches with incision ratios of greater than 2.0. Other potential restoration techniques for Reach 30 include arresting the seven identified head cuts within the reach. These areas are shown of Figure 17. In order to prevent further incision, and/or upstream migration of these head cuts permanent grade controls should be installed. Stream buffer enhancement is another important technique for both segments. Much of the reach lacks any substantial woody buffer which would help filter out nutrients, stabilize streambanks, and improve wildlife habitat.

Table 7: Projects and Practices Table - Upper Winooski Watershed
Reach 30

River Segment	Restoration/Conservation Technique	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps/Project Notes
R30A	Protect River Corridor - All of Segment A	High	High	Yes	Corridor currently undeveloped with a mix of active and recently abandoned agricultural lands. Entire segment good candidate for protection and passive restoration to restore floodplain access and enhance sediment and nutrient attenuation within watershed and reach.
R30A	Plant Stream Buffer - Large portions of segment have little to no woody buffer	High	High	Yes	Reach incised with active widening/erosion, planting efforts should be concentrated along more stable sections of reach or placed to accommodate for future widening
R30A	Arrest Head Cuts - 3 head cuts identified in reach, grade control structure needed to prevent further incision and migration of head cut	High	High	Yes	Selection and design of grade control structure
R30B	Protect River Corridor - All of Segment B upstream to Patty's Crossing Road	High	High	Yes	Corridor currently undeveloped with a mix of active and recently abandoned agricultural lands. Entire segment good candidate for protection and passive restoration to restore floodplain access and enhance sediment and nutrient attenuation within watershed and reach.
R30B	Plant Stream Buffer - Large portions of segment have little to no woody buffer	High	High	Yes	Reach incised with active widening/erosion, planting efforts should be concentrated along more stable sections of reach or placed to accommodate for future widening
R30B	Arrest Head Cuts - 4 head cuts identified in reach, grade control structure needed to prevent further incision and migration of head cut	High	High	Yes	Selection and design of grade control structure
R30B	Replace undersized structure - Bickford farm bridge	Medium	Low	Yes	Private farm bridge highly undersized (44% of bankfull width), floodplain and channel constriction. Bank erosion upstream and downstream of structure. Bridge would be constraint to passive floodplain restoration strategies

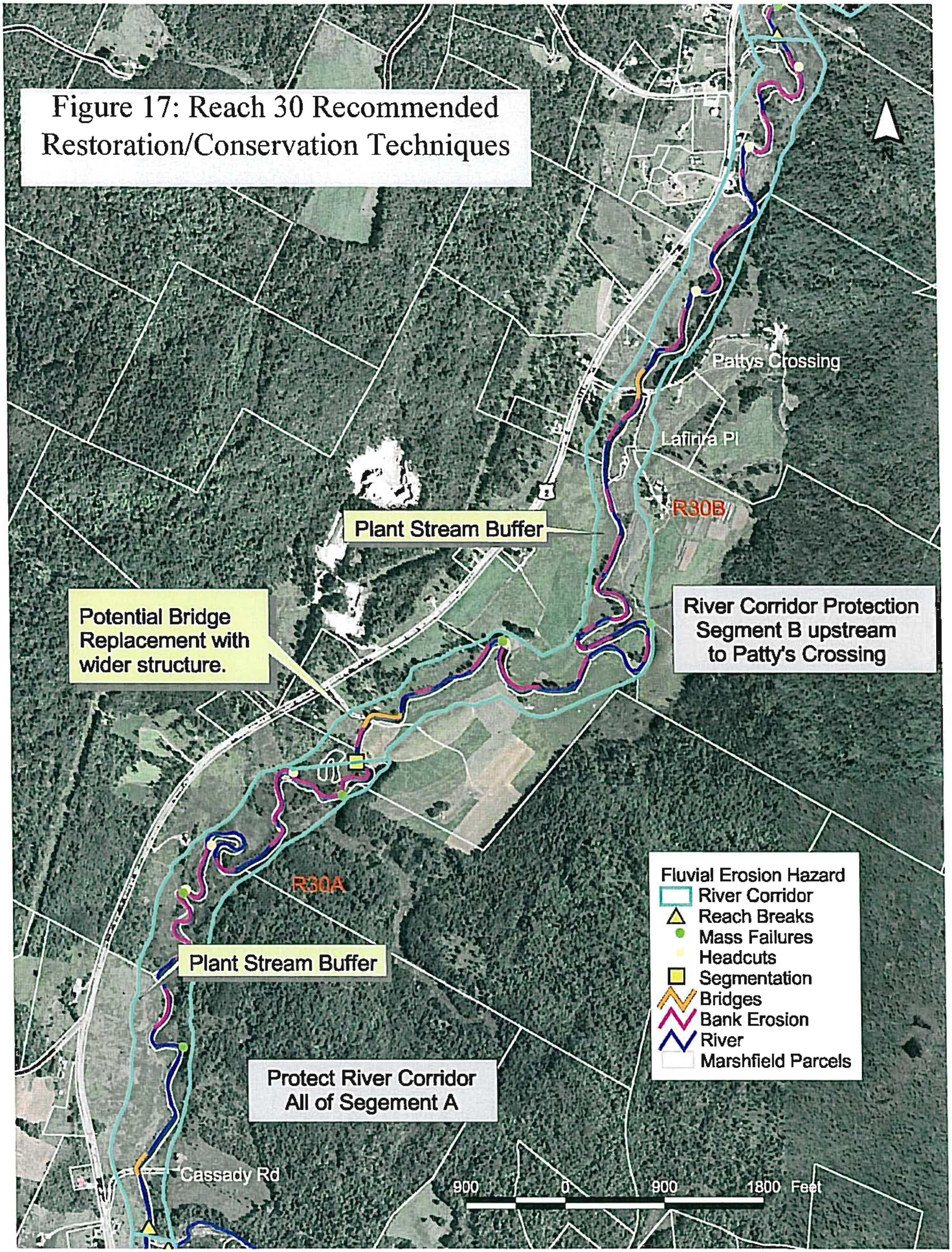


Figure 17: Reach 30 Recommended Restoration/Conservation Techniques
Pattys Crossing
Lafirira Pl
R30B
Plant Stream Buffer
River Corridor Protection Segment B upstream to Patty's Crossing
Potential Bridge Replacement with wider structure.
R30A
Plant Stream Buffer
Protect River Corridor All of Segement A
Cassady Rd
Fluvial Erosion Hazard
River Corridor
Reach Breaks
Mass Failures
Headcuts
Segmentation
Bridges
Bank Erosion
River
Marshfield Parcels
900 0 900 1800 Feet

5.1.4 Reach 31 Description and Project Identification

Reach 31 extends from the confluence with Beaver Meadow Brook upstream for approximately 2 miles to just above the bridge located on Sass Avenue in Marshfield Village. The reach was segmented into two parts, A and B mainly due to differences in channel sinuosity with Segment A being very sinuous and Segment B having low sinuosity. Similar adjustment processes were observed throughout the Reach. Extensive incision has caused the channel to cut down into the streambed and reduced access to the floodplain except during very high flow events. Both segments are in evolution stage III, and similar to other reaches in the study area are in the process of widening to re-create lost floodplain access. The riparian corridor was dominated by hay fields and pasture throughout, with very little riparian buffer. The geomorphic and habitat assessment scores were both rated as poor, and the entire reach was classified as being very sensitive to future adjustments.

Summaries of the preferred restoration and conservation techniques for Reach 31 are shown on Table 8 and Figure 18. As with many of the other reaches in the study area, the main priority for Reach 31 is re-connecting the stream to its floodplain to restore the sediment and nutrient attenuation assets that once prevailed here. Both segments are highly incised (incision ratios of 2.3 and 2.2) and only have access to the adjacent floodplains during very high flow events. As nearly the entire reach is free of constraints and dominated by agricultural fields, this area represents a good opportunity to implement floodplain restoration and river corridor protection. Given the very high incision ratios, the most effective type of project would involve river corridor protection and active floodplain restoration through the use of heavy equipment to lower the adjacent stream banks and re-connect the channel and floodplain. Re-establishment of adequate riparian buffer is also important for this reach, though given the extensive amount of erosion and very high sensitivity, buffer planting locations should be initially concentrated on more stable sections of streambank to prevent loss to erosion. Ideally, re-establishment of adequate buffer should be done in conjunction with floodplain restoration activities.

Table 8: Projects and Practices Table - Upper Winooski Watershed

Reach 31

River Segment	Restoration/Conservation Technique	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps/Project Notes
R31A	Protect River Corridor - All of Segment A	High	High	Yes	Corridor currently undeveloped with a mix of active and recently abandoned agricultural lands. Entire segment good candidate for protection and passive restoration to restore floodplain access and enhance sediment and nutrient attenuation within watershed and reach.
R31A	Plant Stream Buffer - Large portions of segment have little to no woody buffer	High	High	Yes	Reach incised with active widening/erosion, planting efforts should be concentrated along more stable sections of reach or placed to accommodate for future widening
R31A	Restore incised reach - active or combination active and passive restoration to re-establish floodplain connection	High	High	Yes	Segment A may be candidate for more active floodplain development as it is more highly incised than other reaches, Need additional information prior to design - survey, phase III assessment, landowner approval, potential permitting issues, high cost
R31B	Protect River Corridor - All of Segment B downstream of Pike Road	High	High	Yes	Corridor currently undeveloped with a mix of active and recently abandoned agricultural lands. Entire area upstream to Pike Road good candidate for protection and passive restoration to restore floodplain access and enhance sediment and nutrient attenuation within watershed and reach.
R31B	Plant Stream Buffer - Large portions of segment have little to no woody buffer especially along right bank	High	High	Yes	Reach incised with active widening/erosion, planting efforts should be concentrated along more stable sections of reach or placed to accommodate for future widening
R31B	Restore incised reach - active or combination active and passive restoration to re-establish floodplain connection	High	High	Yes	Segment B may be candidate for more active floodplain development as it is more highly incised than other reaches, Need additional information prior to design - survey, phase III assessment, landowner approval, potential permitting issues, high cost
R31B	Replace undersized structure - Bean farm bridge	Medium	Low	Yes	Private farm bridge highly undersized (67% of bankfull width), floodplain and channel constriction. Bank erosion upstream and downstream of structure. Bridge would be constraint to passive floodplain restoration strategies

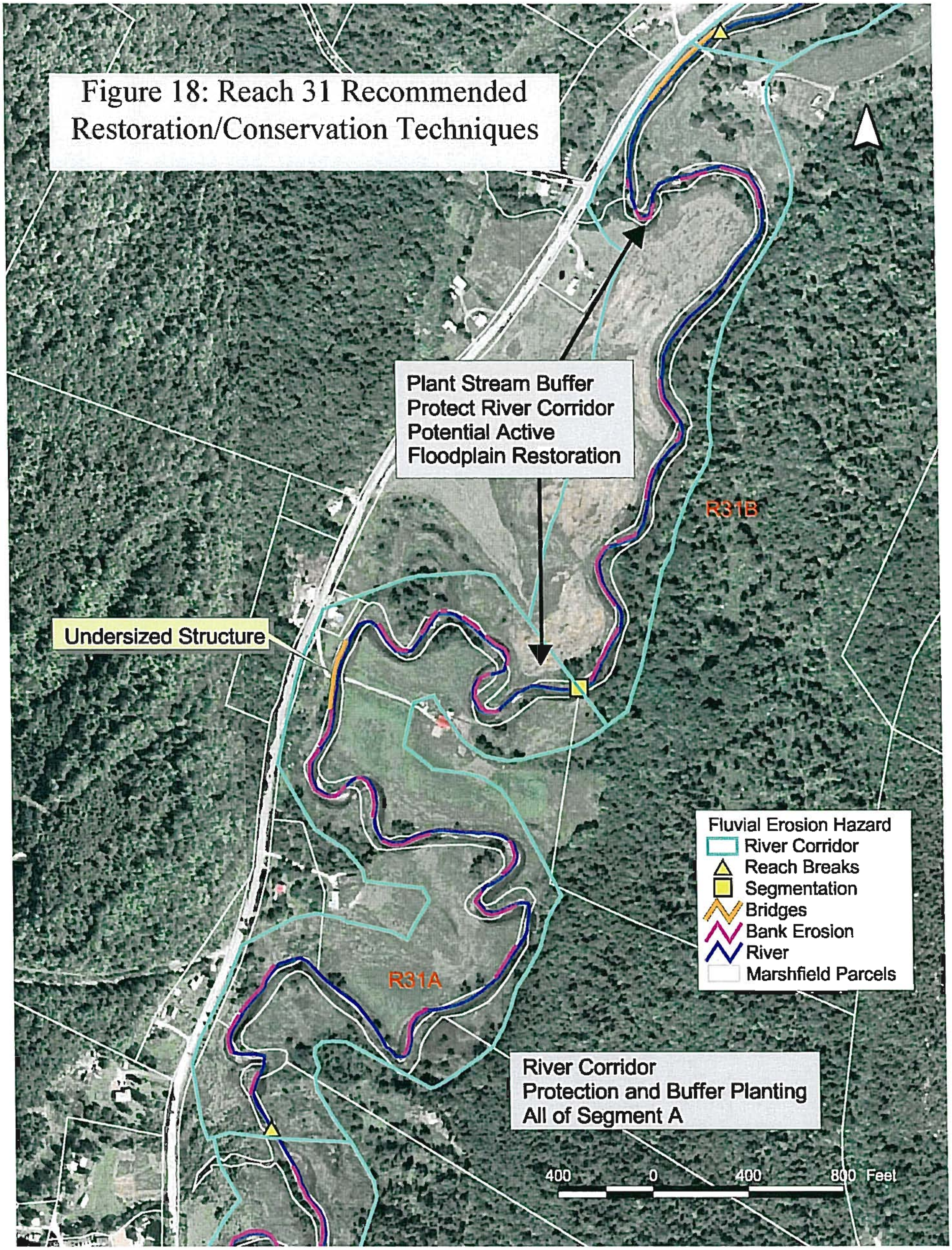


Figure 18: Reach 31 Recommended
Restoration/Conservation Techniques
N
Plant Stream Buffer
Protect River Corridor
Potential Active
Floodplain Restoration
R31B
Undersized Structure
Fluvial Erosion Hazard
River Corridor
Reach Breaks
Segmentation
Bridges
Bank Erosion
River
Marshfield Parcels
R31A
River Corridor
Protection and Buffer Planting
All of Segment A
400 0 400 800 Feet

5.1.5 Reach 32 Description and Project Identification

Reach 32 extends from just upstream of Sass Avenue to Creamery Street near Marshfield Village. The Reach was segmented into 32A and 32B due to measured differences in channel dimensions. Segment 32A makes up the downstream half of the reach, and 32B is the upstream half nearer Marshfield village. Segment A was highly incised (has historically cut down into its bed) due to historic straightening, dredging, and other channel management techniques, and only has access to the floodplain during high flow events. Despite this incision, relatively little bank erosion was observed, though it is expected that future bank erosion will occur as the channel attempts to restore its connection with the floodplain and the energy associated with high flow events is contained within the channel. The riparian corridor was dominated by pasture and hayfields along the right bank, and shrubs and forest on the left. Segment 32B was moderately incised, and still has some access to its historic floodplain during high flow events. This reach has been extensively straightened in the past to accommodate route 2, and a large portion of the reach has been armored to stabilize the banks. Several areas of erosion were noted where the streambanks were not armored. The riparian corridor was dominated by residential property and Route 2 along the right, and pasture and hayfields on the left. Both segments showed relatively poor aquatic habitat with very little woody cover, and few favorable substrate types and flow patterns.

Due to the large number of encroachments and human investments within the river corridor, restoration and conservations opportunities for Reach 32 are somewhat limited. Table 9 and Figure 19 below summarize these opportunities. River corridor protection and passive floodplain restoration opportunities exist along the right bank of Segment A between the river and Route 2, and along the left bank of Segment B. In addition, large portions of the Reach lack adequate riparian buffer, so buffer enhancement and planting is another possible technique for Reach 32.

Table 9: Projects and Practices Table - Upper Winooski Watershed
Reach 32

River Segment	Restoration/Conservation Technique	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps/Project Notes
R32A	Protect River Corridor - All of Segment A	High	High	Yes	Corridor largely undeveloped with a mix of active and recently abandoned agricultural lands. Route 2 runs along right edge of corridor and is a slight encroachment. Entire segment good candidate for protection and passive restoration to restore floodplain access and enhance sediment and nutrient attenuation within
R32A	Plant Stream Buffer - along entire right bank and ~500 feet of left bank along downstream end	High	High	Yes	Reach incised with anticipated widening/erosion possible in the future, planting efforts should be concentrated along more stable sections of reach or placed to accommodate for future widening
R32B	Protect River Corridor - Left Side of Segment B	High	High	Yes	Route 2 runs along right bank for entire segment acting as encroachment. Left Corridor currently undeveloped with a mix of active and recently abandoned agricultural lands. Left corridor is a good candidate for protection and passive restoration to enhance floodplain access and increase sediment and nutrient attenuation within watershed and reach especially as it is immediately downstream of village.
R32B	Plant Stream Buffer - Large portions of segment have little to no woody buffer	High	High	Yes	Reach slightly incised with active widening/erosion, planting efforts should be concentrated along more stable sections of reach or placed to accommodate for future widening

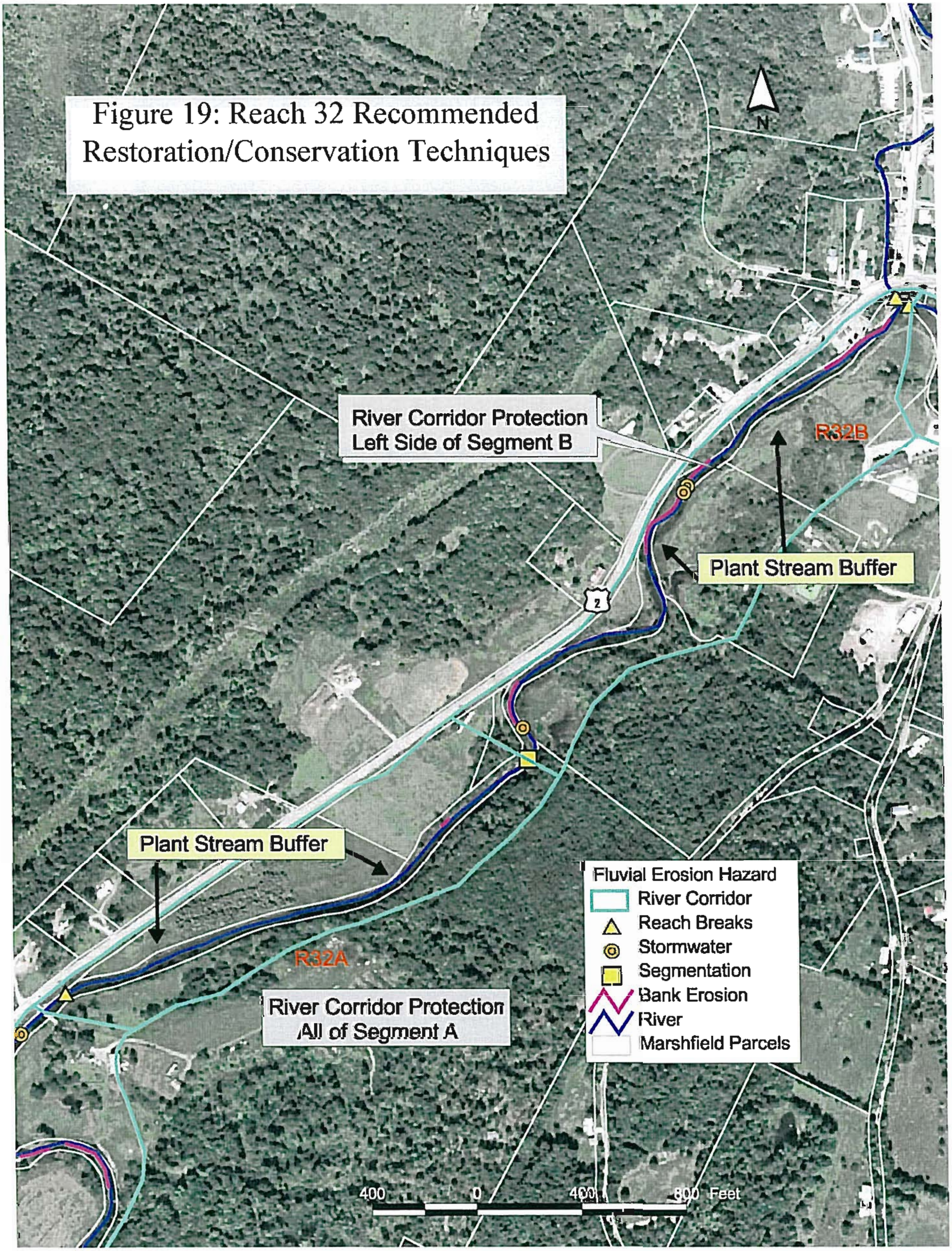


Figure 19: Reach 32 Recommended Restoration/Conservation Techniques
N
River Corridor Protection Left Side of Segment B
R32B
Plant Stream Buffer
2
Plant Stream Buffer
R32A
River Corridor Protection All of Segment A
Fluvial Erosion Hazard
River Corridor
Reach Breaks
Stormwater
Segmentation
Bank Erosion
River
Marshfield Parcels
400
0
400
800
Feet

5.1.6 Reach 33 Description and Project Identification

Reach 33 extends upstream from Creamery Street through Marshfield village to the bridge on Route 2 just east of the Route 215 intersection. The Reach is comprised of a highly confined section of the river dominated by residential development associated with Marshfield village. It was segmented into three parts, 33A, 33B, and 33C, due to differences in channel dimensions. The middle segment, 33B, was not assessed as it is comprised of impounded water behind a dam. Both segments A and C have been extensively straightened and armored to accommodate the development of the village. Overall, both segments are undergoing adjustments similar to other downstream reaches in that they have incised (cut down in their bed) reducing access to their historic floodplain. Both segments had relatively poor habitat scores, with narrow riparian buffers. Much of the river corridor is dominated by residential development, except for a small portion of the left bank along the downstream end of segment A.

Given the large amount of encroachment and human investments in Reach 33, the restoration and conservation options are quite limited. In order to maintain current development within the village, the river will need to be managed in its current state, and continue to be confined to the straightened and armored channel it now occupies. Table 10 and Figure 20 summarize the preferred restoration/conservation techniques for the Reach. One potential area for restoration is at the downstream end of Segment A, along the left bank, where a berm currently limits floodplain access to one of the few undeveloped areas within the reach. Removal of this berm, would restore floodplain access, provide sediment and nutrient storage, and reduce flooding hazard to other areas within the river corridor. Enhancing the riparian buffer is also important in this reach to filter out stormwater runoff from the village and improve wildlife habitat.

Table 10: Projects and Practices Table - Upper Winooski Watershed
Reach 33

River Segment	Restoration/Conservation Technique	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps/Project Notes
R33A	Remove berm located along left bank near downstream end of reach	High	High	Yes	Berm limits floodplain access. Remainder of reach is highly developed, location immediately downstream of current development makes this strategic location. Survey and Phase III assessment needed prior to design,
R33A	Plant Stream Buffer	Medium	Medium	Yes	Reach relatively stable with extensive armoring, planting efforts should be done to improve habitat, filter nutrients, and aid in streambank stabilization
R33C	Plant Stream Buffer - right and left banks downstream of Gilman Street	Medium	Medium	Yes	Reach relatively stable with extensive armoring, planting efforts should be done to improve habitat, filter nutrients, and aid in streambank stabilization

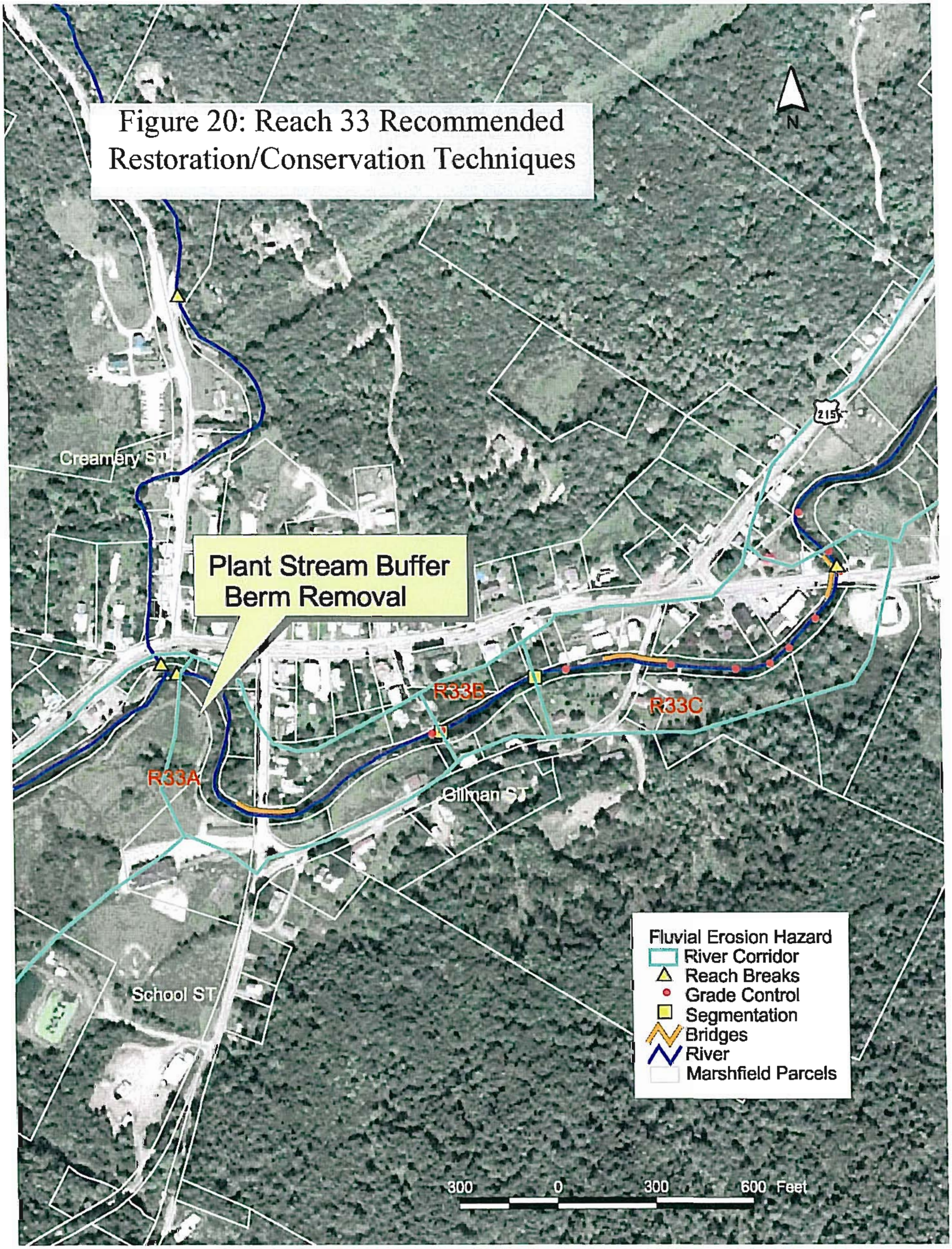


Figure 20: Reach 33 Recommended Restoration/Conservation Techniques

5.1.7 Reach 34 Description and Project Identification

Reach 34 extends from just east of the Route 2 and 215 intersection upstream along Route 215 for approximately ½ mile. Reach 34 was found to be relatively stable, though evidence of previous adjustments was observed. Historically, the stream has cut down in its bed, though more recent sediment build up has restored connection to its historic floodplain. The channel has been extensively straightened in the past, to accommodate Route 215 and agricultural development. A large portion of the reach has been rip-rapped to prevent bank erosion. This reach is directly downstream of the outlet from Molly's Falls reservoir, so sees a large increase in flow during periods of power generation. The riparian corridor was dominated by agricultural land, and limited residential development in the lower portion of the reach. The aquatic habitat was generally poor, with limited buffers up to 25 feet wide.

Table 11 and Figure 21 show the preferred restoration and conservation techniques for Reach 34. Like most of the other reaches in the study area, river corridor protection and buffer enhancement should be the main focus for this reach. Though the reach is not currently incised and has adequate floodplain connection, protecting the river corridor is important to maintain these sediment and nutrient attenuation assets. This reach is in a strategic location, immediately upstream of Marshfield village, so maintaining adequate floodplain here is important and will help prevent flood damage downstream. Much of the reach lacks adequate riparian buffer, so buffer planting is another important restoration technique for Reach 34.

Table 11: Projects and Practices Table - Upper Winooski Watershed
Reach 34

River Segment	Restoration/Conservation Technique	Reach Priority	Watershed Priority	Completed Independent of other Practices	Next Steps/Project Notes
R34	Protect River Corridor - Left bank along upstream half, right bank along downstream half	High	High	Yes	Corridor currently undeveloped with a mix of active and recently abandoned agricultural lands. Route 2 runs along right bank and represents a constriction, but large portion of corridor still available for protection. Reach currently has good floodplain access so protection intented to limit prevent development and maintain sediment and flow attenuation asset in critical location upstream of village.
R34	Plant Stream Buffer	Medium	Medium	Yes	Streambanks relatively stable with extensive armoring and some buffers up to 25 feet wide, planting efforts should be done to improve habitat, filter nutrients, and aid in streambank stabilization

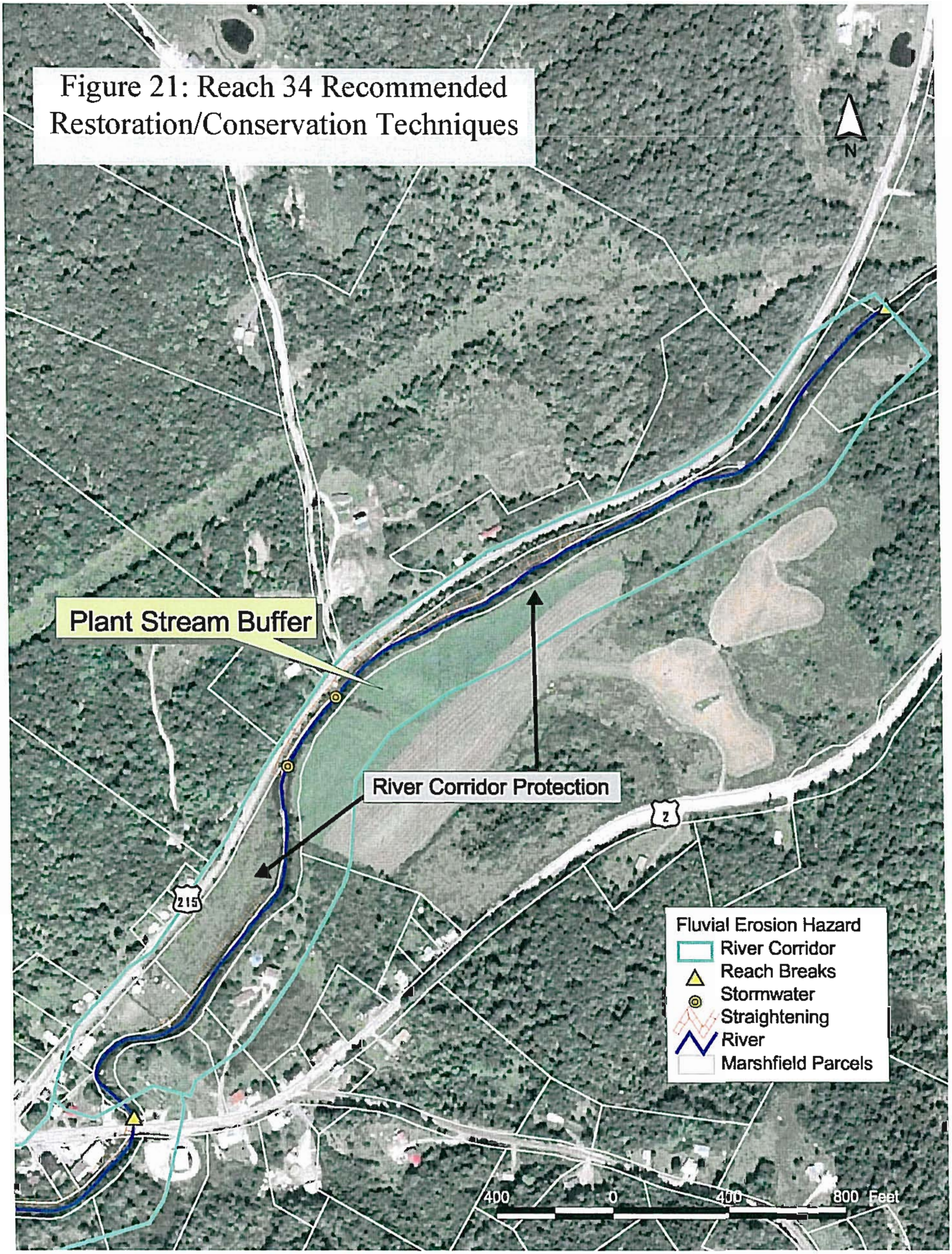


Figure 21: Reach 34 Recommended Restoration/Conservation Techniques

5.2 PROJECT PRIORITIZATION

Historically, most of the study area acted as a sediment and nutrient attenuation zone, where incoming fine sediments from upstream were stored on the floodplain, and inputs of coarse sediment were equal to outputs of coarse sediment. Due to the historic and ongoing adjustment processes and stressors documented in the watershed, it has largely been transformed into a sediment and nutrient source and transport zone where floodplain access is limited and sediment and nutrients are funneled through the system to downstream receiving waters. Given these stressors and current and predicted future adjustments, the highest priority projects are those that attempt to restore the sediment and nutrient attenuation assets which once dominated the system. Other important project types include riparian buffer enhancement to filter out excess nutrients, help stabilize streambanks, and provide shade, cover, and overall improvements to aquatic habitat, replacement of undersized bridges and culverts to reduce channel constrictions, and restore normal flow patterns, and removal of berms, dams, or other encroachments which limit floodplain access. The Upper Winooski watershed in Marshfield is fairly unique in that it is still largely undeveloped and provides opportunities for river corridor restoration. Obviously, there is a large amount of human investment within the river corridor in homes, businesses, and agricultural lands, but the goals of this and other river corridor plans is to find areas within the watershed where a balance can be reached between these human investments and the health and wellbeing of river systems. Table 12 below lists potential projects in the Upper Winooski River corridor in order of recommended priority. It is important to note that this Table is an ever-evolving document and that current priorities can change over time. For the purposes of this Plan, projects were prioritized first upon technical feasibility, and overall benefit to the system (sediment and nutrient attenuation, habitat improvement, and re-establishment of geomorphic equilibrium). Other considerations taken into account were social feasibility, current landowner involvement, amount of additional investigation necessary to complete the project, as well as overall relative costs.

Table 12 Corridor Planning Project and Strategy Summary Table Winooski River - Marshfield

Project # (Figure #)	Reach/Segment Condition-Sensitivity	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority	Other Social Benefits	Cost	Land Uses Conversion & Landowner Commitment	Potential Partner Commitments
1 (13)	30A - Fair-Very High	Incised reach immediately upstream of straightened R29. R29 has large sediment deposition and many roads, homes, businesses in corridor. R30A largely undeveloped agricultural land with extensive erosion and planform adjustments	River corridor protection and passive floodplain restoration; buffer establishment and arresting of 3 head cuts	Feasible; river corridor undeveloped, high watershed priority	Wildlife habitat improvement, possible demonstration project for other reaches, landowner contacts already initiated by FWR	Easement transactions, buffer planting costs, CREP programs, minor construction costs for grade control installation	Active and recently abandoned ag land to floodplain and buffer, FWR has initiated landowner contact with some landowners so far initial response positive	FWR, VT RMP, NRCS, F&W
2 (13)	30B - Fair-Very High	Incised reach upstream of straightened R29. R29 has large sediment deposition and many roads, homes, businesses in corridor. R30B largely undeveloped agricultural land with extensive erosion and planform adjustments	River corridor protection and passive floodplain restoration; buffer establishment and arresting of 4 head cuts	Feasible; river corridor undeveloped, high watershed priority	Wildlife habitat improvement, possible demonstration project for other reaches, landowner contacts already initiated by FWR	Easement transactions, buffer planting costs, CREP programs, minor construction costs for grade control installation	Active and recently abandoned ag land to floodplain and buffer, FWR has initiated landowner contact with some landowners so far initial response positive	FWR, VT RMP, NRCS, F&W
3 (11)	28 - Fair-Very High	Highly incised reach almost entirely on town owned land - current plans call for area to be converted to park/recreation area	River Corridor protection and active or passive floodplain restoration; buffer establishment and arresting 1 head cut	Feasible; river corridor undeveloped and on public land, high watershed priority	Wildlife habitat improvement, possible demonstration project encorporated into development plans with town conservation commission	Easement transactions, buffer planting costs, CREP programs, if active floodplain restoration considered then design and construction costs, minor construction costs for grade control installation	Recently abandoned fallow agricultural fields to river corridor floodplain and buffer; plans already in place for conversion to rec space; FWR already has made contact with Town	FWR, VT RMP, NRCS, F&W, Marshfield Town officials
4 (14)	31B - Poor-Extreme	Highly incised reach with large amount of erosion and in-channel sediment deposition	River Corridor protection and active or passive floodplain restoration; buffer establishment	Feasible; river corridor largely undeveloped agricultural land, high watershed priority	Wildlife habitat improvement, sediment and nutrient attenuation	Easement transactions, buffer planting costs, CREP programs, if active floodplain restoration considered then design and construction costs	Agricultural fields and pasture to floodplain and buffer	FWR, VT RMP, NRCS, F&W

Project # (Figure #)	Reach/Segment Condition-Sensitivity	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority	Other Social Benefits	Cost	Land Uses Conversion & Landowner Commitment	Potential Partner Commitments
5 (14)	31A - Poor-Extreme	Highly incised reach with large amount of erosion	River Corridor protection and active or passive floodplain restoration; buffer establishment	Feasible; river corridor largely undeveloped agricultural land, high watershed priority	Wildlife habitat improvement, sediment and nutrient attenuation	Easement transactions, buffer planting costs, CREP programs, if active floodplain restoration considered then design and construction costs	Agricultural fields and pasture to floodplain and buffer	FWR, VT RMP, NRCS, F&W
6 (15)	32A - Fair-High	Incised reach with extensive historic straightening, little bank erosion currently, corridor encroachment by Route 2	River Corridor protection and passive floodplain restoration; buffer establishment	Somewhat feasible; river corridor largely undeveloped ag land but Route 2 encroachments limit available corridor, high watershed priority	Wildlife habitat improvement, sediment and nutrient attenuation	Easement transactions, buffer planting costs, CREP programs	Agricultural fields and pasture to floodplain and buffer	FWR, VT RMP, NRCS, F&W
7 (15)	32B - Fair-High	Slightly incised reach immediately downstream of village, right corridor dominated by Route 2 and houses, left corridor open land	River Corridor protection and passive floodplain restoration; buffer establishment	Somewhat feasible; river corridor partialy undeveloped ag land but Route 2 and homes limit available corridor along right side, high watershed priority	Wildlife habitat improvement, sediment and nutrient attenuation	Easement transactions, buffer planting costs, CREP programs	Agricultural fields and pasture to floodplain and buffer	FWR, VT RMP, NRCS, F&W
8 (17)	34 - Fair-Very High	Relatively stable reach with good floodplain access immediately upstream of village, slight corridor encroachment from Route 2	River Corridor protection and buffer establishment to retain sediment and nutrient attenuation and flood water retention potential upstream of village	Feasible; river corridor largely undeveloped agricultural land with slight encroachement from Route 2, high watershed priority	Wildlife habitat improvement, retain sediment and nutrient attenuation	Easement transactions, buffer planting costs, CREP programs	Agricultural fields to buffer	FWR, VT RMP, NRCS, F&W

Project # (Figure #)	Reach/Segment Condition-Sensitivity	Site Description including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority	Other Social Benefits	Cost	Land Uses Conversion & Landowner Commitment	Potential Partner Commitments
9 (16)	33 - Fair-Low	Entrenched relatively stable reach within Marshfield village	Berm removal along left bank near downstream end of reach, beyond berm is one of few areas in reach not developed and could provide sediment and nutrient attenuation; buffer enhancement	Feasible; remainder of reach is entrenched and encroached upon by village, low watershed priority, high reach scale priority	Sediment and nutrient attenuation, flood water retention capacity during flood events	Design and construction costs, buffer planting/CREP programs	Agricultural fields to buffer/floodplain	FWR, VT RMP, NRCS, F&W
10 (12)	29 - Fair - Very High	Aggrading reach, multiple encroachments including roads, businesses, homes, historic transport reach, now depositional	Protect existing corridor from further development; stream buffer enhancement; stabilize eroding streambanks (2) along Route 2	Feasible; reach already encroached upon by development, infrastructure needs to be maintained, low watershed priority	Wildlife habitat improvement, protect critical infrastructure	Buffer planting costs, design and construction costs for hard engineering	Residential and ag land to buffer	FWR, VT RMP, NRCS, F&W
11 (11)	28 - Fair- Very High	Highly incised reach almost entirely on town owned land - current plans call for area to be converted to park/recreation area, undersized covered bridge abutments	widen existing abutments to remove constricion	Somewhat feasible; plans already in place to place existing covered bridge on original location; low watershed priority, localized benefits	Demonstration project on properly sized structures	Design and construction costs		FWR, VT RMP, NRCS, F&W, Marshfield Town officials
12 (13, 14)	30B & 31B	Undersized farm bridge in each reach, both incised with extensive erosion	widen and or replace current undersized structures	Feasible; low watershed priority, localized benefits from removing constriction	Improve infrastructure for landowners	Design and construction costs		FWR, VT RMP, NRCS, F&W

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