WELLS RIVER WATERSHED
RIVER CORRIDOR MANAGEMENT PLAN

WELLS RIVER WATERSHED OF THE CONNECTICUT RIVER BASIN

ORANGE AND CALEDONIA COUNTIES, VT

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1.0 EXECUTIVE SUMMARY

In the summer of 2007, the Caledonia County Natural Resources Conservation District, as part of its grant agreement with the Vermont Department of Environmental Conservation, initiated a project to perform Phase 1 and Phase 2 Geomorphic Assessments in the Wells River Watershed in Caledonia County and Orange County, VT. The Phase 1 part of the project includes portions of the river and its tributaries in Newbury, Ryegate, Peacham, Groton, Topsham, Marshfield, and Plainfield. The Phase 2 portion of the project is comprised of nine reaches in the Town of Newbury.

The Wells River is approximately 22 miles long and drains approximately 100 square miles in the upper portion of the western side of the Connecticut River Watershed. Although comprising less than 1% of the total Connecticut River, the Wells River is an important waterway in its own right. Historically important as a source of energy for mill industry, and for transportation; it is most noted now for its natural beauty, significant fisheries and wildlife habitat, vital natural resources, ecologic integrity, and recreational values.

This draft of a Wells River corridor plan is designed to integrate information from Phase 1 remote sensing evaluation and a limited Phase 2 process involving just the most downstream reaches of the watershed. By assessing underlying causes of channel instability at both watershed and localized scales, management efforts can be directed toward long-term solutions that help curb escalating costs, reduce flood and erosion hazards along the river corridor, improve water quality and aquatic habitat, and enhance recreational opportunities along and in the river. By encouraging the stream's return to equilibrium conditions, conflicts with ongoing stream processes can be avoided
The results of Phase 1 (using remotely sensed data such as topographic maps and aerial photography) and Phase 2 (rapid field assessment) geomorphic assessments of the Wells River are summarized in this report. The results are analyzed through the use of stressor, departure, and sensitivity analysis maps to integrate the findings in an understandable and intuitive manner. This analysis informs a stepwise process designed to identify and catalog technically feasible projects that reduce conflicts with stream dynamics in an economically and ecologically sustainable manner, assess the social feasibility of these projects, and make recommendations for the next steps toward implementation of protection and restoration efforts.

Based on the results of those assessments, the following list of projects, in recommended order of importance, were prioritized:

- Develop a fluvial erosion hazard (FEH) zone and belt-width corridors for the entire Phase 2 project area, and incorporatethese zones into town planning processes, in an effort to protect the vital function of floodplains in providing flow, sediment, and nutrient storage and attenuation,
- Protect and enhance buffer zones in critical areas. Many reaches included in the study area have areas of unbuffered or minimally-buffered banks. In many cases these sections of stream are showing considerable bank erosion. Reach segments

to be included in this project design, in order of priority, include: M06A, M07A, M07B, M09B, M08B, M06B, M04B

- Replace or remove bridge structures identified as channel constrictions, as feasible. Bridges constituting channel constrictions that are causing deposition are found in reaches M01, M04B, and M04S3.01. M01 bridges are significant structures and replacement of these is only recommended as needed. The bridge in M04B is a private bridge that is not currently being used and shows considerable decay. This should be replaced or removed. The bridge in M04S3.01is on the railroad pathway maintained by Fish and Wildlife. This bridge looks fairly new, and there is a considerable wetland upstream that can handle backed up stream flow. This bridge should be resized when it is time to rebuild it.
- Stabilize the stream bank and re-direct flow from vulnerable outside meander bend (upper bend) in the village of Wells River. There is significant water pressure on this bank at the turn and the village side of the river is bermed to protect against flooding there. It may be reasonable to place a rock vein in this area to re-direct flow into the center of the river and away from this bank. At the same time, the bank should be stabilized.

Analysis contributing to these recommendations indicates that:

- Portions of the watershed included in the Project area, under equilibrium conditions, would provide flow, sediment, and nutrient storage and attenuation in most stream reaches (reaches are portions of a stream with similar characteristics in terms of channel geometry, valley, and floodplain settings)
- Many of these stream reaches have lost access to historical floodplains due primarily to extensive straightening and channelization, which has led to increased stream power that has historically incised (cut down) through erodible bed materials.
- Portions of all the included reaches are now functioning as transport reaches that transfer flow, sediment, and nutrient loads to downstream portions of the watershed. Sediment loads are being deposited upstream of natural and artificial constrictions, at meander bends, in impoundment areas upstream of hydroelectric dams, and upstream of bedrock control features; all these features reduce stream power sufficiently to accelerate deposition.
- Loss of access to floodplain means that greater flows are now contained within the channel during high flow events; channelization means the stream now diffuses less of its power through meander patterns.
- With interrupted sediment transport and limited access to coarse sediments (dam impoundments interrupt transport, and mainstem stream banks are dominated by fines) stream power is increased in downstream reaches, elevating the danger of erosion where banks are vulnerable.
- A passive restoration approach is generally recommended for the Project area due to low cost, moderate land-use conflicts, and high to extreme stream sensitivity (indicating the rate at which the river will return to dynamic equilibrium given its own energy and watershed inputs). This approach will reduce costs for project implementation in comparison with active floodplain or meander restoration, or

approaches such as continued channelization or armoring, but will require an emphasis on protection of the river corridor to reduce conflicts between land use and stream evolution processes. The primary goal will be to regain access to floodplains and to reestablish stream meander geometry; both intended as a means of diffusing stream power and permitting greater nutrient and sediment storage within the watershed.

- Opportunities for floodplain access and meander reestablishment have already been limited in certain reaches by extensive road encroachment and development. Limiting further development in floodplain and riparian corridor areas will help avert further conflicts with inevitable river dynamics.
- Most reaches in the Project area are at a stage of channel evolution marked primarily by incision.
- Channel evolution is likely to progress to widening and lateral migration, wherever possible, increasing the susceptibility of corridor encroachments to flash flooding scenarios (as opposed to inundation flooding), and escalating costs for installation and maintenance of traditional management approaches. It is highly recommended that the Town of Newbury explore incorporation of FEH zones into town planning processes. Options might include setbacks, buffers, zoning overlay districts, or similar mechanisms.
- Traditional channel management in response to erosion and lateral migration has often entailed further channelization, gravel removal, and riprapping or hard armoring of banks for stabilization. These approaches have elevated both upstream and downstream impacts of increased stream power, and localized sediment deposition, filling of pools. The formation of planebed features appears common in slackwater areas and overwidened portions of the channel. Five reach segments in the project area exhibit planebed features.
- The Wells River watershed contains important agricultural lands, and an essential aspect of protection and restoration will involve development of fair and equitable solutions to allow floodplain access and protection of key attenuation assets in areas of high-value agricultural lands.
- Vegetated stream buffers will be important to the success of most protection and restoration activities in the watershed, where bank materials are often highly erodible. Planting activities can be completed independent of many other projects, and should focus on low-cost approaches.
- Land-use conflicts are elevated in portions of this watershed. Achieving stream channel equilibrium in these areas may not be a reasonable goal, but reducing conflict is critical and can only be achieved through protection of attenuation assets and movement towards stream equilibrium in other parts of the project area. Continued channel management in developed areas should be balanced with increased protections for the stream corridor elsewhere.

2.0 INTRODUCTION

Vermont's rivers and streams have a long history of being utilized and impacted by humans, and dramatic changes in the landscape have resulted over the last two hundred years. Long-term processes resulting from this history of interaction and mounting concerns about the potential effects of a changing climate increase the need to acknowledge and understand the escalating level of investment required to rebuild and/or protect property and livelihoods from damage caused by weather events or by erosion and nutrient loading on ecosystems and recreational resources. With increasing recognition of this situation, and informed with data from geomorphic assessments, communities have the opportunity to reduce conflict with rivers and streams by practicing management that favors an equilibrium between the power of moving water and the transport and storage of sediment that is held within that water (Vermont Agency of Natural Resources-River Management Program (VT ANR-RMP) 2006). Understanding the balance of these forces at a watershed scale, and the fact that occurrences in any portion of a watercourse are linked to processes unfolding in other parts of the watershed over intervals of both space and time, are critical to successful implementation of such management practices. The time and thought that go into this work may transform perpetually frustrated attempts at control, with often unanticipated consequences, to enjoyment of enhanced, vital resources.

2.1 PROJECT OVERVIEW

The Wells River drains into the upper Connecticut River Basin. Encompassing 100 square miles, it comprises less than 1% of the Connecticut River watershed. With a total stream length of 22.36 miles, the Wells River begins in Peacham, flows through Groton, Ryegate, and Newbury, where it converges with the Connecticut River in Wells River village. The river flows primarily through forest and farmland, as well as through the villages of Ryegate and Wells River.

The village of Wells River is in the northeast corner of the Town of Newbury, Vermont, at the confluence of the Connecticut and Wells Rivers. With these two major water sources to use for generating power and for transportation, this village was central to many industrial activities in the late 1800s and early 1900s. The was a major sawmill in town, as well as fulling and grist mills (Delaittre, 1983).

The first railroad to arrive in Wells River was the Connecticut and Passumpsic River Railroad in 1848. Two years later, this line was extended to St. Johnsbury, thus connecting northern Vermont to industrial centers and markets in the south. In 1858, the major east-west railroad line, the Boston Concord and Montreal Railroad, reached Wells River. The Montpelier and Wells River Railroad, completed in 1873, helped secure Wells River's position as an important railroad junction.

Although the fortunes of the village were dependent for many years upon the two rivers, it is ironic that these same rivers often brought great misfortune. Over time, Wells River village has frequently flooded (Figure 3), sometimes damaging or obliterating essential bridges. In the flood of November 1927, the Wells River flooded down mainstreet. Vermont's worst recorded flood to date, the 1927 flood caused 55 deaths and $13,500,000 of damage in the State of Vermont. The loss of life and property during this event was greater than any other flood in New England. The most recent flooding events on the Wells occurred in 1973 and 1983, when water rose over the banks in downtown Wells River Village and flooded Main Street (pers. comm. May, 2009, Joe Provost, Wells River Highway Department). There have been flooding events on the Wells River in the last 25 years, although the summer of 2008 had some of the highest water levels on record.

Several grassroots community groups have formed to promote and protect the Wells River watershed. SEWeR (aka Save Everyone's Wells River) was born in 1992 to fight the Casella unlined landfill (built in the 1970s) in an effort to stop expansion and force cleanup (pers. comm. June, 2008, Alice Allen, community activist).

The group made it into environmental court twice, managing to stop proposed landfill expansion. The landfill is now closed. Leach sites are currently being monitored by the State of Vermont, but cleanup activities have not yet been initiated.
In 2004, a summer program, funded by a Vermont Watershed Grant and supported by the White River Natural Resources Conservation District, was developed to help students from towns along the Wells River explore and investigate how five different developments over the past 100 years along a one-mile stretch of the Wells River have affected the water quality and flow of the river (http://www.crossvermont.org/BLUE/index.htm). Named Boltonville Land Use Exploration (B.L.U.E), the program was expanded in 2008, when the White River Natural Resources Conservation District B.L.U.E. Program partnered with the Vermont Institute of Natural Science (VINS) and expanded its Conservation Day Camp to include nature activities interspersed with science-based monitoring studies. Hosted on Allan and Alice Al-len's organic dairy farm, children were introduced to a variety of human land uses and learned how these land uses impact water quality and ecosystem health.

As a part of the overall efforts in the watershed, in the summer of 2007 Caledonia County Natural Resources Conservation District, as part of a grant agreement with the Vermont Department of Environmental Conservation, initiated a project to perform Phase 1 and 2 Geomorphic Assessments on the Wells River. This work was conducted by Redstart Consulting, in conjunction with the CCNRCD and ANR RMP (henceforward "the Partners"), in 2008. The Phase 1 process was initiated in late January, 2008, and was completed for 247 reaches. Part way through this process, and partially based on the initial results of that assessment, the Partners chose a selection of prioritized reaches for the Phase 2 assessment process.

The 2008 Wells River Watershed Phase 2 Assessment provides information to prioritize protection and restoration efforts on eight mainstem "reaches" and one tributary "reach" A "reach" is section of river with similar slope and valley setting. These nine reaches comprise roughly 6.29 miles of stream (Fig. 1). The primary goal of the Project is to cooperate with landowners, community members, local towns, and other stakeholders to develop a community-based river corridor management plan for the Wells River and its tributaries that will enhance community and ecological health within the watershed. VT ANR-RMP has been developing the framework for a process to facilitate such a prioritization strategy (VT ANR 2007), and earlier phases of that process helped to identify the reaches selected for inclusion in the Project area. The goal of the River Management Program is to manage, protect, and restore the equilibrium conditions of Vermont rivers by resolving conflicts between human investments and river dynamics in the most economically and ecologically sustainable manner. The objectives include:

1. FEH mitigation;
2. Sediment and nutrient load reduction; and
3. Aquatic and riparian habitat protection and restoration

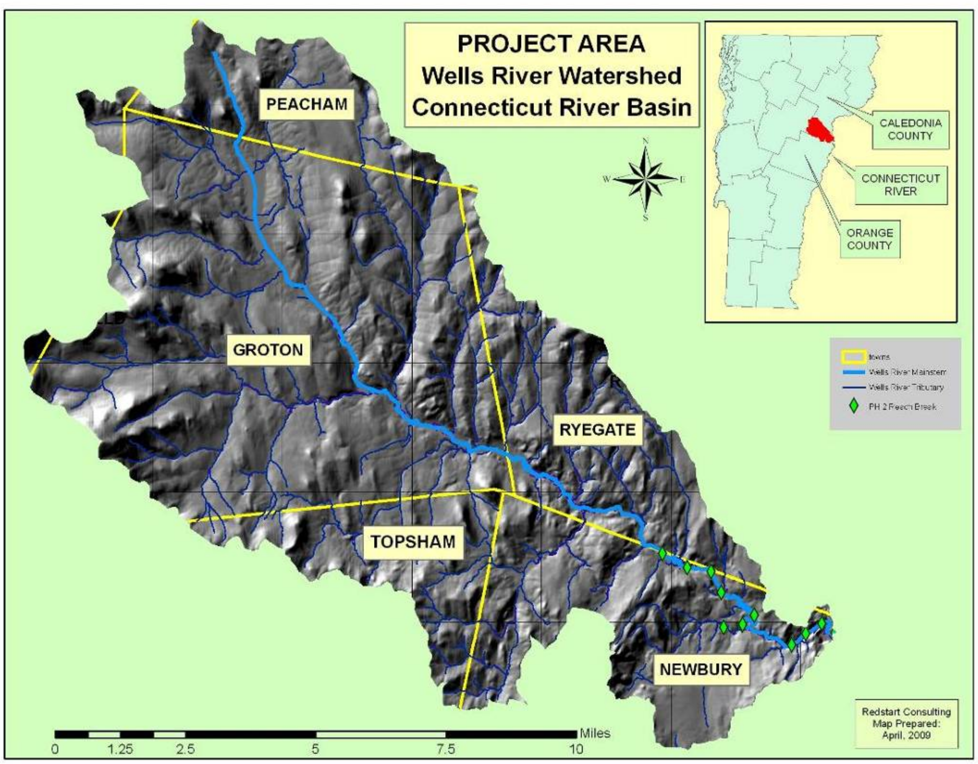

Figure 1: Wells River Watershed. Insert shows the watershed in relation to entire State of Vermont.

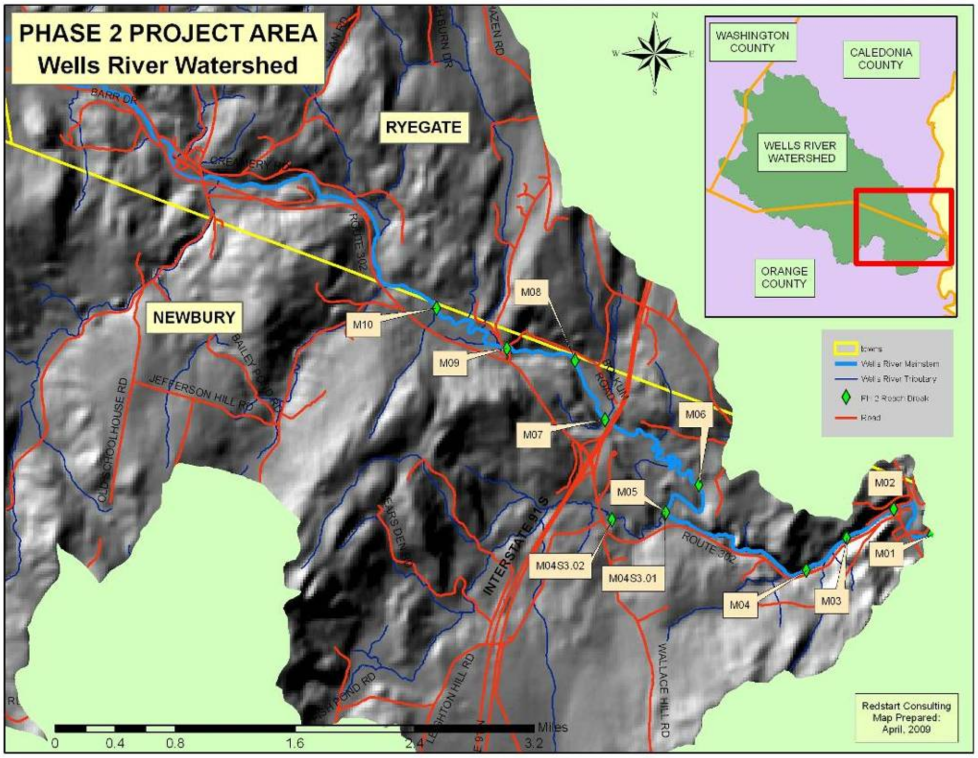

Figure 2. Eight mainstem reaches (M01, M02, M04, M05, M06, M07, M08, and M09) and one tributary reache (M04S3.01) were included in the Wells River Corridor Planning process. Inset shows the location of this area within the entire watershed.

3.0 BACKGROUND INFORMATION

3.1 GEOGRAPHIC SETTING

3.1.1 Watershed description

The Wells River basin is located within the Connecticut River Basin of Vermont and New Hampshire (Fig. 1). The Connecticut River is the largest river in New England, draining 11,250 square miles in the States of Vermont, New Hampshire, Massachusetts, and Connecticut. It has a total length of 407 miles, beginning in the Connecticut Lakes of Northern New Hampshire and flowing south to Long Island Sound in Old Saybrook, Connecticut.

The Wells River watershed drains approximately 100 square miles, or less than 1% of the total watershed area for the Connecticut. It is roughly 22 miles (37 km) long, beginning upstream of Osmore Lake in the town of Peacham. The river flows generally southeast through Osmore Pond, Groton Lake, and Ricker Pond, joins with the North and South Branches in the southeast part of the Town of Groton, continues southeast though the towns of Ryegate and Newbury, finally reaching the Connecticut River at the village of Wells River.

The Vermont portion of the Connecticut River Basin is comprised of 18 tributary watersheds. Vermont's Water Quality Division has separated them into groups to facilitate planning. The Wells River falls in a group that includes the Wells, Waits, Stevens, and Ompompanoosuc Rivers (Basin 14). (http://www.anr.state.vt.us/dec/waterq/planning/docs/pl_basin14)

There are seven large lakes and ponds in the Wells River watershed, including Lake Groton (422 acres), Kettle Pond (109 acres), Ricker Pond (95 acres), Ticklenaked Pond (54 acres), Osmore Pond (48 acres), Noyes Pond (39 acres), and Levi Pond (20 acres). There are numerous large and significant wetlands in the Wells River watershed. The largest wetland, Peacham Bog, is entirely within the Groton State Forest and is protected, but there are many smaller wetlands on private property that also provide important functions and values. Elevations range from roughly 3340 feet along the highest parts of the watershed to 400 feet at the mouth.

The Phase 2 assessment evaluates eight reaches on the mainstem, from the mouth to the town line between Newbury and Ryegate, as well as one reach on an unnamed tributary of the Wells, that has been named Fish Pond Brook for ease of communication during this project.

3.1.2 Political jurisdictions

The Phase 1 project area encompasses the entire watershed, with portions in the towns of Newbury, Rygate, Peacham, Groton, Topsham, Marshfield, and Plainfield (Fig. 1). Topsham and Newbury lie within Orange County; a region covered by Two Rivers-Ottauquechee Regional Commission (Figure 1 inset). The other towns are found in Caledonia County and a tiny part of Washington County. This region is covered by the Caledonia County Conservation District. Phase 2 project reaches in the Wells River basin are all located in the Town of Newbury.

3.1.3 Land use history and current general characteristics

The Phase 2 Project area lies wholly within the Town of Newbury. It flows through forest and farmland to, and through, the village of Wells River. U.S. Route 302 follows the river for most of its length.

The village of Wells River is in the northeast corner of the Town of Newbury, Vermont, at the confluence of the Connecticut and Wells Rivers. These two water sources were determinant factors in the settlement and development patterns of the Town. Both rivers provided water power for mills, and the Connecticut River served as a major highway for transporting goods and facilitating migration throughout northern New England. Although Wells River Village does not have the same broad, expansive intervale farmland as the Villages of Newbury and South Newbury further south, the abundance of water power and easy access to the Connecticut River helped ensure the success of Wells River as a milling center and transportation junction (Delaittre, 1983).

Besides its location along major transportation routes, much of the Village's growth during the first half of the nineteenth century can be attributed to milling activities. A paper mill was constructed on the Wells River in 1808 and, within 50 years, was the largest employer in town. The main street, known as Paper Mill Street, is now what is known as U.S. Route 302. With plentiful supplies of timber surrounding the Village, the lumber business also grew during these years. Numerous sawmills sprang up, shipping lumber south on boats or, later, by rail. Other industries active in the late 1800s and early 1900s included fulling mills, additional grist mills, blacksmithing, brickmaking, a tannery, and slaughter houses.(Delaittre, 1983).

The USDA Forest Service denotes common patterns throughout much of Vermont that are highly applicable for the Wells River watershed area:

> " …low population densities and primarily non-intensive land use likely had minimal impact on the landscape. With the arrival of European immigrants, land-use and settlement patterns after the late 1700s had a more dramatic effect on the landscape and hydrology. "Land clearing, logging, altered stream channels, intensive agricultural practices, home building, and the establishment of road systems created the "classic" Vermont landscape of open hillsides, rural homesteads and stream-side roads and mills…" (USDA-FS 2001).

This description is consistent with photo documentation of Wells River village surrounding landscape (Fig. 3) available through the University of Vermont Landscape Change Program (http://www.uvm.edu/landscape/menu.php).

With industrial development, transportation venues were quick to develop. Water transport was dominant until the arrival of the railroads, beginning in the mid 1800s.

As in most of New England, dams played an important role in the development of the Wells River watershed by providing power for a number of historic mills.
There are at least 13 dams in the watershed, more than half of which are still operational (http://www.anr.state.vt.us/dec/waterq/planning/docs/pl_basin14). Many of these dams are at the outlets to lakes and ponds.There are also two active hydroelectric dams, the Boltonville Dam and the Adams Paper Company Dam, both on the main stem of the Wells River and within the Phase 2 project area. The Boltonville Dam was initially built in 1928; the Adams Paper Company dam, in 1912. Both of these dams were privately redeveloped for hydropower generation (Wells River Hydroelectric, and CHI energy, respectively) in the 1980s. Additional recent or current commercial land use activities in the Project area of the watershed include historic and active gravel mining, and a commercial landfill.

As Wells River village is located on a flood plain (alluvial fan) at the mouth of the Wells River, flooding has inevitably also been part of its history. Major flooding in the village has been recorded for: the late 1800s (Figure 3), 1927, and 1973.

Figure 3. Pictures of Wells River village valley during floods during the late 1800s (top) and in 1927 (middle). Views of distant hills behind Wells River village in the late 1800s show signs of extensive forest clearing (bottom).

Many rivers were affected by straightening and maintenance along valley walls when railroads were built along the rivers in the 19th century, frequently narrowing the valley width significantly and sometimes pinning the river between the valley wall and the bed on which the railroad was built. Within the project area, much of the length of the Wells River (except reach M06), was affected by the building and maintenance of and west-east railroad line. Topographic maps from 1935 show the presence of Route 302 and the railroad line. Currently, within the project area, the railway line is defunct. East of reach M04 segment B, it either no longer exists or has been swallowed up by Route 302. West of this point, there are portions that exist as trails or roadbed.

Though undocumented, it is conceivable that in the days of river transport of logs, the Wells River was straightened and periodically “snagged” (debris removed) to keep the channels clean for efficient transport of logs to the rail line. Evidence of this might be found particularly in reach M05 which abuts the railway and shows significant evidence of straightening and manipulation. Water flows on the Wells have also been significantly regulated, both historically and more recently, by existing dams in the project area.

According to 2002 land cover/land use analysis (UVM-SAL 2002), the Wells River watershed in the early 21st century is 75% forested, with almost half of this comprised of mixed conifer-broadleaf forest. (Fig. 4; Table 1). Agricultural land use in the watershed occupies only 4% of the land base, with half of this in cultivated row crop production. Roughly 15% of the overall watershed land use is comprised of residential and transportation land uses (Table 1). Agricultural and residential uses are concentrated mostly in the valley locations, and to some extent in the uplands of Ryegate and Newbury. Groton is primarily forest land.

Preliminary research indicates that “urban” land use conversions approaching 10% of a subwatershed can be sufficient to be reflected in stream dynamics (Booth and Jackson 1997), and agricultural land use strongly affects hydrology as well (Schilling and Wolter 2005).

Table 1. Wells River watershed land cover/land use from satellite imagery analysis

Category	
Broadleaf forest (generally deciduous)	27%
Coniferous forest (generally evergreen)	13%
Mixed coniferous-broadleaf forest	35%
Water	4%
Forested Wetland	1%
Non-Forested Wetland	1%
Row crops	2%
Hay/rotation/permanent pasture	2%
Residential	9%
Transportation	6%

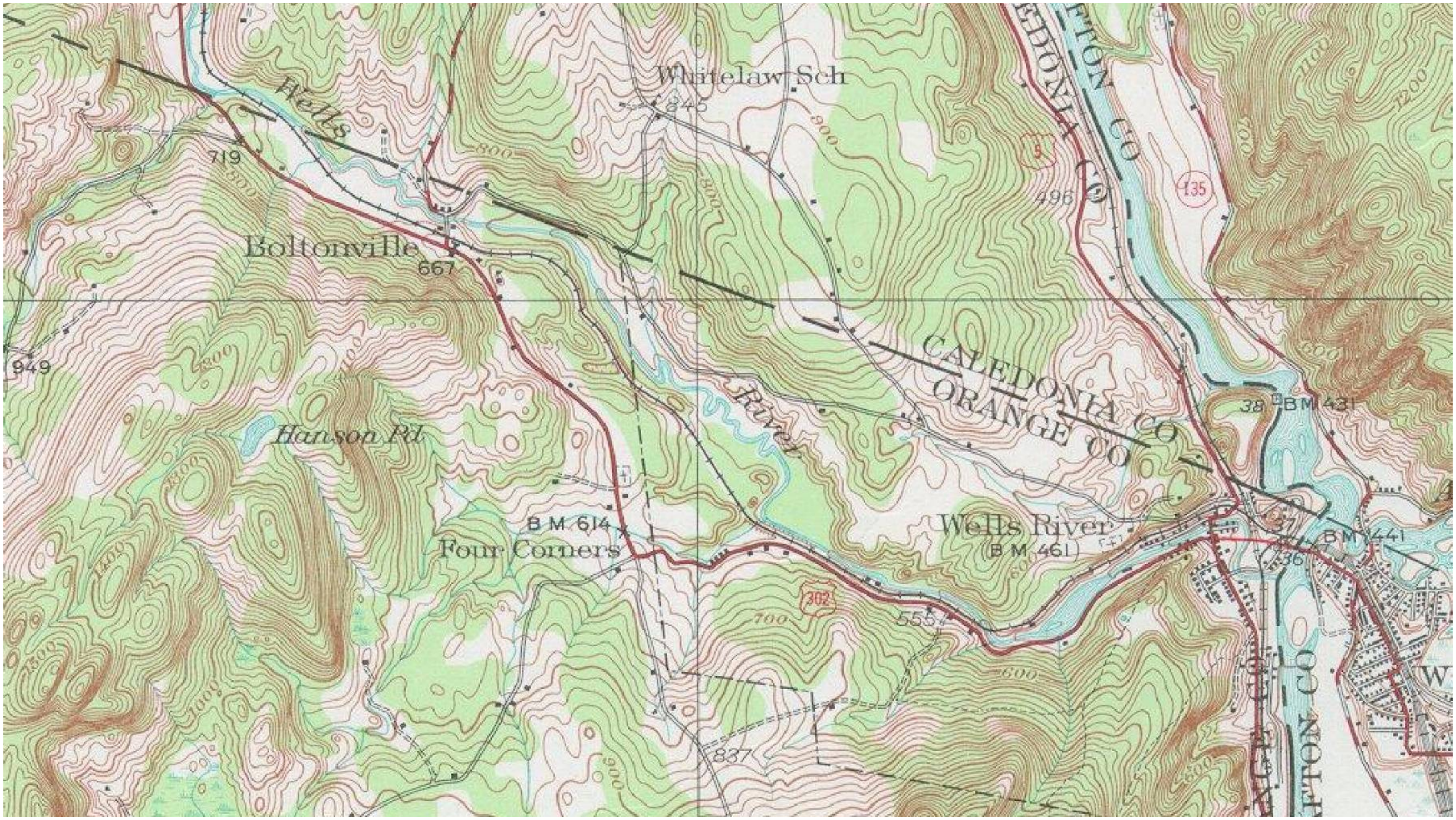

Figure 4: 1935 topographic map of the Project Area region.

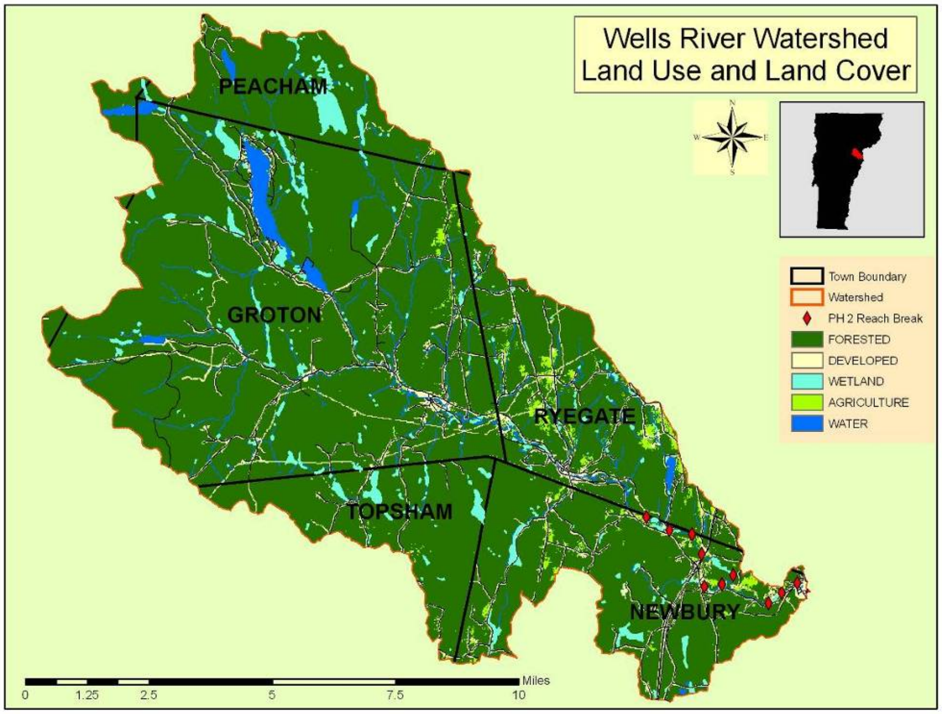

Figure 5: Land cover/land use analysis based on satellite imagery (UVM-SAL 2002) indicates extensive forest cover in the Wells River basin, with agricultural and developed land concentrated along the river corridor and in areas of upland in Newbury and Ryegate.

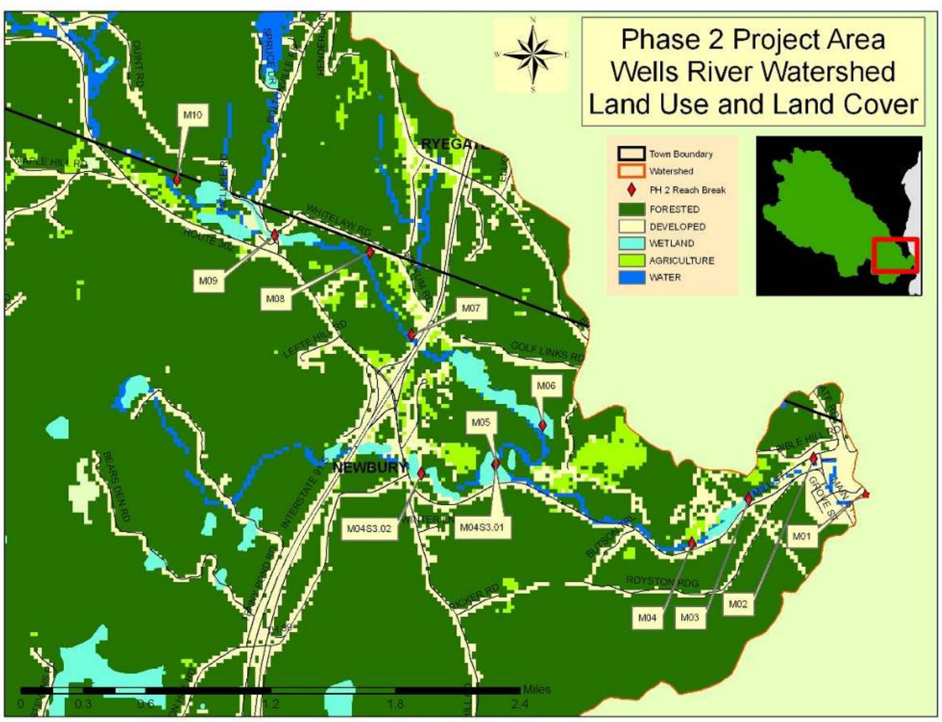

Figure 6: Phase 2 project area land use and cover shows developed land in the corridor for the lower part of the project area and forest, wetland, and agricultural land dominating the corridor in the upper reaches.

3.2 GEOLOGIC SETTING

The Wells River watershed lies within an area divided between two basic bedrock delineations. Silurian-Devonian and Ordivician bedrock units are found in the west and east (respectively)(Fig. 5). Gile and Waits River formations dominate these bedrock units, consisting primarily of metamorphic schists and phyllites, with lesser amounts of slate, limestone, quartizite, greenstone, amphibolite, and other minerals. These rocks were deposited about 400 million years ago as sediments in a warm tropical ocean. Heat and pressure later changed these into metamorphic rocks (around 350 million years ago). This alteration occurred during a collision of the old North American continent with another of the Earth's plates in a mountain-building event.

3.2.1 Surficial geology

In the Wells River region almost all of the surficial materials owe their origin, either directly or indirectly, to the Laurentide ice sheet. The Laurentide ice sheet was the last continental-scale glacier that covered all of New England. It first formed in the Hudson's Bay region of Canada sometime between 80–100,000 years ago. As the climate slowly cooled, the ice sheet grew and advanced slowly towards New England, flowing south and east, across Vermont to New Hampshire and beyond. As the ice sheet advanced and thickened it eventually overwhelmed and completely buried the Green Mountains (as well as the Adirondacks and White Mountains) and, by approximately 23,000 years ago, extended as far south as Long Island. Climate rapidly warmed and the ice sheet responded by thinning and retreating to the north, leaving most of Vermont ice-free by approximately 14,000 years ago. (Wright and Larsen, 2004)

Since the retreat of the glacier, the Wells River and its tributaries have reworked the glacial, glaciofluvial, and glaciolacustrine deposits that were left behind after the glacier melted. As the glacier retreated, a large moraine formed in Connecticut a created an enormous glacial lake (Lake Hitchcock) that stretched from Connecticut to northern Vermont. This glacial lake persisted until approximately 2,500 years ago. Much of the Wells River project area lies within the area flooded by Lake Hitchcock. Since the draining of this lake, lake sediments have been partially washed out of the Wells River valley, often exposing the bedrock below. Many areas have now been overlain by younger alluvium. Further evidence of past glaciation can be seen in the presence of kame and moraine deposits. Most notable in this watershed, is the presence of extensive deposits of the vast Danville Moraine; the largest moraine deposit in New England. Above approximately 600 feet in elevation (the elevation of Glacial Lake Hitchcock), areas not covered by moraine deposit are covered by glacial till, a mixed up combination of many different kinds of rock compacted and crushed under the weight of the glacier.

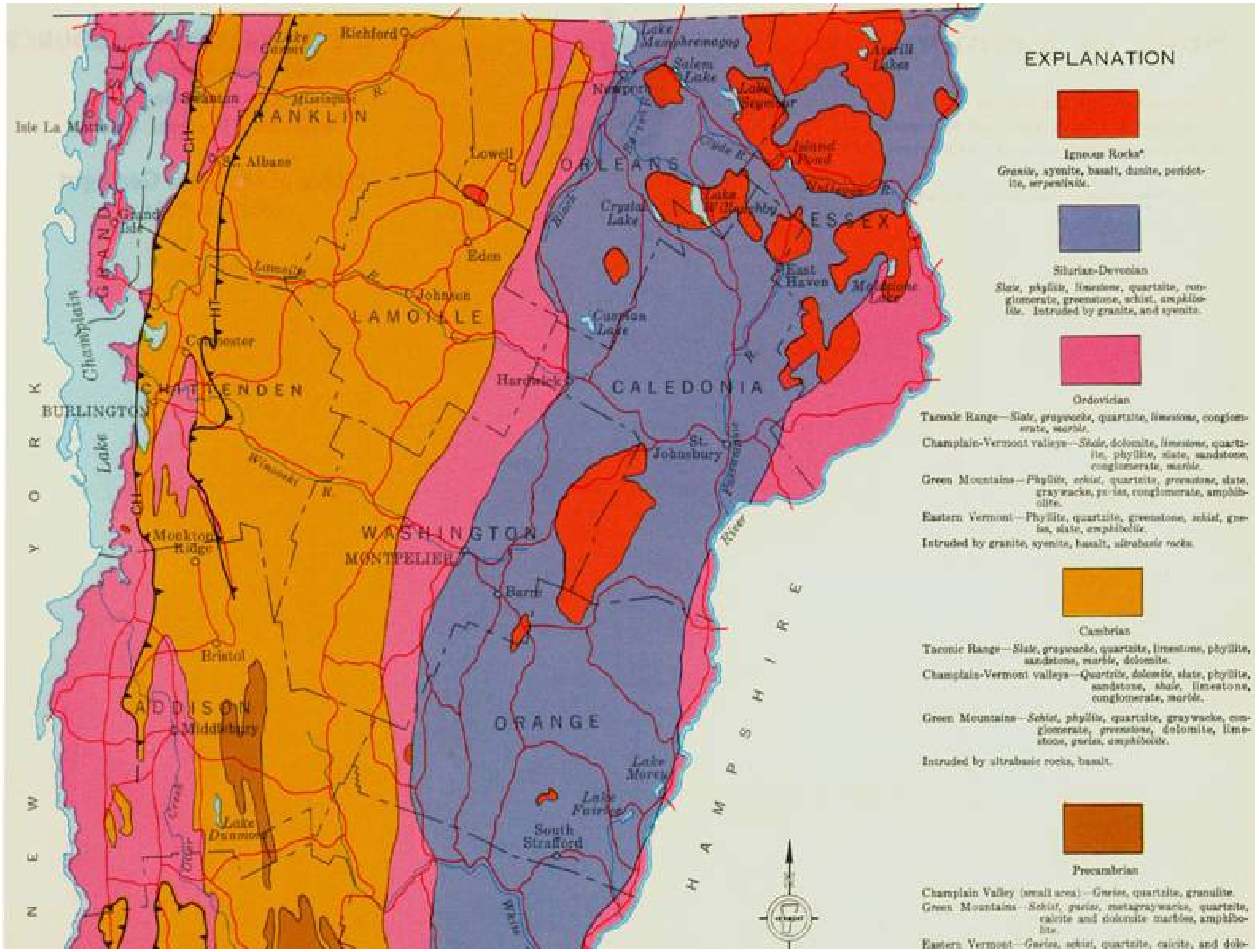

Figure 7: Bedrock geology map for central Vermont.

3.2.2 Soils

The Wells River watershed has two main soil groups. The valley bottoms are dominated by silt and fine to very fine sandy loams of glacio-lacustrine, glacio-fluvial, or fluvial origin. Hillsides and headwaters are dominated by glacial till soils, such as the well to moderately well-drained Tunbridge-Vershire and Vershire-Glover complexes, or by somewhat poorly drained hardpan soils such as Cabot silt loam (NRCS, 2003). Soil formation is dependent on both the bedrock and the surficial geology. The calcium-rich waters of the ancient ocean left soils that support maple trees and rich woods on the Gile Mountain and Waits River Formations. There is a wide mix of hydrologic soil groups within the project area (NRCS, 2003). NRCS hydrologic groups A and B are most common, together dominating seven of the nine reaches. Hydrologic group A soils have high permeability with high infiltration and low runoff potential. Hydrologic Group B soils have a moderate infiltration rate and moderate runoff potential. Group A soils tend to be deep and sandy. Group B soils are moderately deep and have moderately fine texture to moderately coarse texture. Hydrologic Group C is also fairly common in the project area, occurring in five reaches and dominating two of those. These soils have a slow infiltration rate and consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. Hydrologic Group D is less common overall, but is found in four reaches. This group has a very slow infiltration rate and high run-off potential. These soils consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. Reach-level watershed and corridor geologic and soils details can be found in Table 2.

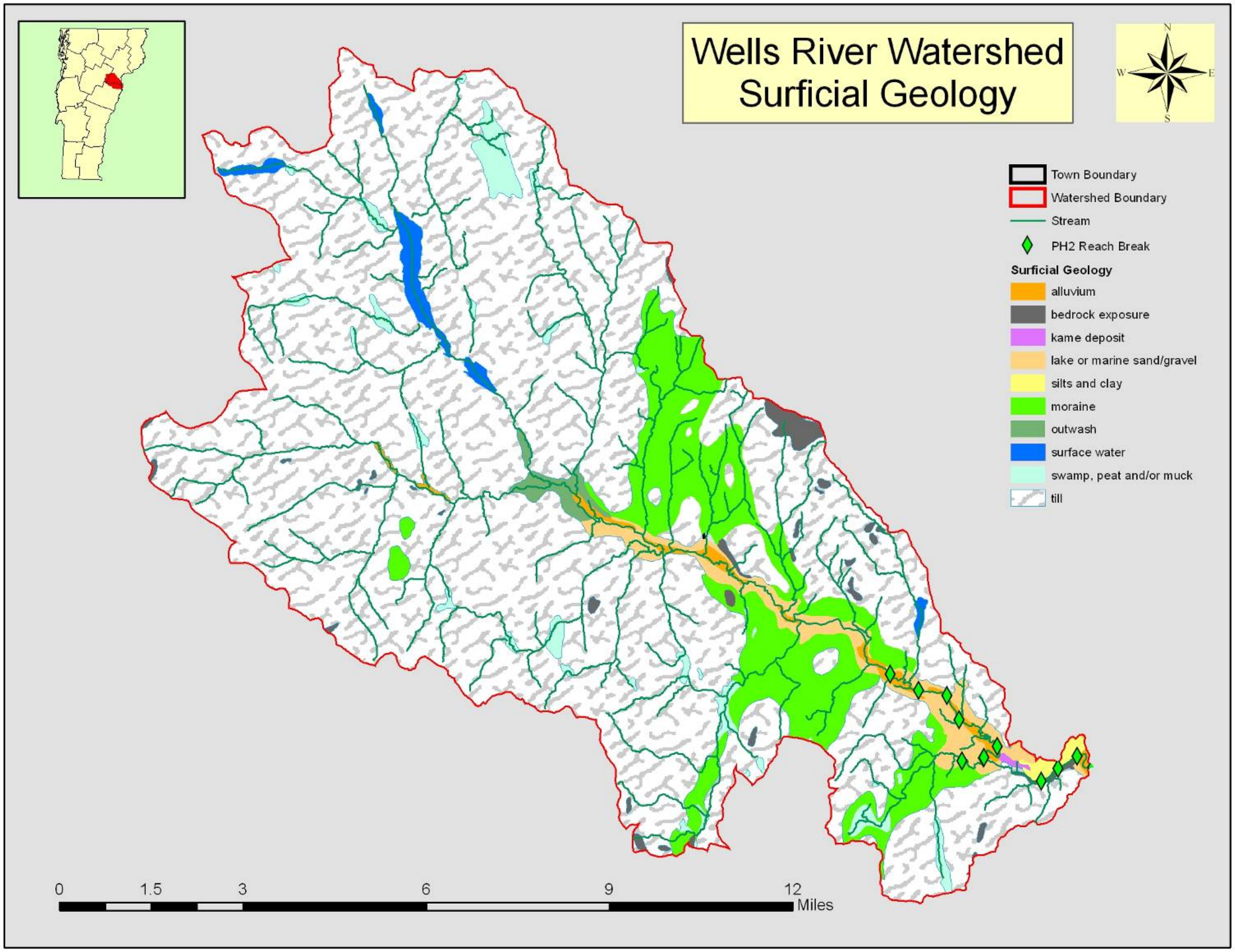

Figure 8: Surficial Geology in the Wells River Watershed

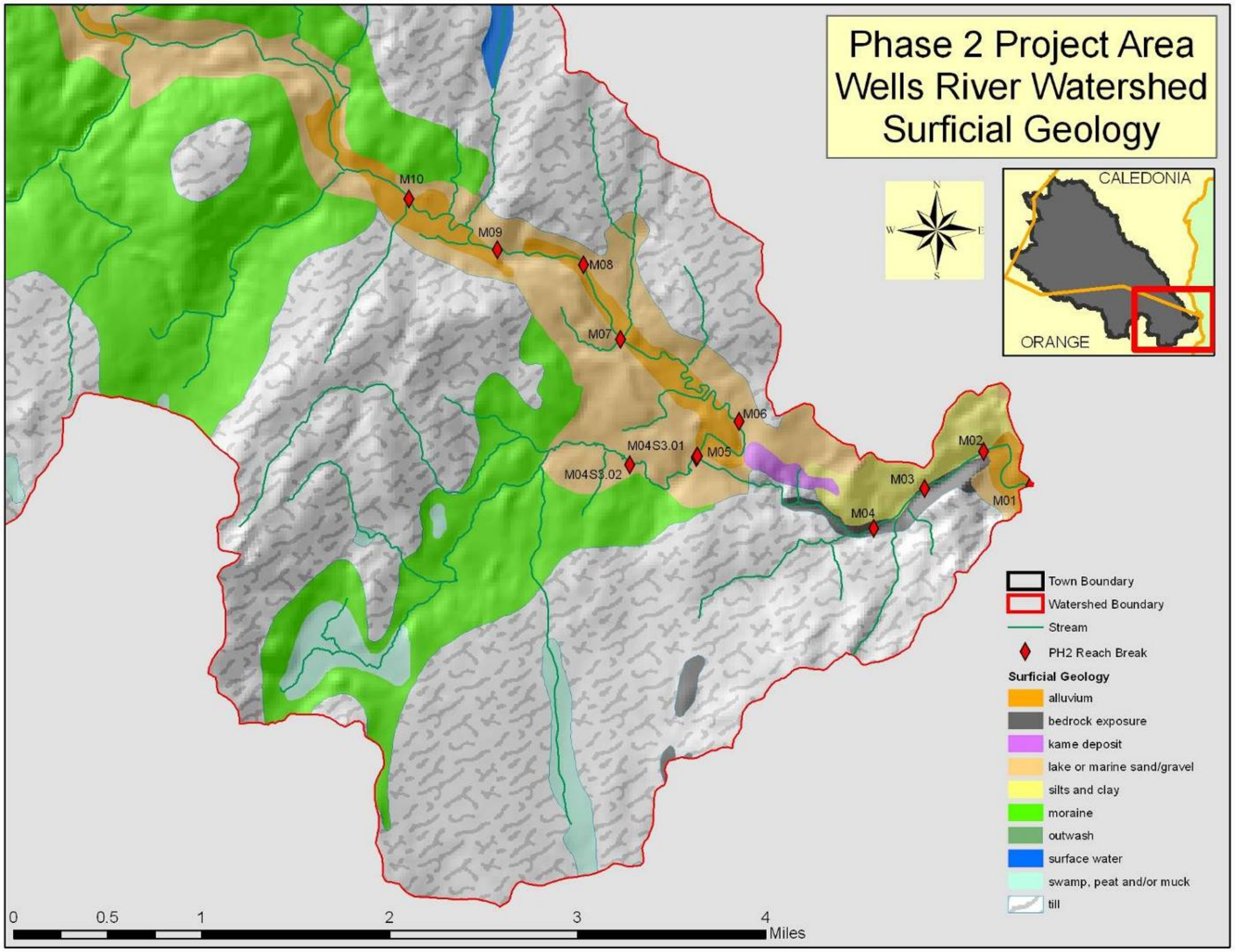

Figure 9: Surficial Geology of the Wells River Phase 2 Project Area

Table 2. Wells River watershed geology and soils for 2008 Phase 2 reaches (excerpted and combined from Phase 1, Step 3 (geology) and Step 3.5 (soils) analyses. "%" indicates the dominant portion of a soil complex characterized by the stated rating.

	Geologic Materials			Valley Sideslope		Soils	
Reach ID	**Dominant**	**%**	**Subdominant**	**Left**	**Right**	**Erodibility**	**%**
M01	Ice-Contact	47.0	Alluvial	Hilly	Hilly	Severe	53
M02	Till	96.0	Ice-Contact	Extremely Steep	Extremely Steep	Very Severe	98
M04	Till	45.0	Ice-Contact	Very Steep	Extremely Steep	Very Severe	91
M05	Ice-Contact	55.0	Alluvial	Steep	Very Steep	Severe	51
M06	Alluvial	81.0	Ice-Contact	Extremely Steep	Steep	Slight*	16
M07	Alluvial	82.0	Ice-Contact	Steep	Extremely Steep	Slight	16
M08	Aluvial	78.0	Ice-Contact	Extremely Steep	Extremely Steep	Slight	14
M09	Aluvial	81.0	Till	Steep	Steep	Slight	16
M04S3.01	Ice-Contact	57.0	Alluvial	Very Steep	Steep	Slight	13

*Erodibility ratings are based on soil unit. In several instances (M06, M07, M08, M09, and M04S3.01), the erodibility rating of "slight" does not seem to correspond with valley slopes that are steep and soils that are alluvial. This discrepancy has to do with the soil being rated for the area within the corridor, and the valley slopes being calculated using topographic maps for the valley walls that were frequently outside of the corridor delineation.

3.3 GEOMORPHIC SETTING

For the purpose of geomorphic assessment and corridor planning, streams in the study area were divided into "reaches," nine of which are included in this report. A reach is a relatively homogenous section of stream, based primarily on physical attributes such as valley confinement, slope, sinuosity, dominant bed material, and bed form, as well as predicted morphology based on hydrologic characteristics and drainage basin size. Eight mainstem reaches (M01-M09) and one tributary reach (M04S3.01) were chosen for inclusion. Table 3 outlines stream and valley details for the Phase 2 reaches.

Table 3. Reference stream types and geomorphic characteristics for the Wells River and tributary reaches included in 2008-09 corridor planning Project area.

Reach Number	Stream Type/ Bed Form *	Confinement (Valley Type)	Channel Slope (%)	Channel Length (ft)	Grade Controls
M01	C4/Riffle Pool	Broad	0.71	2806	Weir
M02	Bc3/Riffle Pool	Narrowly Confined	1.52	1977	Multiple
M04	B2/Step Pool	Semi-Confined	1.29	6220	Multiple
M05	C5/Dune Ripple	Narrow	0.04	2824	None
M06	E5/Dune Ripple	Very Broad	0.06	6957	None
M07	E4/Riffle Pool	Narrow	0.64	2349	None
M08	B3/Step Pool	Semi-Confined	3.24	2778	Multiple
M09	E5/Dune Ripple	Very Broad	0.51	2922	None
M04S3.01	E5/Dune Ripple	Very Broad	1.34	3361	None

* **See Appendix A for explanation of terms.**

A longitudinal profile of the study area indicates gentle gradients along most of the study reaches, with increasing slopes noticeable in M04: Segment A, and M08: Segments A and C. Fish Pond Brook begins at the top of Wells mainstem reach M04, with a gentle grade, increases slightly in Segment B, flattens out in Segment C, and finally rises fairly steeply in Segment D. Ledge grade controls are present in the areas of steepening gradient mentioned above. A significant falls is found at the top of M08, at the Boltonville Dam. An alluvial fan was mapped for reach M01 in the vicinity of the village of Wells River.

3.4 HYDROLOGY

Hydrology is a function of how much rain falls, how much becomes surface flow that reaches the rivers, how much soaks into the ground to become groundwater (see discussion in Sec. 3.2, Geologic characteristics), how much is taken up by plants through evapo-transpiration (note particularly the forested portions of the watershed in Fig. 4 and Sec. 3.1.3 discussion on land use history and current general characteristics of the basin), and how much is evaporated into the air.

3.4.1 Wells River Watershed StreamStats

The United States Geological Survey (USGS) administers a *StreamStats in Vermont* website, which is designed to help compute streamflow and drainage basin characteristics for ungaged sites (application description: http://water.usgs.gov/osw/streamstats/ssinfo.html; Vermont state application: http://water.usgs.gov/osw/streamstats/Vermont.html).

3.4.2 Wells River watershed flood history

Although there is common acknowledgement of significant flood events in the Wells River basin (Fig. 3 in this report shows photos of Wells River village during two different flooding events), scientific documentation of impact levels throughout a watershed can be harder to obtain. Streamflow statistics and basin characteristics estimated for the entire watershed area, available from the USGS stream statistics interactive-map internet site mentioned above, are found in the Report below, and in Figure 7. Stream peak flow characteristics can help in flood history comparison with other watersheds. Basin characteristics and stream peak flow statistics for the Wells River drainage basin are summarized in Figure 10.

Streamstats for the Wells River Watershed (Ungaged Site Report)

Date: Tue Apr 14 2009 08:53:44
Site Location: Vermont
NAD83 Latitude: 44.1523 (44 09 08)
NAD83 Longitude: -72.0424 (-72 02 32)
Drainage Area: 100 mi2

Peak Flow Basin Characteristics			
100% Statewide Peak Flow (100 mi2)			
Parameter	**Value**	**Regression Equation Valid Range**	
		Min	**Max**
Drainage Area (square miles)	100	0.211	850
Percent Lakes and Ponds (percent)	1.39	0	6.86
Percentage of Basin Above 1200 ft (percent)	63.7	0	100

Statistic	**Flow (ft^3/s)**	**Prediction Error (percent)**	**Equivalent years of record**	**90-Percent Prediction Interval**	
				Minimum	**Maximum**
PK2*	2260	42	1.4	1180	4340
PK5	3290	40	2.3	1740	6230
PK10	4020	41	3.2	2110	7680
PK25	5010	42	4.6	2610	9630
PK50	5780	43	5.5	3000	11100
PK100	6570	44	6.3	3300	13100
PK500	8560	49	7.6	4010	18300

*These are peak flow statistics, where *PKx* = *x*-year peak flood, i.e., maximum instantaneous flow that occurs on average once in *x* years

Figure 10. USGS StreamStats peak streamflow and basin characteristics statistics reports for the Wells River drainage basin.

Bankfull flows typically occur every 1.25 - 2 years (PK2 in Fig. 7). These are the flows that move the most sediment, and are also known as “channel forming flows” (Leopold, 1973).

Attenuation of flood flows is provided by lakes, ponds, and valley flood plains. Areas with wetland soils that can absorb and store large amounts of water for more gradual release are particularly important. Although basin characteristics for the Wells River indicate a relatively small percentage of lakes and ponds in the basin (4%, Table 1), adding in hydric soils, which also serve to provide storage and attenuation of flows within the watershed, indicates that quite a larger percentage of the watershed, particularly in the upper reaches, has storage capacity than indicated by land cover mapping alone (Figure 11). Not all hydric soils indicate good attenuation, but those within the stream valleys are likely to have wetland characteristics.

It is worth noting that the Phase 2 study consistently found channel widths less than what would be expected under reference conditions (for all stream types). It is possible that the hydrology of this watershed is somewhat unique, and that wetlands and hydric soils could be playing a significant role in mediating the hydrology of the watershed, resulting in smaller channel widths than would be expected for a watershed of this size.

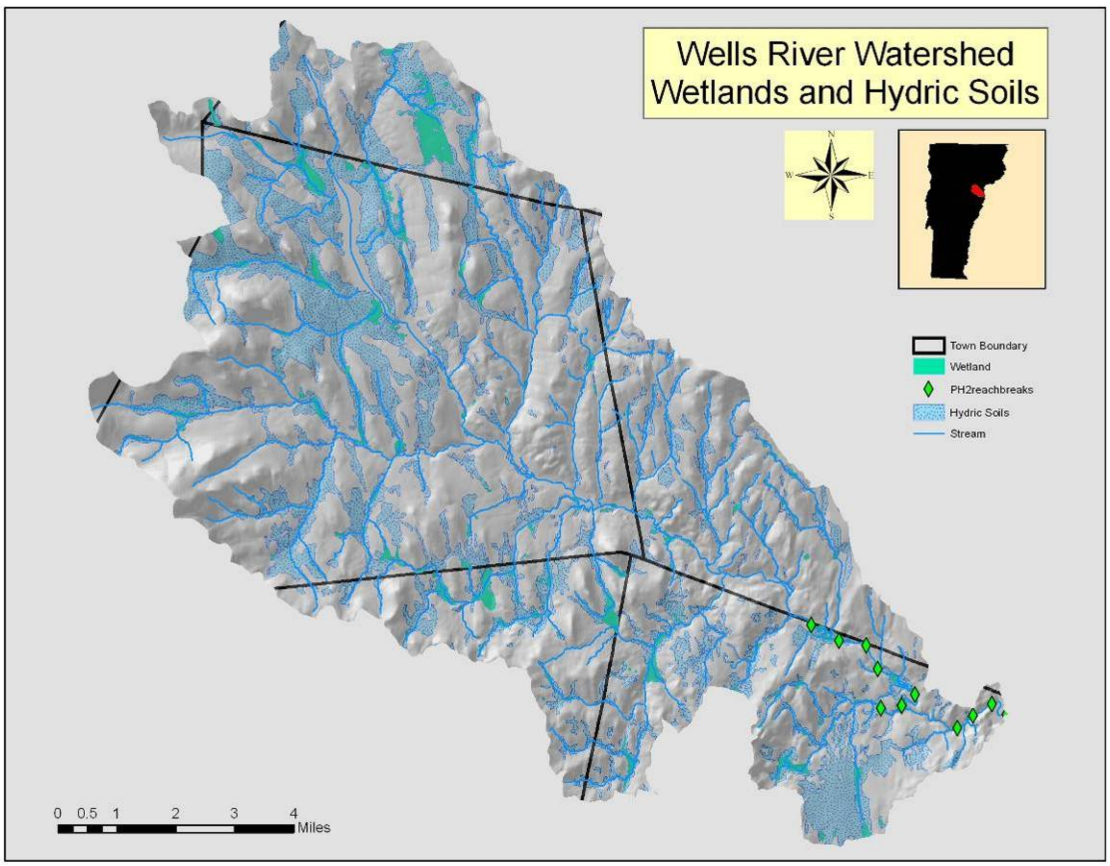

Figure 11: Wetlands and hydric soils map for the Wells River Watershed

For this project area, there is additional stream flow information available from a USGS stream gage located near the base of reach M04, upstream of Wells River village. Stream flow data for this gaging station is summarized in Table 4 and Figures 12 and 13. Note flow rate peaks differ from those calculated from the entire watershed in Figure 10, and direct comparison is not possible.

Table 4: WELLS RIVER (at Wells River): DRAINAGE AREA: 98 mi². Extreme flow data for the year of 2006 (http://wdr.water.usgs.gov/wy2006/pdfs/01139000.2006.pdf).
EXTREMES FOR YEAR 2006.--Peak discharges greater than base discharge of 980 ft³/s and (or) maximum (*):

Date	Time	Discharge (ft³/s)	Gage height (ft)
Oct 16	0100	1,280	4.80
Oct 26	0045	1,110	4.56
Nov 17	0515	1,490	5.08
Nov 30	1500	1,030	4.44
Jan 14	2100	1,020	4.42
Jan 18	2300	*1,910	*5.58
Feb 05	1730	1,150	4.62
May 20	0700	1,280	4.80
Jun 27	0530	1,160	4.63
July 13	1100	1,130	4.59

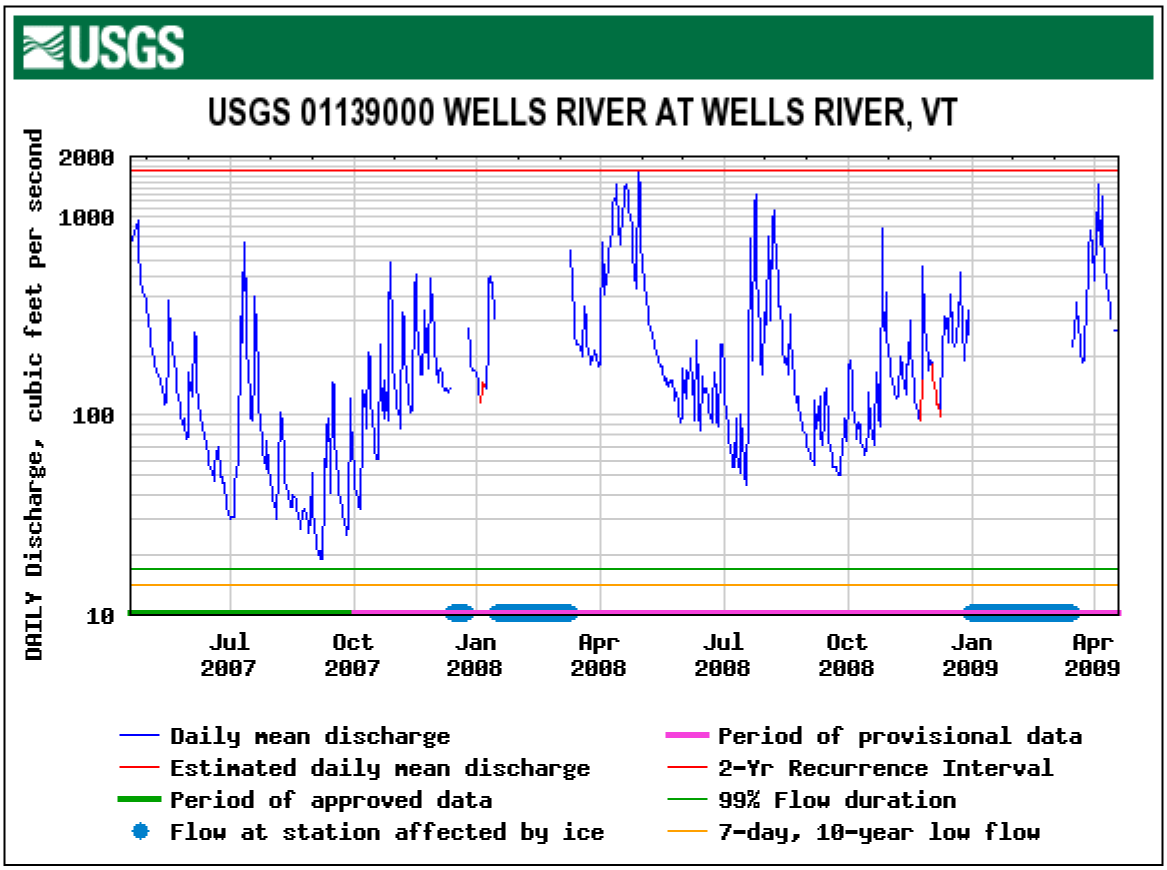

Figure 12: Wells River daily stream flow for July, 2007 through July, 2009.

Using the base flow discharge of 980 cubic feet per second suggested in Table 4 for 2006, flows for 2007 and 2008 surpassed base discharge levels on July of 2007; in April, July, and October of 2008; and in April of 2009. Discharges surpassed the 2006 maximum discharge rate in April, 2008.

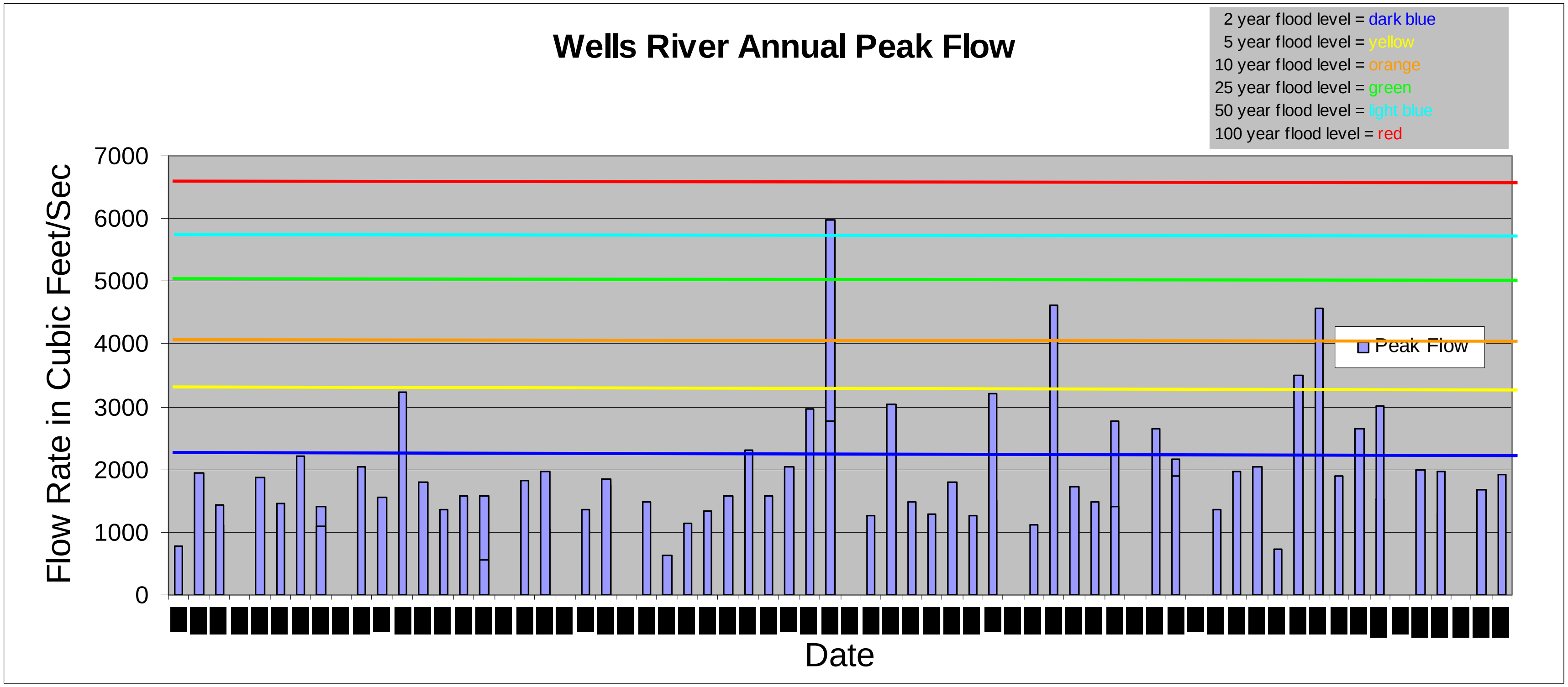

Figure 13: Annual peak flows at the Wells River gage, from 1941 to 2006. Flood level years are taken from PK values in Figure 10. 50-year flood levels were observed in 1973. Note PK values in Figure 10 are calculated on the entire watershed, and this chart is from the gaging site.

The most recent flooding event recorded on the Wells River was in 1984 when the water rose above the banks in downtown Wells River village and flooded the main street. NOAA's Advanced Hydrologic Prediction Site (http://newweb.erh.noaa.gov/ahps2/) indicates flood dangers in relationship to gage height as follows:

Flood Categories (in feet)	
Major Flood Stage:	9
Moderate Flood Stage:	8
Flood Stage:	6
Action Stage:	5

Historic extreme gage readings listed are as follows (moderate and major flood stages in italics):

- 6.87 ft on 12/18/2000
- *8.54 ft on 07/15/1997*
- 7.52 ft on 01/20/1996
- 6.83 ft on 04/01/1987
- *8.68 ft on 06/07/1984*
- 7.32 ft on 10/28/1981
- 7.12 ft on 04/01/1976
- *9.82 ft on 06/30/1973*
- 7.03 ft on 05/05/1972
- *8.12 ft on 06/02/1952*

This information does not match completely with the above Figure 13, since the PK values upon which Figure 13 bases its flood-level lines is derived from the entire watershed, and the extreme gage reading listed above are from the gaging site.

Historic assessment of gage levels indicates that heights of 8.5 feet and higher are likely to cause flooding hazards in Main Street of Wells River. Gage heights of 6.0 and higher cause flooding damage hazards along US Highway 302. (w*ww.weatherforyou.com/wxinfo/hw3/hw3.php?forecast=**river**sobs&gauge)*

The potential for expensive flooding damage in Wells River Village is significant. News stories and local historians describe the 1927 flood in Wells River (*larrycoffin.blogspot.com/2009/03/water-came-down-from-hills.html)*:

> The greatest damage in our area occurred in the village of Wells River…. located along the banks of the Connecticut and Wells Rivers, lower in elevation than other area villages. Local historians Horace Symes and Katherine Blaisdell both write about the flood damage in detail. The rapidly rising water of the Wells River caught the village residents by surprise. It was the ringing of the church bell and village alarm system that prevented loss of life as 45 families scrambled to safety.
>
> The Woodsville Times of November 11, 1927 reported the extensive damage to private dwellings and businesses in Wells River. "The river cut a new channel at the north end of

> the village and came tearing onto main street … where it uprooted the street. Symes explains that the damage was compounded by the collapse of an underground flume that had bisected the main street for over one hundred years, providing waterpower from the Waits to mills along its course. Fourteen buildings were either swept away or damaged beyond repair.

This year (2008) included the third wettest summer in 114 years of record in much of Vermont (NRCC 2009) and record annual precipitation levels in nearby New Hampshire, with both high snow and rainfall throughout much of the northeast (NCDC 2009). In reviewing the records at stream gages, it is important to recognize the sometimes localized nature of storms that can have significant flood and erosional impacts. While this is in part related to weather patterns, it is also important to recognize the effects of changes in hydrology over time, as further discussed in Section 5.1 (Watershed hydrologic stressors) of this report.

3.5 ECOLOGICAL SETTING

The Wells River watershed lies within the Northern and Southern Vermont Piedmont biophysical regions (Thompson and Sorenson 2001). Most of the watershed is found within the Northern Piedmont, a hilly landscape with a mix of agriculture and forest. The Southern Piedmont this far north is restricted to the easternmost portion of Vermont, along the Connecticut River valley. The 2008 Phase 2 project area is found mostly within the region of the Southern Piedmont. This landscape is comprised of low rolling foothills, with a similar mix of agricultural land and forest. The dominant feature of the Southern Piedmont is the Connecticut River valley. The Connecticut River valley most resembles the Champlain Valley in climate, being significantly warmer overall than the interior hilly and mountainous portions of Vermont. In the Wells River watershed there are climatic variations east to west, as well as variations with elevation.

The Wells River watershed is home to a variety of aquatic species. A fisheries reference station is located approximately 1 mile upstream of the Boltonville Dam (approximately 0.5 miles upstream of the project area), near the Creamery Road bridge. The upper Wells River watershed (particularly the South Branch) contains habitat that supports naturally reproducing (i.e.wild) trout populations (pers. comm.. Jud Kratzer, VT Fisheries Biologist, April 2009). The Wells River is warm at the start, because it flows from Ricker Pond, but tributaries like the South Branch of the Wells River help to cool it as it continues downstream. The majority of the Wells River is too warm for trout during the summer months, but trout can survive in cold water refugia in the Wells River and its tributaries (Kratzer, 2007). The State stocks the river with brook trout from the confluence of the South Branch downstream to South Ryegate village, and with rainbow trout (previously brown trout) from the outlet of Ricker Pond to the confluence with the South Branch of the Wells River and again from South Ryegate Village almost to the confluence with the Connecticut River. As part of the Connecticut River Salmon Restoration Project, Atlantic salmon are also stocked along the length of the Wells. Salmon will not be able to ascend to the upper Wells River because of the dams close to its confluence with the Connecticut River. However, it is the intention that this nursery stream will boost the total numbers of salmon returning to the Connecticut River and ascending the accessible tributaries.

In addition to stocked fish, the reference station data indicate that natural populations of dace species are abundant, and that slimey sculpin, common shiner, and lake chub are common. Rarely occurring species include largemouth bass (at the mouth), yellow perch, brook and brown trout, white sucker, pumpkinseed, longnose sucker, bluntnose minnow, and creek chub. Unfortunately, the flows provided in the bypassed reach at Boltonville Dam are insufficient to support aquatic biota in accordance with the levels set in Vermont Water Quality Standards, preventing movement of fish past this barrier (http://www.anr.state.vt.us/dec/waterq/planning/docs/pl_basin14). In addition to fish and other aquatic species, Wells River watershed streams support a multitude of other wildlife, including many bird and mammal species.

Riparian habitat has been heavily influenced by human habitation in the last 200 years, with intensive agriculture and development largely occupying what would likely be floodplain forest habitats. Wetland habitats are fairly common in the watershed (Figure 11) and soils maps indicate that many riparian zones might have been classified as wetlands (hydric soils) before they were drained for agriculture and development.

4.0 METHODS

4.1 STREAM GEOMORPHIC ASSESSMENT

In an effort to provide a sound basis for decision-making and project prioritization and implementation, the Vermont Agency of Natural Resources has developed protocols for conducting geomorphic assessments of rivers. The results of these assessments provide scientific background to inform planning in a manner that incorporates an overall view of watershed dynamics, as well as the reach-scale dynamics that have been a primary focal point of project planning in the past. Incorporating upstream and downstream dynamics in the planning process can help increase the effectiveness of implemented projects by addressing the sources of river instability that are largely responsible for erosion conflicts, increased sediment and nutrient loading, and reduced river habitat quality (VT ANR 2007). Trainings have been held to provide consultants, regional planning commissions, and watershed groups with the knowledge and tools necessary to make accurate and consistent assessments of Vermont’s rivers.

The stream geomorphic assessments are divided into phases. A Phase 1 assessment is a preliminary analysis of the condition of a stream through remotely sensed data such as aerial photographs, maps, and “windshield survey” data collection. This phase of work identifies a “reference” stream type for each reach assessed. Phase 2 involves rapid assessment fieldwork on which to base a more detailed analysis of what adjustment processes are taking place, whether the stream has departed from its reference conditions, and how it might continue to evolve in the future. This sometimes requires further division of “reaches” into “segments” of stream, based on such field-identified parameters as presence of grade controls, change in channel dimensions or substrate size, bank and buffer conditions, or significant corridor encroachments. River Corridor Plans analyze the data from the Phase 1 and 2 assessments to inform project prioritization and methodology. Phase 3 involves detailed fieldwork for projects requiring survey and engineering-level data for identification and implementation of management and restoration alternatives.

As noted in the Project Overview, Phase 1 Stream Geomorphic Assessment (SGA) for the Wells River watershed was conducted in 2008, just previous to the Phase 2 process. The Phase 2 SGA was initiated on the Wells River and an unnamed tributary during the late summer of 2008, with data collected by Redstart Consulting in conjunction with RMP river scientists, and with help from the Caledonia County Conservation District. Phase 2 fieldwork was completed by the late autumn of 2008. Field-collected data were processed and analyzed during the autumn and winter of 2008-2009 and entered into the most current version of the VT ANR Stream Geomorphic Assessment Database (https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm), where it is available for public viewing. Phase 1 data were updated, where appropriate, using the field data from the Phase 2 assessment; these changes are tracked and documented within the SGA Database. Spatial data for bank erosion, grade control structures, bank revetments, debris jams, depositional features, and other important features were documented within all segments and entered into the spatial component of the statewide database (the Feature Indexing Tool, FIT) via the SGA Tool (SGAT) ArcView extension, which permits implementation of the data via geographic information systems. Maps displaying this information are available for public use as well (http://maps.vermont.gov/imf/sites/ANR_SGAT_RiversDMS/jsp/launch.jsp).

4.2 QUALITY ASSURANCE, QUALITY CONTROL, AND DATA QUALIFICATIONS

Quality assurance/quality control (QA/QC) checks of the Phase 1 and Phase 2 data were carried out with procedures specified in the Phase 2 Protocols (VT ANR 2007b). Review by both River Management Program personnel and the consultants conducting the assessments were cross-checked to verify integrity of the data. Documentation of the quality control checks is maintained within the SGA database (https://anrnode.anr.state.vt.us/ssl/sga/security/frmLogin.cfm). General questions about data collection methods can be answered by referencing the SGA Protocols (VT ANR 2007b). Full geomorphic Bridge and Culvert Survey data (VT ANR 2007b, Appendix G; data are viewable at https://anrnode.anr.state.vt.us/ssl/sga/structures.cfm) are not available for the full Phase 1 project area, but was collected for the Phase 1 mainstem and significant tributaries, and for all the Phase 2 reaches, during the 2008 field season (in conjunction with other data collection). The importance of these structures in flow and sediment transport dynamics makes these data extremely valuable for a more complete picture of watershed dynamics, as well as important information for structure maintenance and replacement prioritization, scheduling, and capital budgeting.

5.0 RESULTS

The following sections summarize pertinent results of Phase II SGA data collection for the Wells River watershed. Stressor, departure, and sensitivity maps are presented as a means to integrate the data that have been collected and show the interplay of watershed and reach-scale dynamics. These maps should assist in identifying practical restoration and protection actions that can move the river toward a healthy equilibrium (VT ANR 2007). Alterations to watershed-scale hydrologic and sediment regimes can profoundly influence reach-scale dynamics, and greater understanding of these processes is vital to increasing the effectiveness of protection and restoration efforts at a reach level (VT ANR 2007). Section 5.1 presents an analysis of stream departure from reference conditions. Sections 5.1.1 and 5.1.2 summarize watershed-scale stressors contributing to current stream conditions, and Sections 5.1.3–5.1.6 characterize reach-scale stressors. Section 5.1.7 characterizes the hydrologic and sediment regime departures for reaches included in Phase 2 assessment within the Wells River watershed. Section 5.2 presents a sensitivity analysis of these reaches, indicating the likelihood that a stream will respond to a watershed or local disturbance or stressor and an indication of the potential rate of subsequent channel evolution (VT ANR 2007b, Phase 2, Step 7.7; VT ANR 2007, Section 5.2).

Data used for the analyses can be found in the appendices. Phase 1 Reach summary statistics and channel geometry data are found in Appendix C. Reach/segment scale data from Phase 2 fieldwork are provided as summary sheets in Appendix D. Plots of channel cross sections are found in Appendix E.

5.1 DEPARTURE ANALYSIS

5.1.1 Watershed-scale hydrologic regime stressors

The hydrologic regime involves the timing, volume, and duration of flow events throughout the year and over time; as addressed in this section, the regime is characterized by the input and manipulation of water at the watershed scale. When the hydrologic regime has been significantly changed, stream channels will respond by undergoing a series of channel adjustments. Where hydrologic modifications are persistent, the affected stream will adjust morphologically (e.g., enlarging through either downcutting or widening when stormwater peaks are consistently higher) and often result in significant changes in sediment loading and channel adjustments in downstream reaches (VT ANR 2007).

As noted in Sec. 3.1.2 on land use history and current general characteristics, the Wells River watershed today is roughly 75 % forested. Limited field observations of current forest species and age distributions indicate that the Wells River watershed likely experienced extensive areas of deforestation, similar to the majority of the Vermont landscape during the 1800s. Changes in hydrology accompanying this extensive clearing included higher peak flows and direct-runoff discharges, lower minimum flows, and significant inputs of sediment. A reduction in peak flows and higher minimum flows gradually returned with reforestation through the 20th century (USDA-FS 2001).

Roads, parking lots, construction areas, lawns, and similar land uses are broadly classed in remote-sensing data from aerial imagery (Phase 1 data; Fig. 5) under “urban” land uses, which can reduce infiltration capacity and hence attenuation of flows as well as increase direct stormwater inputs to the stream. These land uses are significant in the Wells River basin, particularly within the riparian corridor towards the base of the watershed (Figure 14).

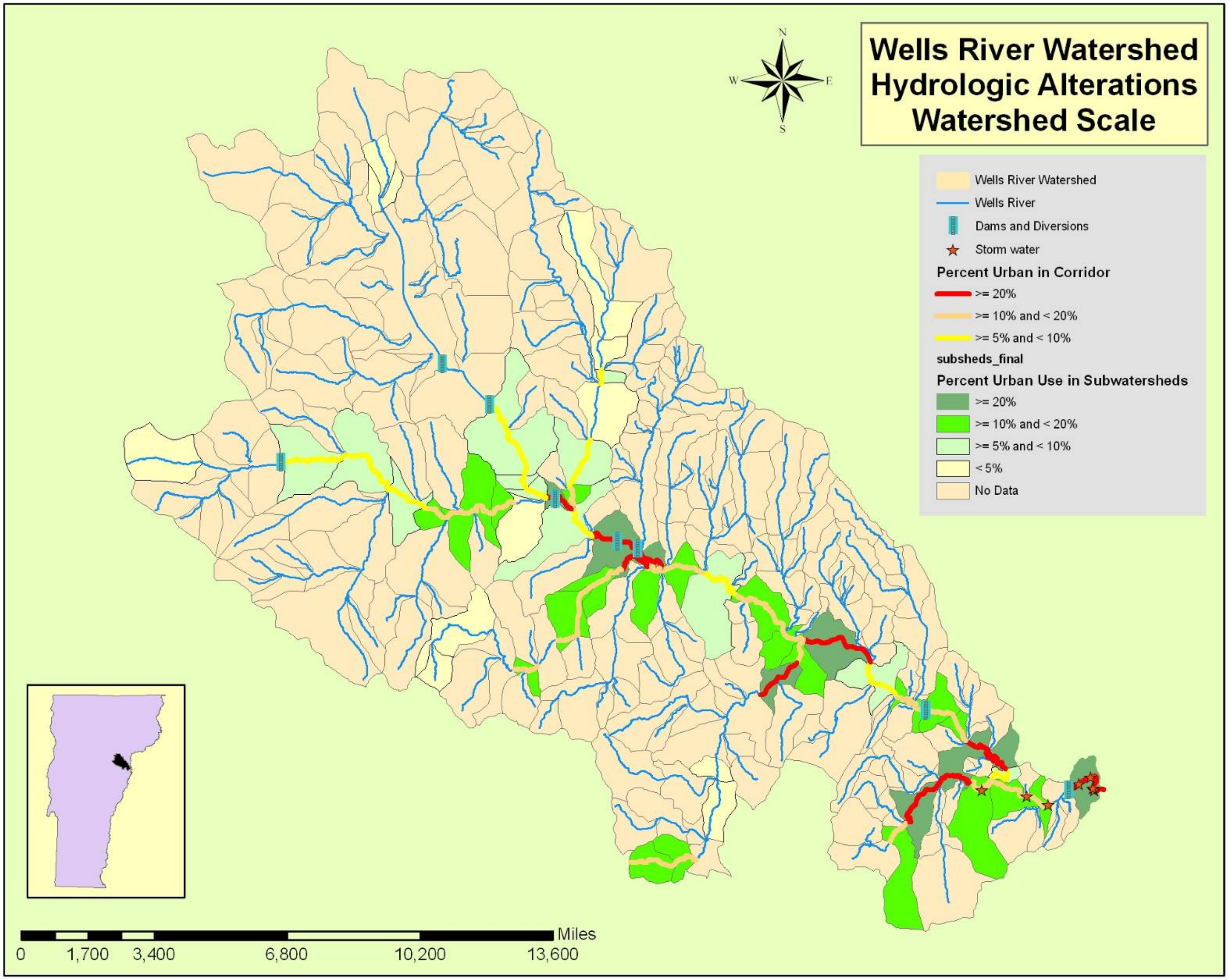

Figure 14: Hydrologic alterations for the entire Wells River Watershed.

The urban landscape dominates parts of the stream corridor that correspond to the reaches in this study area (Fig. 14), where three of nine reach corridors have urban land use as a dominant category, four have 10-20% urban use, and one has 5-20% urban use.

Agricultural uses are found along parts of four reaches (M06, M07, M08, M09). Areas of agricultural land that show up as wetland or hydric soils have often been drained historically to facilitate agriculture. This process of actively draining wetlands reduces the ability of these areas to serve as attenuation for intense precipitation events. Of these reaches, M06 and M09 show significant indication of loss or impairment of wetland attenuation assets (Figure 15).

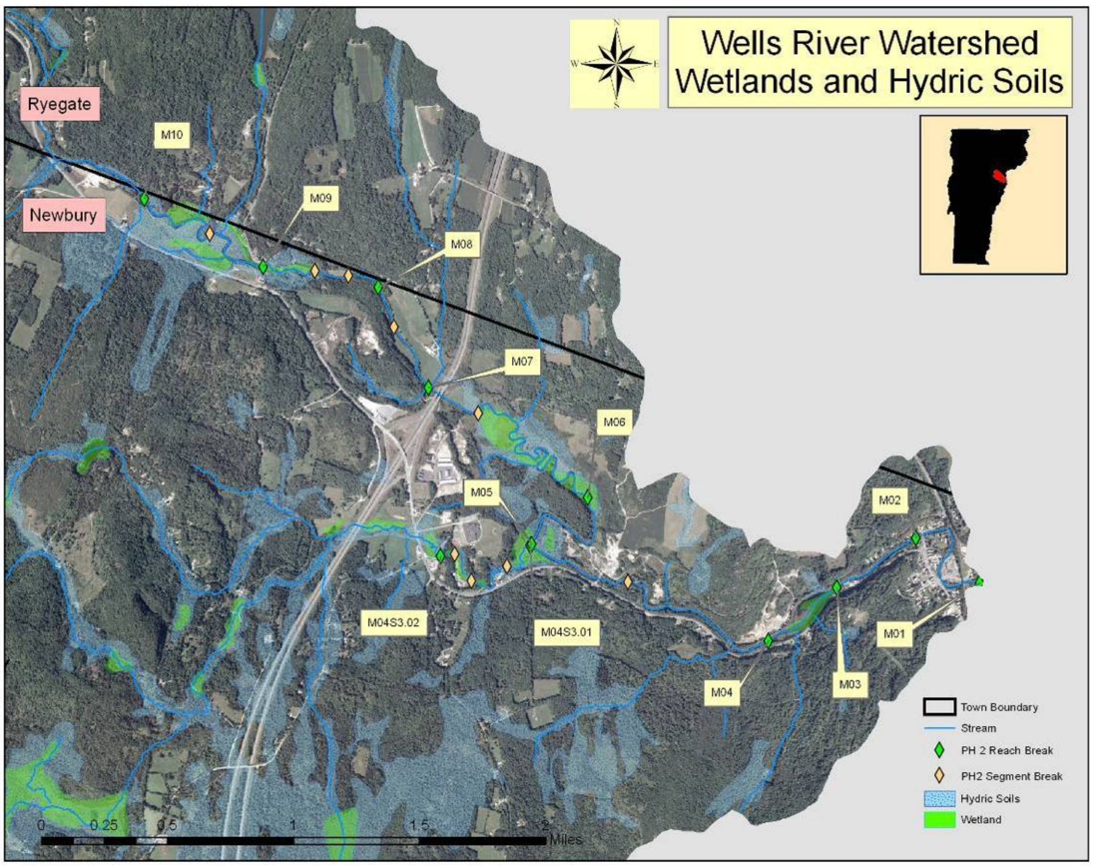

Figure 15: Hydric soils and wetlands overlap with agricultural uses in reaches M06 and M09, potentially causing a loss of attenuation assets.

Historical clearing throughout much of Vermont in the late 19th century and throughout the 20th century initially contributed to higher runoff of both water and sediment, which accrued in the river valleys. Removal of large woody debris from stream channels, often related to the use of streams for log drives, mill power, and agricultural uses, frequently combined with road development and other encroachments, channel straightening, and bank armoring to change the rainfall-runoff regime in such a way that water inputs and power intensified through deposited sediments. Hydrologic regimes became more "flashy" as streams cut downward in areas where the stream bed was erodible, and greater stream flows were consequently contained within the channel (VT ANR 2007).

Although it is difficult to quantify the extent of hydrologic changes due to deforestation, the active role of trees as “pumps,” helping to cycle water and thus moderate both the amount and timing of water delivered to a stream system should not be underestimated. While the problems caused by deforestation have diminished as trees have grown back, channel enlargement indicated by both current and historical channel incision, as well as current widening, were noted in Phase 2 data collection for the Wells River watershed. Although much of the watershed is reforested today, the legacy of deforestation forms a backdrop that often exacerbates or otherwise influences adjustment processes evidenced in the assessed streams.

It is not clear how much of the Phase 2 study reaches might have been used for the running of logs during the peak of river-transport days, but parts of the Wells River are straightened and near rail road lines, so it is possible that the Wells was used in this way. An iron ring and an iron pin embedded in bedrock at the top of reach M04, (just downstream of the strange dogleg section of stream that is M05), may indicate historic presence of a barrier to log movement downstream. The railroad is right next to the stream here and it is possible this was a loading area. The mystery of this stretch of river lies in the presence of a large falls less than 2 miles upstream. It is hard to imagine that logs were driven over these falls, but, if not, the area accessed by this section of stream was somewhat limited in size.

In areas of log-running and mill activities, a common practice of “snagging,” or removing coarse woody debris, was used to keep channels clear and regulate flows. These practices would increase the erosive power of water at release times, further abetted by a reduction in the amount of sediment being moved by that water if the sediment was being held at dams and other constrictions.
Old mill sites were in evidence on reach M02 and M04. There are still two active dams in the project area (M02, M08); both of which are hydroelectric.

5.1.2 Watershed-scale sediment regime stressors

The following description of the sediment regime is taken from the most current version of the VT ANR River Corridor Planning Guide (VT ANR 2007):

> The sediment regime may be defined as the quantity, size, transport, sorting, and distribution of sediments. Sediment erosion and deposition patterns, unique to the equilibrium conditions of a stream reach, create habitat. Generally, these patterns provide for relatively stable bed forms and bank conditions…
>
> ….During high flows, when sediment transport typically takes place, small sediments become suspended in the water column. These wash load materials are easily transported and typically deposit under the lowest velocity conditions, which exist on floodplains and the inside of meander bendways at the recession of a flood. When these features are missing or disconnected from the active channel, wash load materials may stay in transport until the low velocity conditions are encountered….This … unequal distribution of fine sediment has a profound effect on aquatic plant and animal life. Fine-grained wash load materials typically have the highest concentrations of organic material and nutrients.
>
> Bed load is comprised of larger sediments, which move and roll along the bed of the stream during floods…. The fact that it takes greater energy or stream power to move different sized sediment particles results in the differential transport and sorting of bed

> materials….When these patterns are disrupted, there are direct impacts to existing aquatic habitat, and the lack of equal distribution and sorting may result in abrupt changes in depth and slope leading to vertical instability, channel evolution processes, and a host of undesirable erosion hazard and water quality impacts.

At a watershed scale, the Wells River basin contributes to both a high bed load and a high wash load system. Phase 1 analysis indicateds that surficial geology of the watershed is dominated by fluvial, ice-contact and till substrates, often with steep to extremely steep valley wall topography (see Section 3.2, Geologic background, of this report). “Severe” to “Very High” erodibility ratings were noted for M01, M02, M04, and M05. The “Slight” erodibility ratings found in the upper reaches and in the unnamed tributary to M04 are related to the fact that these stream sections have relatively wide valleys where steep valley slopes are located outside of the river corridor.

Geomorphic instability related to the downcutting of streambeds in the Wells River basin (and loss of floodplain access), is leading to the concentration of flows in the stream channel, increased stream power, and the redistribution of fine sediment loads farther downstream in the system. The presence of two dams in the project area serves to interrupt the transport of sediments downstream except in high flow events. This combination of increased flow from downcutting and barriers to sediment movement create a scenario in which “equilibrium” conditions are extremely hard to achieve.

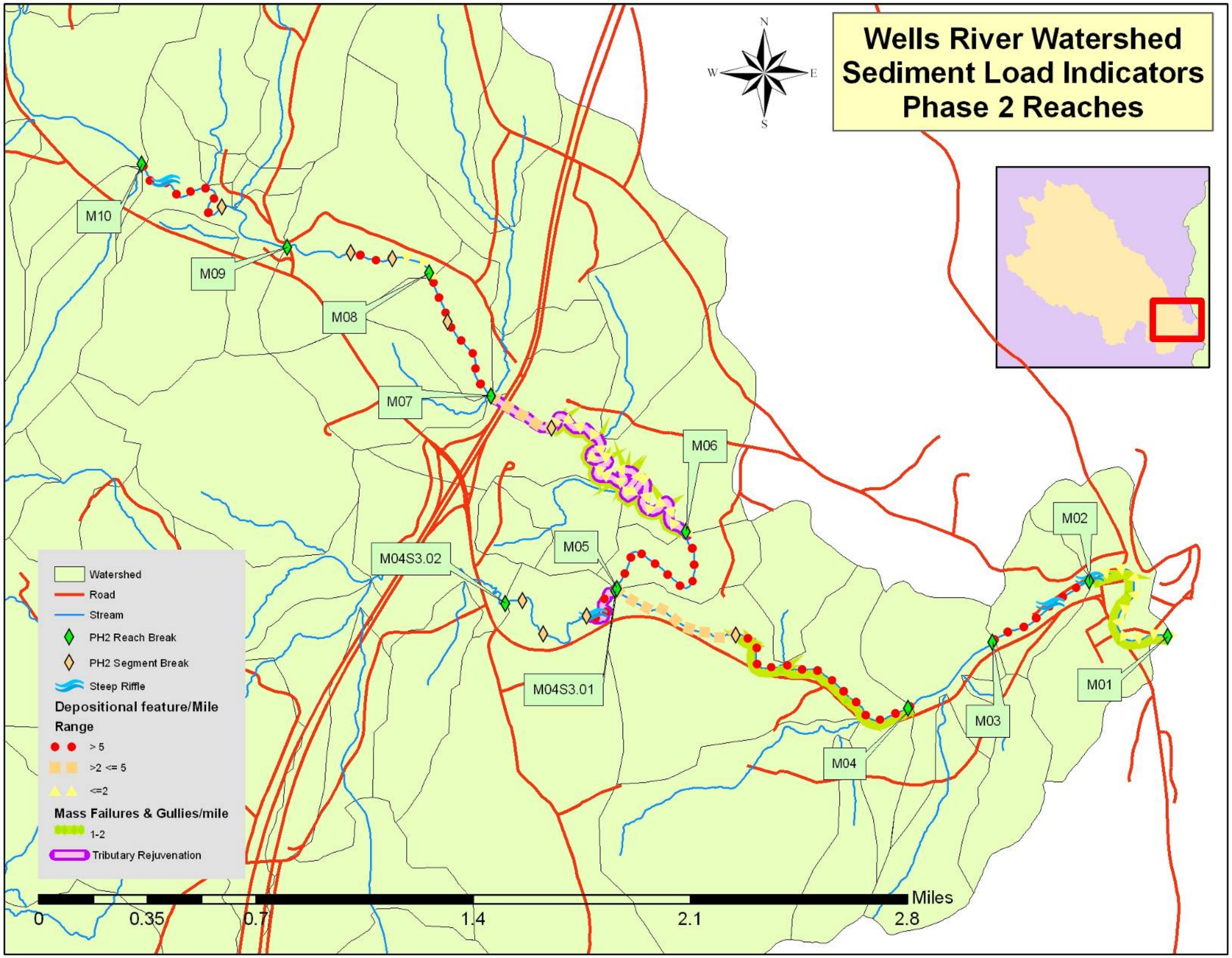

Figure 16: Sediment Load Indicators for Phase 2 study reaches.

5.1.3 Reach-scale stressors

Watershed-scale stressors form a hierarchical pretext for understanding the timing and degree to which reach-scale modifications are contributing to field-observed channel adjustments (VT ANR 2007). Modifications to the valley, floodplain, and channel, as well as boundary (bank and bed) conditions, at the reach scale can change the hydraulic geometry, and thus change the way sediment is transported, sorted, and distributed (Table 4). Phase 1 and Phase 2 assessments provide semi-quantitative datasets for examining stressors and their effects on sediment regime when channel hydraulic geometry is modified .

Table 4. Reach level stressors: relationship of energy grade and boundary conditions in sediment transport regime (VT ANR 2007).

		Sediment Transport Increases	**Sediment Transport Decreases**
	Stream power as a function of:	**Stressors that lead to an increase in power**	**Stressors that lead to a decrease in power**
Energy Grade	**Slope**	• Channel straightening • River corridor encroachments • Localized reduction of sediment supply below grade controls or channel constrictions	• Upstream of dams, weirs • Upstream of channel/floodplain constrictions, such as bridges and culverts
Energy Grade	**Depth**	• Dredging and berming • Localized flow increases below stormwater and other outfalls	• Gravel mining, bar scalping • Localized increases of sediment supply occurring at confluences and backwater areas
	Resistance to power by the:	**Stressors that lead to a decrease in resistance**	**Stressors that lead to an increase in resistance**
Boundary Conditions	**Channel bed**	Snagging, dredging, and windrowing	Grade controls and bed armoring
Boundary Conditions	**Stream bank and riparian**	Removal of bank and riparian vegetation (influences sediment supply more directly than transport processes)	Bank armoring (influences sediment supply more directly than transport processes)

The primary hydrologic and sediment stressors in each stream segment assessed in the 2008 Phase 2 assessment of the Wells River watershed are identified in Table 5. Channel Slope (Figure 17) and Depth Modifier Maps (Figure 18) (Sections 5.1.4 and 5.1.5, respectively) can be used to determine whether stream power has been significantly increased or decreased. A Channel Boundary and Riparian Modifiers Map (Figure 19)(Section 5.1.6) can help explain whether the resistance to stream power has been increased or decreased.

Table 5. Wells River Watershed Stressors Identification tables, indicating some of the hydrologic and sediment load stressors that are likely to be causing or contributing to channel adjustment and a departure from equilibrium conditions (Appendix A and sSection 5.1.4)

Wells River Mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
M01	*Increased flows* Deforestation Urbanization Industrial development Roads and ditching P1 watershed: 86% forest, sub dom = urban P1 corridor: 85% urban, sub dom = forest		*Increased stream power: slope* Straightening: 100% Encroachment: 75-100% Three stormwater inputs Industrial runoff *Increased stream power: depth* Dredging likely after flooding events *Decreased stream power: slope* Deposition above one bridge	*Decreased bed resistance* Dredging likely after flooding events. *Increased bed resistance* Large amount of riprap in bed *Decreased bank resistance* Dom. buffer <25 ft both banks *Increased bank resistance* Armoring >75% both banks
M02	*Increased flows* Historic Deforestation Urbanization Industrial development Roads and ditching P1 watershed: 86% forest, sub dom = urban P1 corridor: 54% urban, sub dom = forest	*Increased load* P2 deposition range: >5/mi	*Increased stream power: slope* Encroachment: >50% both banks One stormwater inputs *Decreased stream power: slope* P2 deposition range: >5/mi	*Increased bank resistance* Bank armoring: >20% RB *Increased bed resistance* One ledge grade control Dam
M04A	*Increased flows* Historic Deforestation Urbanization Roads and ditching	*Increased load* P2 deposition range: >5/mi	*Increased stream power: slope* Encroachment: >50% one side Two stormwater inputs	*Increased bed resistance* Nine bedrock grade controls *Increased bank resistance* Bank armoring: 5-20% RB

Wells River Mainstem Stressors Identification Table	Watershed Input Stressors		Reach Modification Stressors	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
	Gravel Pit P1 watershed: 86% forest, sub dom = urban P1 corridor: 46% forest, sub dom = urban		*Decreased stream power: slope* P2 deposition range: >5/mile	
M04B	*Increased flows* Historic Deforestation Gravel Pit Urbanization Roads and ditching P1 watershed: 86% forest, sub dom = urban P1 corridor: 46% forest, sub dom = urban	*Increased load* P2 deposition range: 2-5/mi	*Increased stream power: slope* Encroachment:>50% one side *Decreased stream power: slope* P2: deposition range: 2-5/mi	*Decreased bed resistance* Substrate = sand *Decreased bank resistance* Substrate = sand *Increased bed resistance* Three bedrock grade controls *Increased bank resistance* Bank armoring: >20% RB
M05	*Increased flows* Historic Deforestation Gravel Pit P1 Watershed: 86% Forested, subdom = Urban P1 Corridor: 72% Forest, subdom = wetland	*Increased load* Stream bank erosion >20% LB P2 deposition range: >5/mi	*Increased stream power: slope* Straightening: 75-100% Possible historic dredging *Decreased stream power: slope* P2 deposition range: >5/mi	*Decreased bank resistance* Substrate = sand Erosion: >20% LB
M06A	*Increased flows* Deforestation Ongoing Agriculture	*Increased load* Erosion > 30% both banks		*Decreased bed resistance* Substrate = sand

Wells River Mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
	P1 Watershed: 86% Forested, subdom = Urban P1 Corridor: 44% Forest, subdom = wetland			*Decreased bank resistance* Substrate = sand Erosion >30% LB & RB Subdom buffer <25 LB Buffer vegetation = grasses *Increased bank resistance* RR 10-20% LB
M06B	*Increased flows* Deforestation Ongoing Agriculture Road Building P1 Watershed: 86% Forested, subdom = Urban P1 Corridor: 44% Forest, subdom = wetland	*Increased load* P2 deposition range: 2-5/mi Tributary input	*Increased stream power: slope* Straightening: almost 100% *Decreased stream power: slope* P2 deposition range: 2-5/mi	*Decreased bank resistance* Erosion: 10-20% RB Dom. buffer <25 ft LB *Increased bank resistance* Armoring >50% both banks
M07A	*Increased flows* Deforestation Ongoing Agriculture P1 Watershed: 86% Forested, subdom = Urban P1 Corridor: 60% Forest, subdom = field	*Increased load* Bank erosion 20-30% RB P2 deposition range: >5/mi	*Increased stream power: slope* Straightening: almost 100% *Decreased stream power: slope* P2 deposition range: >5/mi	*Decreased bank resistance* Erosion: >20% RB Dom. buffer <25 ft both banks *Increased bank resistance* Bank armoring: 10–20% LB
M07B	*Increased flows* Deforestation Ongoing Agriculture P1 Watershed: 86% Forested, subdom = Urban	*Increased load* P2 deposition range: >5/mi	*Increased stream power: slope* Straightening: almost 100%	*Decreased bank resistance* Dom. buffer <25 ft LB Subdom. Buffer <25 ft RB *Increased bank resistance* 20% riprap LB

Wells River Mainstem Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
Stream segment	**Hydrologic**	**Sediment load**	**Energy grade**	**Boundary resistance**
	P1 Corridor: 60% Forest, subdom = field			
M08A	*Increased flows* Roads and ditching P1 Watershed: 86% Forested, subdom = Urban P1 Corridor: 66% Forest, subdom = urban	*Decreased load* Upstream dam	*Increased stream power: slope* Encroachment: >50% one bank *Decreased stream power: *? Bedrock channel constriction	*Increased bed resistance* Two ledge grade controls *Increased bank resistance* Bedrock in banks
M08B	*Increased flows* Deforestation Ongoing Agriculture P1 Watershed: 86% Forested, subdom = Urban P1 Corridor: 66% Forest, subdom = urban	*Increased load* P2 deposition range: >5/mi Erosion 40-50% LB *Decreased load* Upstream dam	*Increased stream power: slope* Straightening: 75-100% Encroachment: 20-30% one side Upstream dam *Decreased stream power: slope* P2 deposition range: >5/mi Upstream dam	*Decreased bed resistance* Substrate = sand *Decreased bank resistance* Substrate = sand Erosion 40-50% LB Dom buffer <25 ft LB
M09B	*Increased flows* Deforestation Ongoing Agriculture Roads and ditching P1 Watershed: 86% Forested, subdom = Urban P1 Corridor: 60% Forest, subdom = field	*Increased load* P2 deposition range: >5/mi Bank erosion 10-20% both banks	*Increased stream power: slope* Straightening: 10-20% Encroachment: >50% one side *Decreased stream power: slope* P2 deposition range: >5/mi	*Decreased bank resistance* Erosion: 10-20% both banks Dom. buffer <25 both banks

Unnamed tributary to Wells River Mainstem (Fish Pond Brook) Stressors Identification Table	**Watershed Input Stressors**		**Reach Modification Stressors**	
M04S3.01A	*Increased flows* Deforestation Railroad and road P1 watershed: 85% forest, sub dom = urban P1 corridor: 62% urban, sub dom = urban	*Increased load* P2 deposition range: >5/mi Erosion 10-20% LB	*Decreased stream power: slope* Deposition above bridge Bridge constriction	*Decreased bed resistance* Substrate = sand *Increased bed resistance* Large amount of riprap in bed *Decreased bank resistance* Substrate = sand Buffer vegetation = grasses
M04S3.01B	*Increased flows* Roads Deforestation P1 watershed: 85% forest, sub dom = urban P1 corridor: 62% urban, sub dom = urban	*Increased load* P2 deposition range: >5/mi	*Decreased stream power: slope* P2 deposition range:>5/mi	*Increased bed resistance* Coarse substrate *Increased bank resistance* Coarse substrate

5.1.3a Channel slope modifiers

Results for the Wells River Phase 2 reaches indicate that primary stressors are variable, reach to reach. Straightening is found in 9 of 14 segments; seven of which are extensively straightened (>20%). Encroachment is important for only 4 of the 14 segments; all of which are found lower in the watershed. Sediment deposition is important in 9 of the 14 segments, serving to modify slope increases from straightening and encroachment in all but reach M01. Only one headcut was found in the project area; on the only reach unaffected by straightening, encroachment, or significant deposition. Bed and bank resistance, in the form of bedrock, was found in three segments. Erodible sand beds and banks were found in five segments. In areas with erodible boundary materials, channel straightening can lead initially to slope increases through bed erosion (exacerbated if downcutting has led to a loss of floodplain access), enhancing sediment transport capacity as a result of the increased channel slope and depth. These same erodible boundary materials then readily allow for stream widening through bank erosion, reversing the trend by reducing slope through deposition. These forces are at play in the straightened sections of the Wells River where substrates are dominated by sands. Where downcutting has led to loss of floodplain access, instead of storing some of the increased load from bank erosion processes, the straightened reaches are now conveying sediment further downstream until a constriction or significant decrease in slope is encountered. In the Wells River Phase 2 project, overall, the regularly alternating pattern of sand substrate with bedrock grade controls modifies sediment transport in such a way as to provide a relatively stable stretch of river. The urbanized portion of downtown Wells River is protected from excessive sediment deposition by two reaches with extensive bedrock grade controls, and a dam empoundment.

During the 2008 Phase 2 assessment in the Wells River watershed, tributary rejuvenation was noted for three segments: M06A and B, and M04S3.01A. Tributary rejuvenation is an indication of recent incision in the main channel and generally suggests increased sediment contributions from tributaries as they incise to the elevation of the incised main channel.

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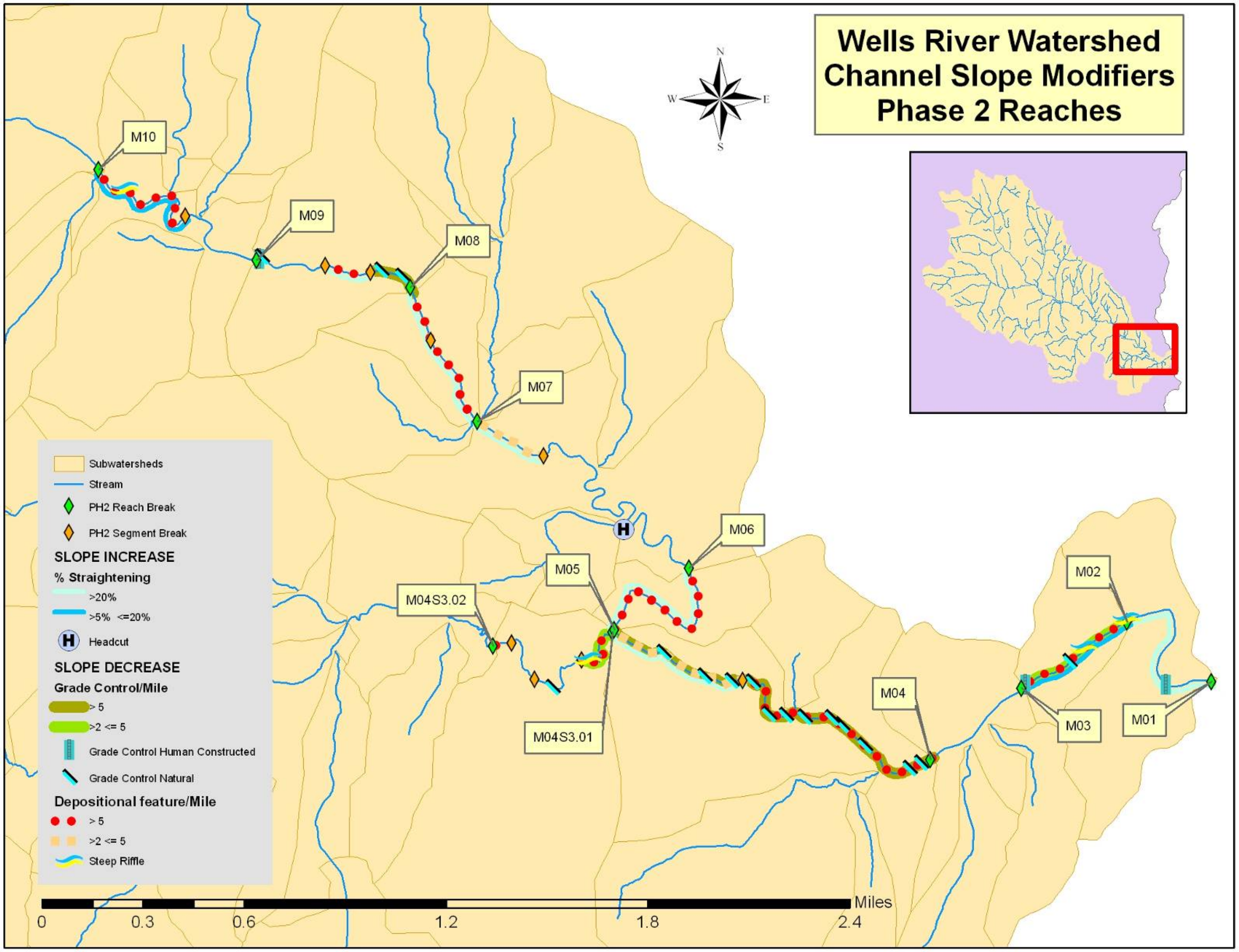

Figure 17: Reach-scale stressors: Channel Slope Modifiers for Phase 2 reaches on the Wells River.

5.1.3b Channel depth modifiers

Phase 1 and 2 data collection on the Wells River indicates extensive road and development encroachment in the lower portion of the project area (M01-M04). This has served to reduce the effective width of the valley and floodplain in this area. Elevated roads and development within the river corridor increase the depth of flood flows, and thus also increase stream power. Stormwater inputs and bridges also serve to increase channel depth. These features are more prevalent at the downstream end of the project area. Direct storm water inputs to the stream can significantly increase peak discharge during high water events, which typically results in an increase in flow depths and stream power. Bridges often function as a channel constriction, which deepens the channel in the vicinity of the bridge.

Significant deposition creates the potential for shallower depths during low and moderate flows. Stream power is then reduced in these areas, leading to further deposition. Moderate to heavy deposition was noted in eight of the 12 assessed segments of the Wells mainstem, and one of the two segments assessed for the tributary to M04 (Figure 18).

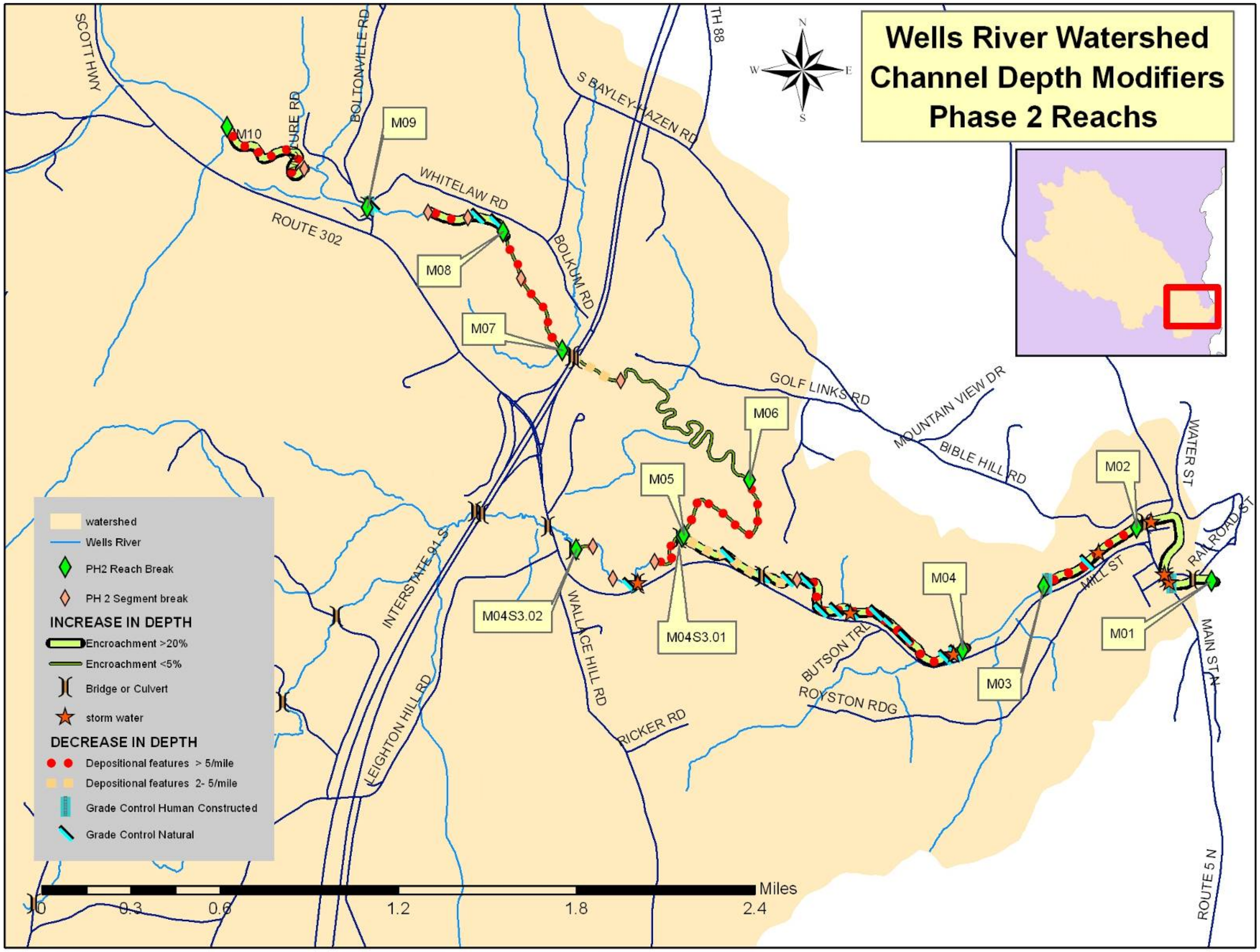

Figure 18: Reach-scale stressors: Channel Depth Modifiers for the Phase 2 reaches on the Wells River

5.1.3c Boundary condition and riparian modifiers
Stream boundaries include bed and banks, and are also affected by the state of buffer vegetation in the riparian corridor (Figure 19). Root systems from woody vegetation and, to a lesser extent, herbaceous vegetation, help bind streambank soils.
Bed materials were coarse in seven of the 12 segments assessed on the Wells River mainstem, and one of the two segments assessed on the unnamed tributary to M04. Stretches of coarse bed material tend to alternate with stretches of fine bed materials. This can be explained by the presence of bedrock grade controls in the upper part of the project area; where sands naturally drop out upstream of a slope-modifying barrier. Upper bank materials are often more easily eroded in flood flows than the bed and lower banks. Sands dominated the upper banks in all but M01 (which has a man-made bank), M04A, M08A, and M04S3.01D. Bank erosion was noted fairly extensively in areas where riparian buffers lack significant vegetation and banks are not armored. Small mass failures were found in a few reaches that have steep valley walls and where the stream channel pushed up against the valley wall. Figure 18 illustrates the importance of a forested buffer to bank stability.

Figure 19: Bank contrast in M09, showing an intact bank in a forested area next to an eroding bank in an agricultural area.

The importance of a forested buffer is well illustrated in reaches that have both agriculture and forest along their banks: Reaches M06, M07, M08, and M09 all have a combination of agricultural use (fallow in much of M06) and a forested buffer. Minor to locally extensive areas of hard bank and riprap revetments have been placed throughout the watershed to limit erosion in areas of development and agricultural use where these buffers are lacking (Figure 19), exacerbating some of the channel slope and depth modifications discussed in sections 5.1.3a and 5.1.3b above. There was no physical evidence of dredging or gravel mining in the project area, although it is likely that M01, in the downtown area of Wells River village, has been dredged after flooding events.

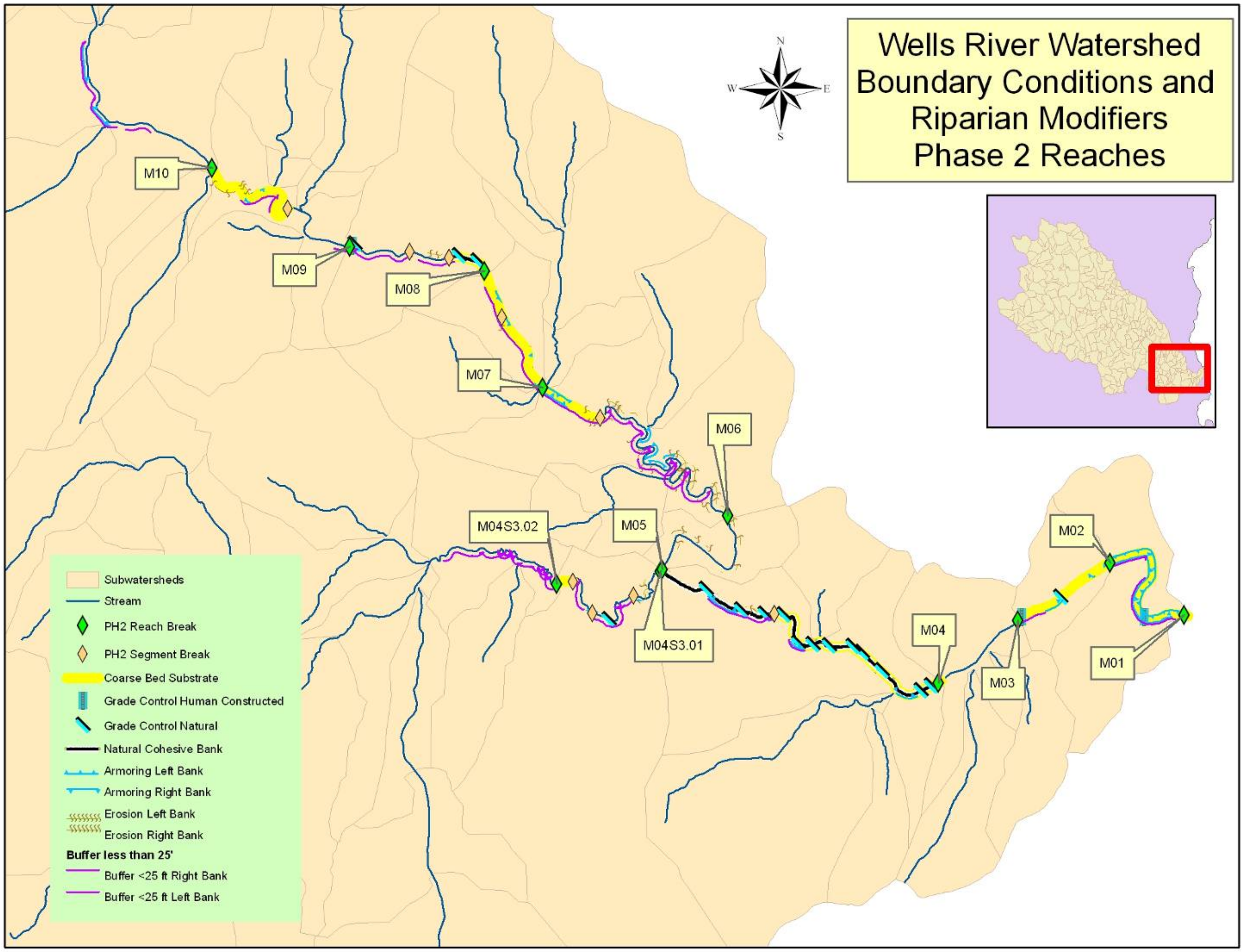

Figure 20. Reach-scale stressors: Boundary condition and riparian modifiers map for the Phase 2 reaches on the Wells River.

5.1.4 Sediment regime departure, constraints to sediment transport, and attenuation
Within a reach, the principles of stream equilibrium dictate that stream power and sediment will tend to distribute evenly over time (Leopold 1994). Changes or modifications to watershed inputs and hydraulic geometry create disequilibrium in the balance of these forces and lead to an uneven distribution of power and sediment (Fig. 21). Whether a project works with or against the physical processes at play in a watershed is primarily determined by examining the sources, volumes, and attenuation of flood flows and sediment loads from one reach to the next within the stream network. If increasing loads are transported through the network to a sensitive reach, where conflicts with human investments are creating a management expectation, little success can be expected unless the restoration design accommodates the increased load or finds a way to attenuate the loads upstream (VT ANR 2007).

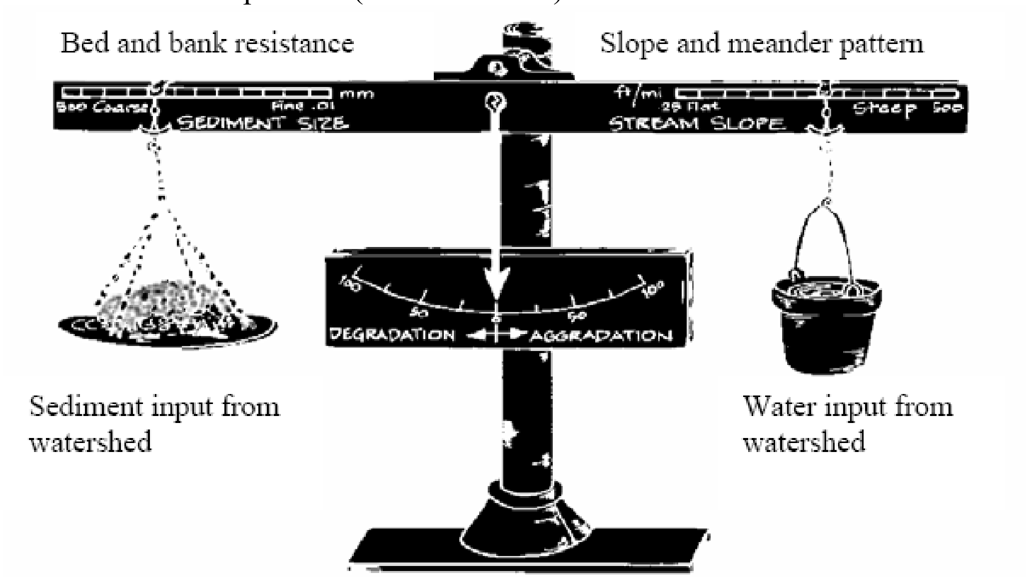

Figure 21. The channel balance indicates how changes in watershed inputs influence channel adjustment processes (Lane 1955).

Phase 1 designates a “reference type” for all reaches. Downstream reaches M01-M04 were classified as B and C type streams with coarser substrates. M05 appears as a transition reach where substrates become finer and the C channel shape shifts towards the deeper and narrower E channel shape (this transition includes the unnamed tributary to M04). Continuing upstream, this E-type stream with finer substrates continues until M08, where it was again classified as a B stream with coarse substrate. Upstream of M08, gentle and fine sediments dominate once again, returning to an E-type stream.
The C and E channel types are typically found in unconfined valleys with very gentle slopes, highly sinuous meander patterns, and extensive floodplains for sediment storage and dissipation of stream power. Under reference conditions, the sediment regime for both of these stream types would provide for coarse particle equilibrium (in = out: stream power, which is produced as a result of channel gradient and hydraulic radius, is balanced by the sediment load, sediment size, and channel boundary resistance) and fine sediment deposition at annual flood flows (Coarse Equilibrium and Fine Deposition regime, Table 5; VT ANR 2007, pp. 34–36).

The B channel type is generally found in semi-confined valleys with a moderate to gentle slope, a moderately sinuous meander pattern, and a small amount of floodplain storage. B-type reference conditions would be expected to provide for sediment transport (Transport regime, Table 5; VT ANR 2007, pp. 34-36).

Table 5. Reference sediment regime parameters for Wells River basin 2008 study area reaches

Sediment regime	Natural valley types	Pertinent reference stream types	Applicable Wells River basin reaches
Transport	NC, SC, NW Valley slope >2%	A, B	*
Coarse equilibrium (in = out) & fine deposition	NW, BD, VB Valley slope <2%	C, E	*

NC, Narrowly confined; SC, Semi-confined; NW, Narrow; BD, Broad; VB, Very Broad

Table 6. Pertinent data for characterizing existing sediment regime, using Phase 2 data (VT ANR RCPG 2007)

<table>
<tr><td rowspan="2">Transport</td><td rowspan="4">Incision <1.3</td><td colspan="3">Valley type = NC, SC, or bedrock gorge</td></tr>
<tr><td rowspan="2">Valley type = NW</td><td colspan="2">A, B, G, or F</td></tr>
<tr><td rowspan="2">Coarse equilibrium & fine deposition</td><td colspan="2">Bc, C, E, or D</td></tr>
<tr><td colspan="3">Valley type = BD or VB</td></tr>
<tr><td>Confined storage & transport</td><td rowspan="4">Incision ≥1.3</td><td colspan="3">Valley type = NC or SC</td></tr>
<tr><td>Unconfined storage & transport</td><td rowspan="3">Valley type = NW, BD, VB</td><td rowspan="2">Channel evolution stage = I/II/III/V</td><td>Bank armoring and straightening ≥50%</td></tr>
<tr><td rowspan="2">Fine storage & transport, coarse deposition</td><td>Bank armoring or straightening <50%</td></tr>
<tr><td colspan="2">Channel evolution stage = IV</td></tr>
</table>

Sediment regime departure is determined based on a number of parameters measured in Phase 2 assessments (VT ANR 2007b, pp. 34–36), as summarized in Table 5. These include field signs of active adjustment processes indicating that streams are in a state of disequilibrium, including a likely stage of channel evolution.

Once a stream has entered a state of disequilibrium, it will begin a series of channel adjustments or evolutions to fulfill the physical mandate to restore equilibrium. Schumm (1977 and 1984) has described five stages of channel evolution (Fig. 21) for reaches such as those found in the Project area, where the stream has a bed and banks that are sufficiently erodible to be shaped by the stream over time, paraphrased from the SGA protocols (VT ANR 2006, Appendix C) as follows:

I. Stable — in regime, reference to good condition. Insignificant to minimal adjustment; planform is moderate to highly sinuous.

II. Incision — Fair to poor condition, major to extreme channel degradation. High flow events are contained in the channel, and channel slope is typically increased.

III. Widening/Migration — Fair to poor condition, major to extreme widening and aggradation.

IV. Stabilizing — Fair to good condition, major reducing to minor aggradation, widening and planform adjustments
V. Stable — In regime, reference to good condition. Insignificant to minimal adjustment.

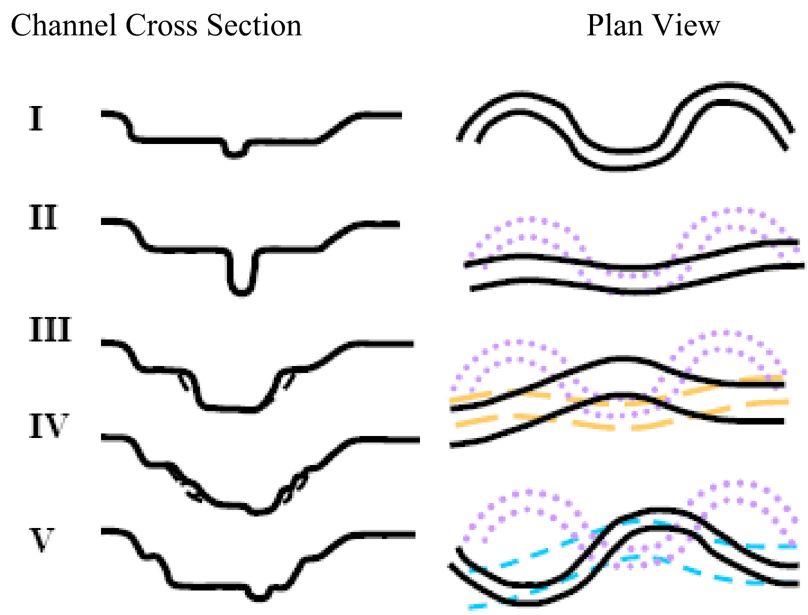

Figure 22. Channel evolution process, showing channel downcutting or incision in Stage II (cross section), widening through Stages III and IV, and floodplain reestablishment in Stage V. Stages I and V represent equilibrium conditions. Plan view shows straightening and meander redevelopment that accompany cross-section changes, a flood-driven process taking place over decades (VT ANR 2007b).

Phase 2 measurements found incision (downcutting) throughout much of the Wells River basin 2008 assessment area, indicating reduced access of the river to historical floodplains in most reaches in conjunction with significant straightening and channelization that have served to increase stream power. Seven of the 14 assessed segments are in stage II evolution, with incision as a dominant process. Of these, all but one have been straightened for much of their length.

Planebed systems (if not reference condition) are often indicative of initial erosion of bed features and subsequent deposition of relatively finer-grained (small cobble, gravel, and sand) particles, which serve to reduce channel bed roughness and thus further increase stream power and transport capacity. There are five segments on the Wells mainstem (M04B, M06B, M07A&B, M08B) described as planebed. These reaches have been extensively straightened.

Sediment regime departures from reference condition are common in the project area, with a total of six of 14 segments being reclassified based on Phase 2 assessment (Table 7; Fig 24). A few of these are due to subreach re-classifications when the Phase 1 reaches were reanalyzed using Phase 2 data. Examples of this are found in M08B, which was mapped as a B-type Transport Reach, but due to valley configuration, is actually a C-type Coarse Equilibrium and Fine Deposition (CEFD) subreach; and in M04S3.01D, which was mapped as an E-type CEFD reach and is actually a B-type Transport subreach. M04 was not given a sediment regime type during the Phase 1 process. The Phase 2 classifies segment A as B-type Transport, and Segment B as E-type CEFD, both of which seem to reflect reference condition sediment regimes, with Segment B being a subreach. Stream type departures that reflect stream adjustment processes are found in four segments. All four were originally mapped as having a CEFD sediment regime and have been converted through stream processes to transport reaches. Two of these have been re-classified as Fine Source and Transport and Coarse Deposition (FSTCD), one as Confined Source and Transport (CST) and one as Unconfined Source and Transport. (UST). Historic or current incision, straightening, and armoring have converted these stream segments from equilibrium to transport.

Table 7. Sediment regime characterization criteria for Wells River corridor planning Project area reaches (see Tables 8 & 9 above for color coding and brief description of sediment regimes).

Reach/Segment Existing Sediment Regime Reference sediment regime in parentheses	Incision Ratio	Natural Valley Type (existing type in parentheses)	Straightening and Bank armor (% range)	Channel Evolution Stage Geomorphic Condition	Existing/Reference Stream Type
Wells River mainstem					
M01 CEFD (CEFD)	1.23 1.9 HEF	B (B)	80-90 90-100	II Fair	C3/C4
M02 CST (CEFD)	1.55	NC (NC)	5-10 >20	II Fair	Bc3/Bc3
M04A T (unknown)	1.00	SC (NC)	None 10-20	I Reference	B2/B2
M04B CEFD (unknown)	1.15 2.18HEF	SC (SC)	20-30 20-30	II Fair	C5/C5
M05 FSTCD (CEFD)	1.39	N (N)	>50 None	II Fair	C5/C5
M06A CEFD (CEFD)	1.00	VB (VB)	None 10-20	IIc* Fair	E5/E5
M06B UST (CEFD)	1.70	VB (B)	90-100 >50	II Fair	C4/E5
M07A FSTCD (CEFD)	1.48	N (B)	90-100 10-20	II Fair	C4/C4
M07B CST (CEFD)	2.14	N (SC)	90-100 5-10	II Fair	F3/B3
M08A T (T)	1.00	SC (NC)	None None	I Reference	B3/B3
M08B CEFD (T)	1.26	SC (N)	90-100 None	II Fair	C5/C5
M09B CEFD (CEFD)	1.00	VB (VB)	10-20 <5	I Good	E5/E4
Un-named tributary to M04					
M04S3.01A CEFD (CEFD)	1.00	VB (VB)	5 5-10	IIc* Fair	E5/E5
M04S3.01D T (CEFD)	1.00	VB (NC)	None None	I Reference	Ba3/Ba3

* Using D evolution model for streams with relatively resistant beds where lateral erosion dominates over incision.

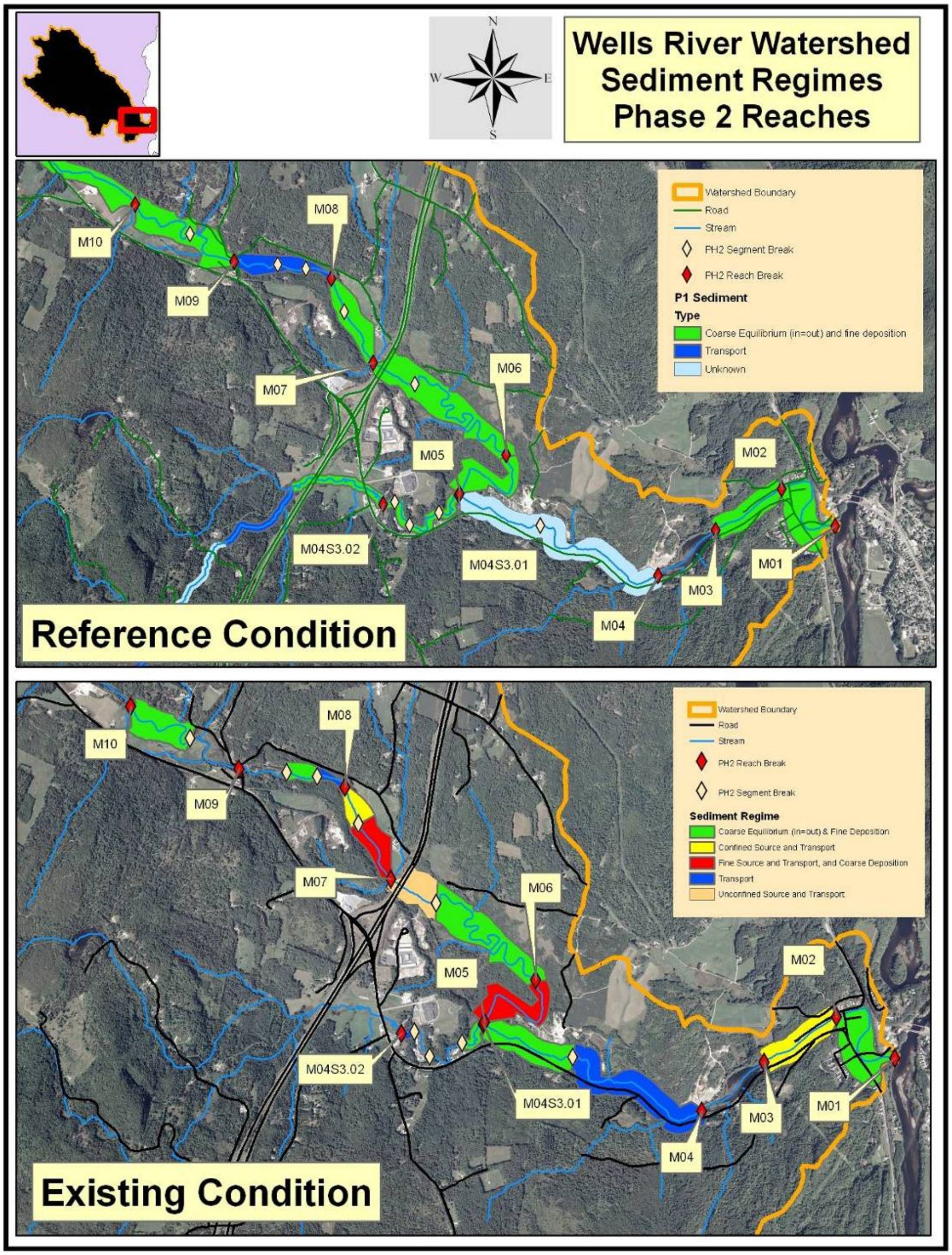

Figure 23: Sediment Regime Departure: Sediment regimes for the Phase 2 project area; reference conditions vs. existing conditions.

With increased stream power prevalent in parts of the study area, sediments are being recruited from upstream reaches and tributaries as downstream reaches attempt to re-establish equilibrium.

With primary channel-forming processes usually occurring on an annual or biannual basis during high flows, coarse bedload sediments can take a good deal of time to move through the stream network and be restricted from such movement by constraints such as bridge and bedrock constrictions. The larger sediments may only be energized in high flow events exceeding these annual events. A compounding factor within this project area is the presence of two dams; one at the top of M02 and one at the top of M08. Both dams have impoundment areas upstream. Fine sediments can move over the tops of these dams at high flow, but coarse sediments are trapped behind the dams. The existence of these dams may explain the relative absence of large depositional features in the project area. Although many reaches indicate a high level of sediment deposition (>5/mile), these features tend to be small in size, and are only very rarely mid-channel bars. Only four steep riffles were mapped in the project area. Sediment-starved sections of stream can be particularly destructive downstream as they erode stream beds and banks in the process of regaining equilibrium.

With extensive development in the stream corridor, as is the case in parts of the project area, constraints to lateral adjustment also become stream adjustment-limiting factors. Fill for roads and building is often compacted material that erodes slowly, but, more importantly, these features are investments that towns and landowners will willingly make, largely to protect themselves from stream encroachment. Figure 23 shows the extent of lateral constraints in the project area.

To summarize, the existing sediment regime in the Wells River 2008 study area features increased stream power. Some deposition is occurring, but not enough to balance degradation. Due to the presence of two dams, the project area presents a potentially sediment-starved system. Of the 14 segments, three are in stage I reference or good condition, seven are incising, and only one has moved through the incision-widening-rebuilding phases to begin stabilizing (M07A). The two remaining reaches best fit a D evolution model (M06A and M04S3.01A). These segments appear to be experiencing widening, without having first incised. This is common when the stream bed is more resistant than the banks. Segment M06A shows some evidence of incision in the upper portion, but generally appears to be widening rather than incising, particularly in the lower reach, where the valley narrows and slopes decrease somewhat.

Primary concerns affecting the project area include the following:

- Incised streams are less able to flood their banks to reduce flow and sediment loading, and these stressors get transferred downstream.
- Where corridor substrates are sands and gravel, banks are very erodible and susceptible to the increased stream power resulting from upstream incision.
- The lack of woody buffers can serve to exacerbate bank erosion and cause rapid lateral movements of the channel.
- Encroachment and development in this corridor is extensive and has the potential to increase without corridor protection.
- Areas where the stream corridor has not been developed or encroached upon are frequently in agricultural use. Limited farm land availability has led to farmers trying to maximize farmable land by haying, pasturing, and tilling right up to the

river's edge; contributing to river instability. Inevitably this leads to bank erosion and the loss of some of this same farm land to the river.

- Corridor protection is generally compatible with agricultural uses, but where buffers need to be established there can be some loss of available crop and pasture land for farming. Overall, however, conservation practices and stream corridor protection can benefit farmers by supporting a less dynamic river system. Losses from unfarmed land can be recouped by not having to invest in stabilization practices and by taking advantage of conservation incentive programs.

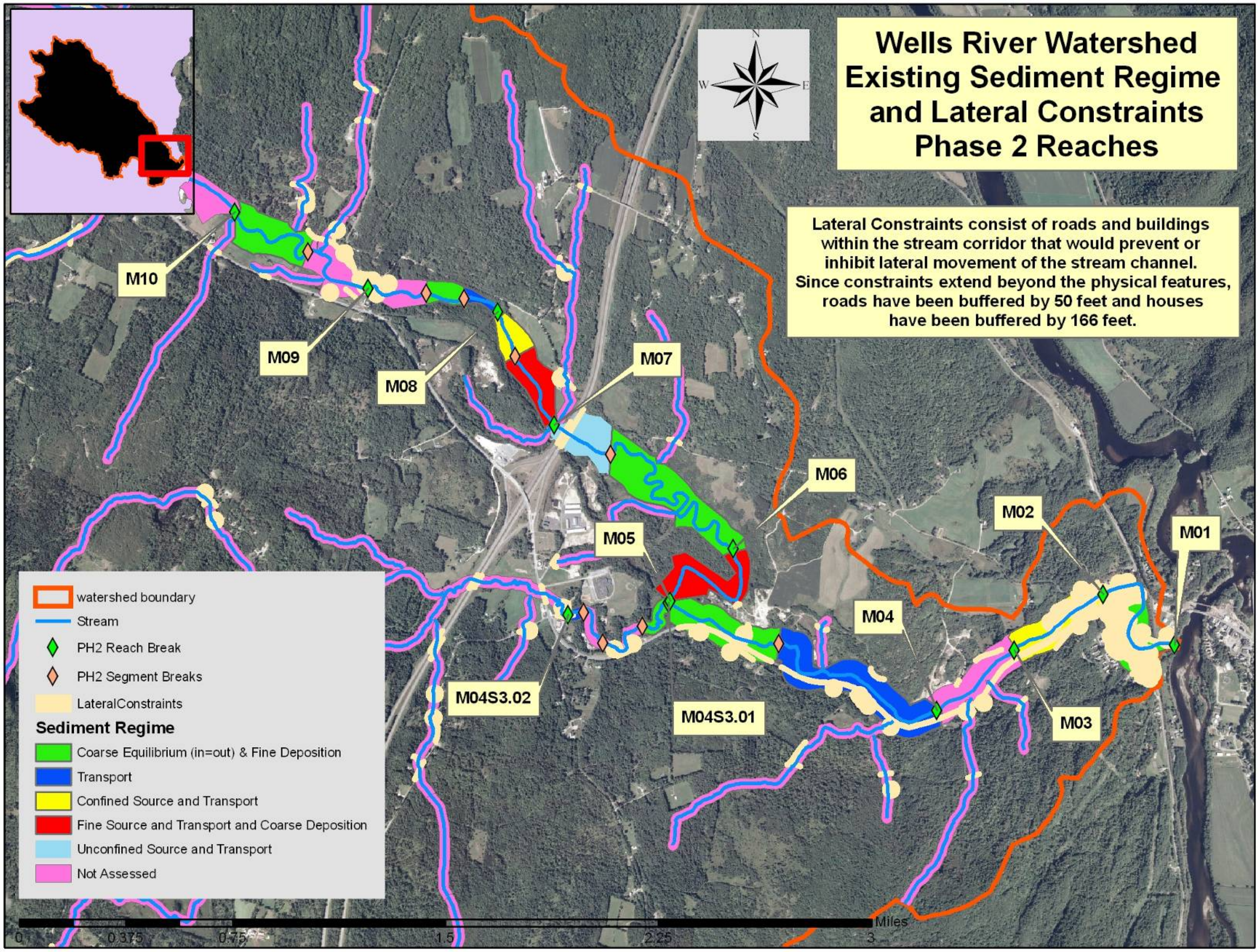

Figure 24. Map of existing sediment regime in conjunction with vertical and lateral constraints to channel evolution for the Wells River reaches within the Wells River corridor planning Project area.

Table 8. Wells River Project area Departure Analysis Table, indicating where river segments are constrained from adjustment, converted to transport streams, and/or have or may someday have potential for attenuating flow and sediment loads

Wells River Phase 2 Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
Wells River mainstem							
M01	Cement weir mid-segment	Human: roads, three bridges, development. Armor 90-100%			X		Very limited due to development
M02	Natural Grade Control and Hydro-dam	Human: roads, development, hydro-dam Armor >20%		X			None
M04A	Natural Grade Control	Human: road, Armor 10-20%	X				Very Limited
M04B	Natural Grade Control	Human: road			X	X Gravel Pit	X If vegetated
M05				X	X	X Gravel Pit	X If gravel pit is vegetated
M06A		Human: agriculture Armor 10-20%			X		X Extensive and Important

Wells River Phase 2 Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
M06B		Human: agriculture, roads, interstate bridges, Armor >50%		X	X		X
M07A		Human: agriculture		X	X		X
M07B		Human: roads, development, agriculture Armor 20-50%		X	X		X Somewhat limited by valley width
M08A	Natural Grade Control	Human: road	X				
M08B		Human: agriculture		X Mapped as transport in Ph 1 process	X		X
M09B		Human: agriculture			X		X Extensive
Un-named tributary to M04							
M04S3.01A		Human: bridge			X		X Extensive

Wells River Phase 2 Departure Analysis Table	**Constraints**		**Transport**		**Attenuation (storage)**		
River Segment	**Vertical**	**Lateral**	**Natural**	**Converted**	**Natural**	**Increased**	**Asset**
M04S3.01B	Coarse substrate		X Mapped as CEFD in PH 1				

5.2 SENSITIVITY ANALYSIS

The preceding departure analysis identifies the watershed and reach-scale stressors that help explain the sediment regime departure currently existing in the Wells River corridor planning Project area. Designing stream corridor protection and restoration projects that are compatible with channel evolution processes, and prioritizing them at the watershed scale, requires an understanding of stream sensitivity.

Sensitivity refers to the likelihood that a stream will respond to a watershed or local disturbance or stressor, and is an indication as to the potential rate of channel evolution (VT ANR 2007 Protocols, Phase 2, Step 7.7; VT ANR RCPG 2007, Section 5.2). While every stream changes in time, a sensitivity rating indicates that some streams, due to their setting and location within the watershed, are more likely to be in an episodic, rapid, and/or measurable state of change or adjustment.

Alteration of sediment and flow regimes (conversion of many segments from equilibrium to transport function), erodible boundary conditions, and relatively high levels of current aggradation are indicative of high to extreme sensitivity in many reaches and segments. Stream type departures (indicating a change from the reference-type channels indicated by Phase 1 analysis; see Appendix A for stream type classification) from Phase 1 to Phase 2 analyses are found in six of the 14 segments. Three of these were caused by subreaching (classifying one segment of a reach as a different reference stream type). Stream type departures that reflect stream adjustment processes and sensitivity are found in three segments.

M06B and M07A have both experienced an E to C stream type departure. Both these segments have been straightened and have subsequently incised. Incision has led to widening to the extent that channel dimensions match a C-type stream, although incision appears to still be the dominant process. Although both segments are experiencing aggradation (and M06B is also experiencing degradation), these stream type departures are not classified as aggradational or degradational, since widening is the cause of re-classification. M07B has experienced a B to F stream type departure. This segment has incised to the extent that it is entrenched and has lost access to its historic floodplain, and as such has experienced a degradational stream type departure.

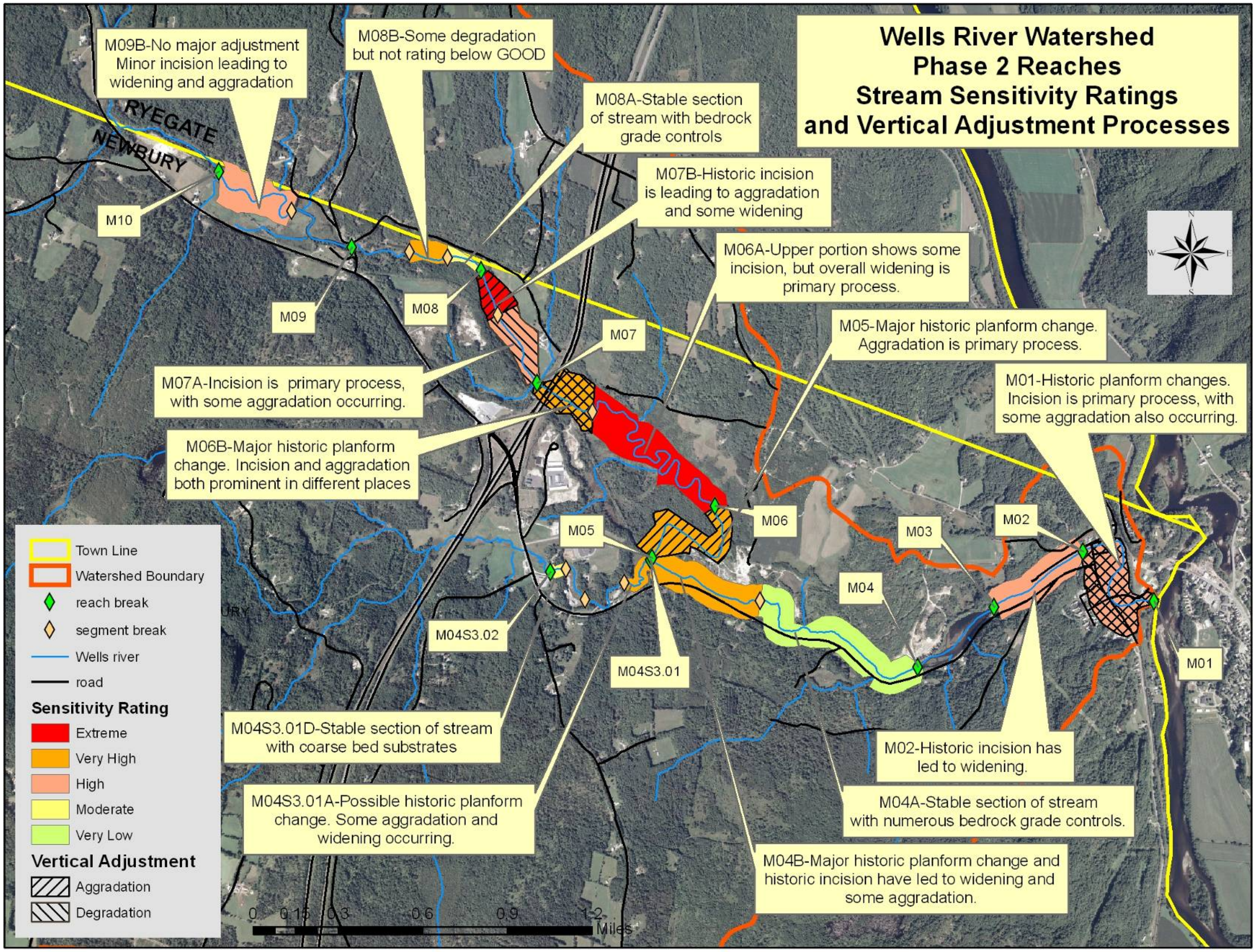

Figure 25: Stream Sensitivity, Vertical Adjustments, and Stream Type Departures for the Wells River 2008 assessment area. Stream type departures are shown with blue labels.

6.0 PRELIMINARY PROJECT IDENTIFICATION

The preceding departure and sensitivity analysis provides the watershed and reach-scale background to inform prioritization and selection of projects in a manner that maximizes their effectiveness and reduces the likelihood of failure, specifically by assessing underlying causes of channel instability. With the information from these maps and tables, a stepwise process has been conducted to identify the following actions, in order of priority, in a manner designed to facilitate restoration of the stream to equilibrium conditions (VT ANR RCPG 2007, Ch. 6; chapter number is included here with the step):

6.1. Protecting river corridors
6.2. Planting stream buffers
6.3. Stabilizing stream banks
6.4. Arresting headcuts and nick points
6.5. Removing berms and other constraints to flood and sediment load attenuation
6.6. Removing/replacing structures (e.g., undersized culverts, constrictions, low dams)
6.7. Restoring incised reaches
6.8. Restoring aggraded reaches

As indicated in Section 5.2 of this report, the high to extreme sensitivity ratings of many reaches in the Wells River Project area indicate that passive geomorphic projects may provide an appropriate management alternative in the Project area. Encroachment issues are commonplace, placing a particularly high priority on Step 6.1: Protecting river corridors. Step 6.2: Planting stream buffers, should also receive a high priority, as there appears to be a strong relationship in the study area between extent of vegetated cover and erosion impacts (see Section 5.1.3c, Boundary Conditions and Riparian Modifiers). Step 6.3: Stabilization of stream banks, is generally not recommended due to vertical instability in many reaches and channel-widening evolution processes that might increase the likelihood of failure of such efforts (and escalating maintenance costs). Step 6.3 recommendations need to be carefully assessed with regard to site-specific recommendations and critical infrastructure. Given the current conversion of many reach sediment regimes from equilibrium to transport types, further armoring of banks or bed is likely to intensify downstream deposition and flooding impacts.

Incision is prominent in many of the Wells River reaches. Only one headcut was mapped, however, in association with M06A. As this reach has somewhat variable processes occurring simultaneously, it shows as having no vertical adjustment. It is not clear that this headcut is moving upstream, since widening and aggradation are also actively occurring upstream of the headcut. Step 6.4, for this reach, is not a likely recommendation. One berm was identified on segment M01. This berm protects a residential area from flooding and it is unlikely that Step 6.5: Removing berms, would be a popular recommendation for the village of Wells River. Step 6.6, Replacing Structures, has some applicability within the project area. Bridges are found in M01, M04, M06 and M08. Structures in M01 and M04 should be evaluated for this particular recommendation. Steps 6.7 and 6.8, which involve more active restoration efforts, would require careful consideration (likely involving engineering-grade surveys and analysis) in this project area.

6.1 REACH DESCRIPTIONS—PRELIMINARY PROJECT IDENTIFICATION

With these overarching considerations, preliminary project identification for the Wells River Project area is presented on a reach-by-reach basis in the following pages. "Left bank" and "right bank" in the reach descriptions are referenced looking downstream. Background imagery for the reach maps is from the National Agricultural Imagery Program (NAIP), dated 2003. Valley walls delineated on the reach maps are based on the Phase 2 field verification of Phase 1 valley walls.

6.1.1 Reach M01: Wells River mainstem from just upstream confluence with the Connecticut River to just upstream of the Water Street Bridge.

Reach M01 comprises 2,325 feet (0.44 miles). It begins at the confluence with the Connecticut River and continues to just upstream of the Water Street Bridge (Figure 26). The reach was not segmented during the Phase 2 process. The valley for this reach has been fully developed for the village of Wells River and the flood plain appears to be somewhat elevated. The entire length of stream has been straightened and armored. The Phase 1 process classified this reach as a C riffle-pool with a gravel substrate and the Phase 2 assessment retained this classification.

This reach lies on an alluvial fan. Specific evidence of this fan is somewhat masked by the extreme level of development here. The reach is characterized by residential lawns and houses in the upstream end, and more industrial/commercial development in the downstream end. At the very base of the reach there are a few hundred feet of undeveloped flood plain.

Historic (1924) topo shows two railroad lines in this segment (http://docs.unh.edu/VT/barre24ne.jpg) (Fig.4). One runs north-south and crosses downstream of the railroad road bridge. The other runs along the north bank of the river for the upstream half of the reach and at some distance from the stream for the downstream half of the reach. It is a little hard to fathom, at this time, how this old RR track managed to get past a point at the upstream meander curve, to cross the north-south railroad above. The elevation of the north-south railroad seems considerably higher in elevation than the presumed location of the east-west railroad. It almost appears that there was room for the RR along the left bank in 1935, where now there is only a steep slope. Possibly the stream has meandered more in the direction of that left bank since 1935.

This segment appears to have had the potential to play a vital role as an attenuation asset upstream of the Connecticut confluence, but straightening, armoring, and an elevated floodplain have essentially eliminated that potential. Key features of this segment include:

- Dominant buffers for both banks are <25 ft.
- Road encroachment is found on both sides for >50% of the segment.
- Development is found on both sides for >50% of the segment.
- The segment has been >75% straightened.
- Armoring is present for almost the entire length on both banks.
- There are 3 stormwater inputs to the segment.
- The area has flooded in the past and some dredging may have occurred following flooding.

- The stream is in stage II, with incision the dominant process and widening limited by armor.
- Substrate is cobble, sensitivity rating is High, geomorphic condition is Fair.

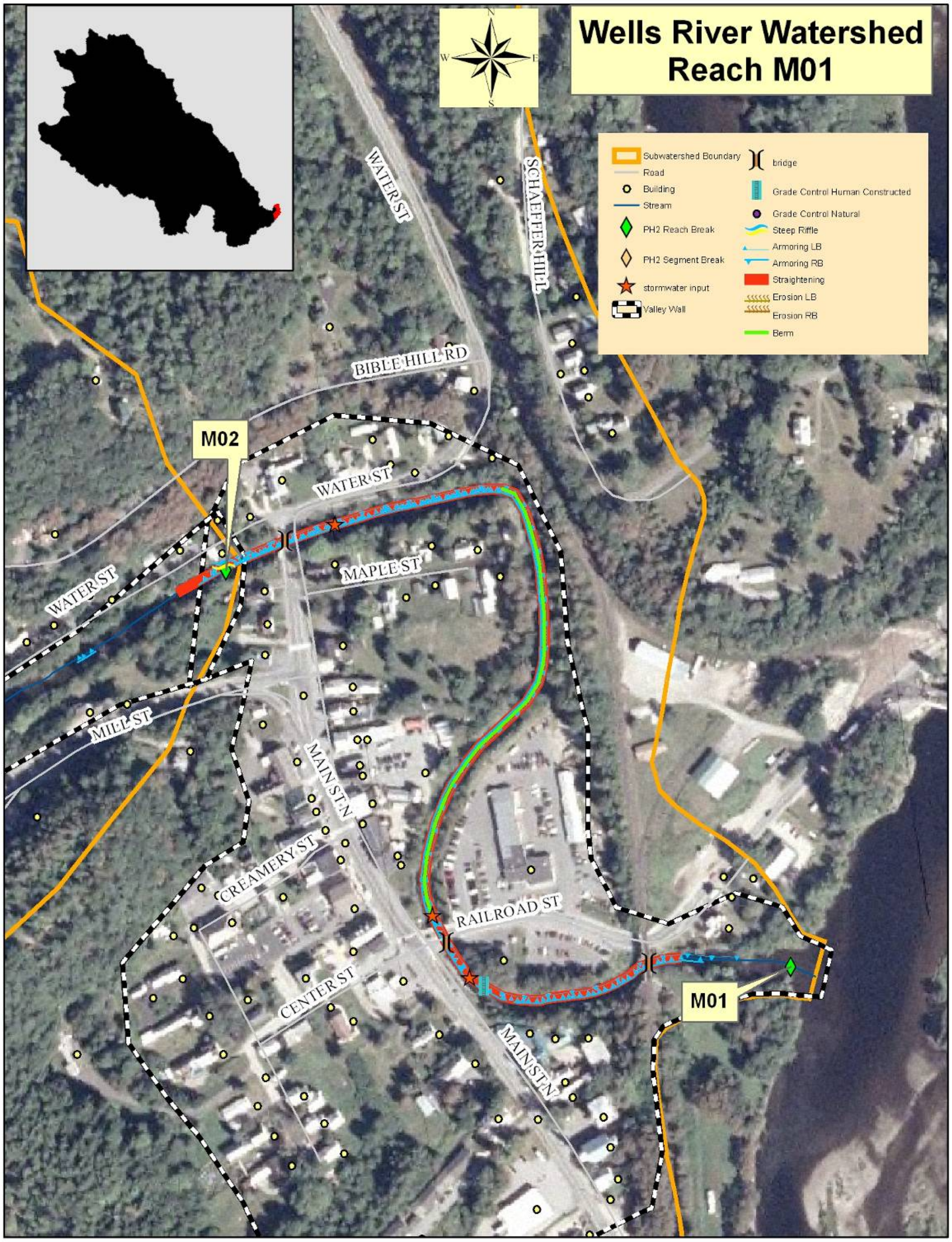

Figure 26: Reach M01 of the Wells River mainstem.

Table 9. Wells River Reach M01: Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M01-0 (1)	Protect river corridor	High	High	N	Area is almost completely developed, but some oversight of stormwater management and construction/reconstruction activities is critical.
M01-0 (3)	Stabilize stream bank	High	Mode rate	Y	At the upstream meander curve the stream has experienced erosion on the left bank. It is currently armored but vulnerable to future erosion. The property on the slope above is at risk. Since the berm on the right bank is necessary to protect the village from flooding damage, there is no option for this area other than to re-enforce the bank to prevent ongoing erosion at the turn.

6.1.1 Reach M02: Wells River mainstem from just upstream of the Water Street Bridge, to the hydroelectric dam impoundment.

Reach M02 comprises 1,977 feet (0.37 miles). It begins upstream of the Water Street bridge and continues to the hydroelectric dam impoundment (Figure 27). The reach was not segmented during the Phase 2 process. The valley for this reach is narrow and straight. The entire length of stream has been encroached upon, and the development of a run-of-the-river hydroelectric dam in 1912 has, over time, altered flow and sediment load into the reach. The Phase 1 process classified this reach as a Bc riffle-pool with a cobble substrate and the Phase 2 assessment retained this classification.

Key features of this segment include:

- Road encroachment is found on both sides for >50% of the segment.
- Development is found on one side for >50% of the segment.
- Armoring is present for >25% of the right bank.
- There is one stormwater input to the segment.
- There are two grade controls in the segment: ledge in mid-segment, and the hydro-dam at the top of the segment.
- The stream is in stage II, with incision the dominant process and widening limited by armor and bedrock.
- Substrate is cobble, sensitivity rating is High, geomorphic condition is Fair.

Table 10. Wells River Reach M02: Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers)

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M02-0 (1)	Protect river corridor	High	Low	N	Area is already developed almost to capacity, but some oversight of stormwater management and construction/reconstruction activities is critical.

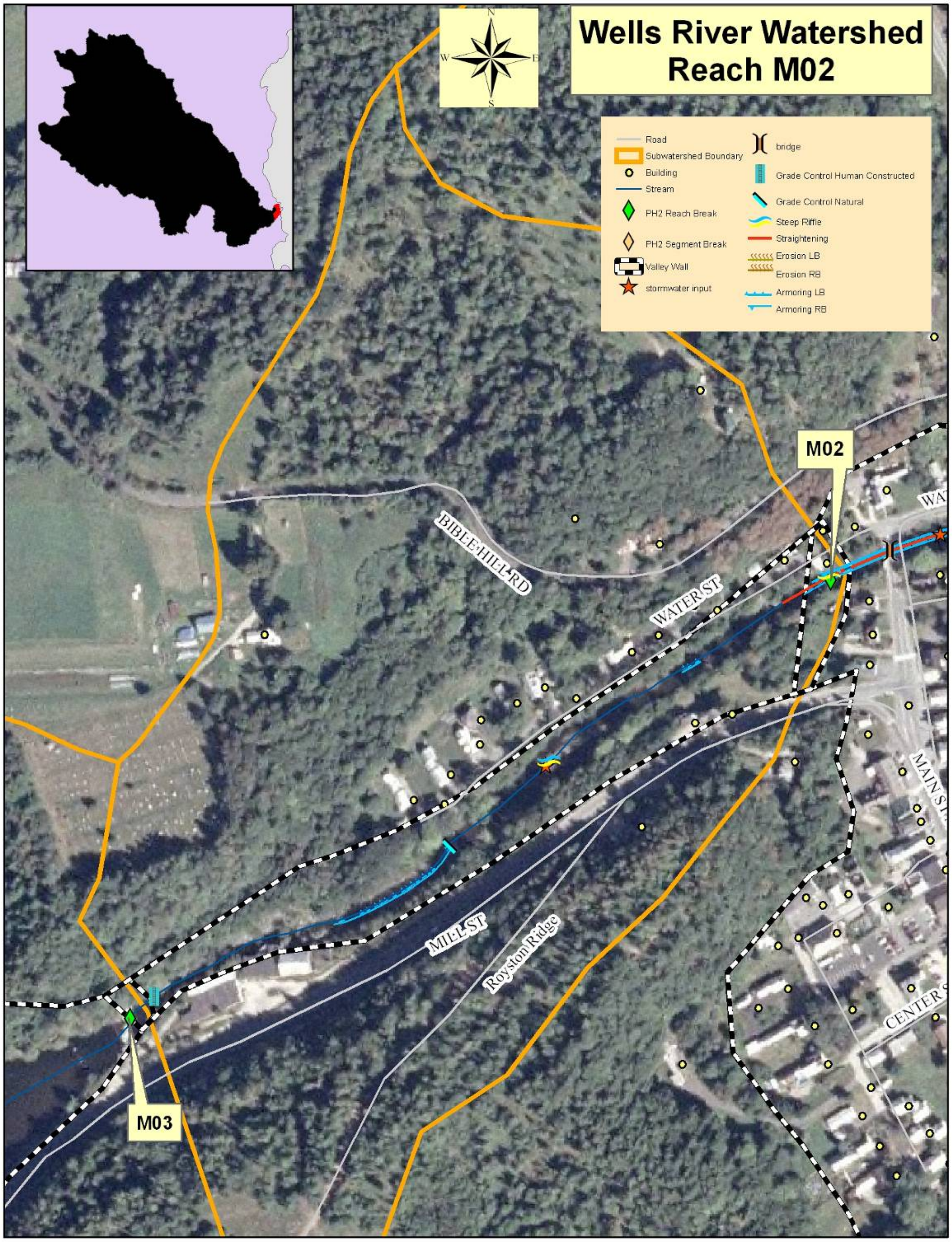

Figure 27: Reach M02 of the Wells River mainstem.

6.1.1 Reach M04: Wells River mainstem from the top of the impoundment for the Hydro-dam (at the site of the historic RR crossing), to just upstream of the tributary confluence approximately 1,600 feet upstream of the now-defunct access bridge to the left bank gravel pit.

Reach M04 comprises 6,220 feet (1.18 miles). It begins at the top of the impoundment from the hydroelectric dam and continues to just upstream of confluence with Fish Pond Brook, entering from the west (Figure 28). The reach was segmented once during the Phase 2 process. The valley for this reach was characterized as semi-confined, with a B-type stream, a step-pool bedform, and a boulder substrate.

Segment A is 3,913 feet long and ends just upstream of the old dam site (US Fish and Wildlife Recreational Area). The Phase 2 process confirmed a B-type, step-pool, boulder substrate stream, but found the valley to be narrowly confined. Road encroachment is a factor along the right bank, particularly in the lower part of the reach, but the confinement was judged to be primarily natural (no human-caused change in valley type).

Historic (1924) topo shows the old railroad line starting out on the north side of the stream and crossing over to the south side, approximately 850 feet upstream. The old abutments are still visible (Figure 29), and the old bed is visible at the east end between Route 302 and the river. At the west end of this segment, the old railroad bed looks to have been incorporated into Route 302.

Figure 28: Wells River mainstem, Reach M04, old railroad bridge abutment.

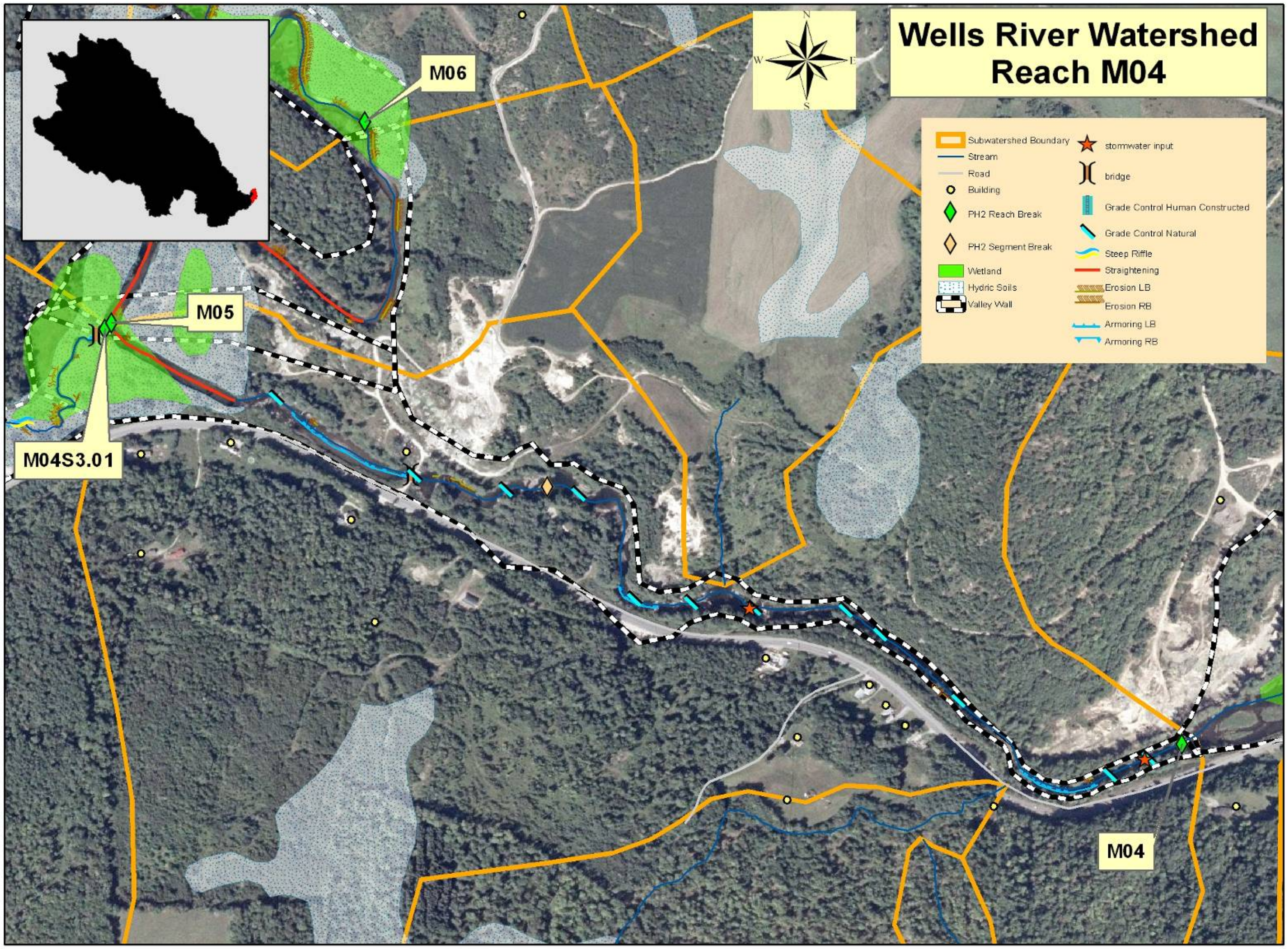

Figure 29: Wells River mainstem, Reach M04 segments A and B.

This segment is characterized by multiple bedrock grade controls and forested buffers. Stream slope varies from fairly steep (in areas of bedrock cascades), to much flatter between grade control features. The upper part of the segment has a Fish and Wildlife recreational area along the right bank. Key features of this segment include:

- Dominant buffers for both banks are >100 ft.
- There is road encroachment along almost the entire right bank.
- There is development along >50% of the right bank.
- Armoring is present for 10-20% of the right bank.
- There are nine bedrock grade controls in this segment, four of which have total heights over 13 feet.
- There are two stormwater inputs to the segment
- There are two old abutments in the downstream part of the segment, one for the railroad and another for an unknown purpose.
- There is an old mill at the top of the segment.
- There is a seep area that may be leaking leachate from an old landfill area on the left bank.
- The stream is in stage I, quite stable.
- Substrate is boulder, sensitivity rating is Very Low, geomorphic condition is Reference

Figure 30: Reach M04 Segment A has numerous grade control features, some of which are large (upper left), a fair amount of road encroachment and armoring (upper right), a historic dam site (lower left), and some potentially problematic leachate (lower right).

Segment B is 2,308 feet long, with a much lower slope than Segment A, and a sand substrate. There are still bedrock features, but they are more intermittent, with longer stretches of flat water between them. This segment was designated as a subreach, with a reference C-type stream in a narrow valley. In reference condition this segment would be expected to have a dune-ripple bedform, but due to straightening has degenerated to plane bed. This area, along with the next reach upstream, is the receiving area for fine sediments being transported from upstream. These sediments drop out when flow rates are reduced by bedrock controls. The old railroad bed is not visible in the downstream end of the segment, but is now found in a public footpath maintained by US Fish and Wildlife at the upper end of the segment, along the right bank. Close to the top of the segment, where the railroad bed is right up against the stream, there are metal features (a chain, an iron rod) embedded in the rock beside the stream (Figure 31). It is possible these were used historically as part of a barrier to log movement, since there is no evidence of this being a mill site.

Figure 31: Reach M04 Segment B has embedded iron features, such as this chain, that indicate historic activities that might be related to log storage before loading onto rail cars.

Key features for Segment B include:

- The dominant buffer along both banks is <25 feet.
- There is encroachment along more than 75% of the right bank.
- There has been gravel pit development along >50% of the segment.
- There is armoring along 20-30% of the right bank.
- Approximately 20% of the segment has been straightened.
- There are three bedrock grade controls in the segment, the largest of which has a total height of 10 feet.
- A defunct bridge to the gravel pit area is found at the lower end of the segment.
- There is a significant area of wetland and hydric soils mapped at the top of this reach.
- The stream is in stage II, with incision as the dominant process. There is some aggradation occurring here, likely from the combination of bedrock grade controls downstream, a bridge constriction, and excessive erosion in upstream reaches.
- Substrate is sand, sensitivity rating is Very High, and geomorphic condition is Fair.

Figure 32: Reach M04 Segment B is characterized by having fairly low gradient (top), except where there are bedrock grade controls, such as that found under the now-defunct gravel pit bridge (bottom left). The gravel pit (bottom right) stretches along the entire left bank of this segment, but is no longer actively being used

Table 11. Wells River Reach M04: Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M04A M04B (1)	Protect river corridor	High	High	N	Both segments are encroached upon or protected on the right bank, but left banks are vulnerable to development or further gravel pit extractions. There is a seep area close to the left bank towards the top of Segment A that is possibly landfill leachate.
M04B (2)	Plant stream buffer	High	High	Y	The gravel pit along the left bank is still not completely revegetated.
M04B (6)	Remove structure	High	Mod erate	Y	The old gravel pit bridge is defunct and decaying, and causes a channel restriction.

6.1.1 Reach M05: Wells River mainstem from just upstream of the tributary confluence for MO4S1 that crosses under the old railroad track from the west to 2,824 feet upstream where the valley begins to broaden out into a wider valley with some wetland associated with it.

Reach M05 is 2,824 feet (0.53 miles) in length. It begins at the first large meander that looks artificial (Figure 33), just upstream of the tributary confluence for MO4S1, and continues approximately 1,000 feet upstream of the third artificial-looking meander, where the valley begins to widen and the meanders begin to have a more normal pattern. This reach was not segmented during the Phase 2 process. This reach was characterized during the Phase 1 process as having a narrow valley with a C-type stream, dune-ripple bedform, and sand substrate. The Phase 2 process confirmed this characterization. The fairly large amount of wetland and hydric soils present in this reach valley indicate that this reach has the potential to be a significant attenuation asset.

This reach is very strange looking, from an aerial perspective, and it is highly unlikely that it could have developed this meander pattern naturally, since streams generally follow a sine-wave pattern unless there are bedrock valley walls that redirect stream flow in an unusual way. There is no bedrock in evidence in the bed or banks of this section of the Wells, so it is safe to conclude that this reach has been significantly straightened and altered by humans.

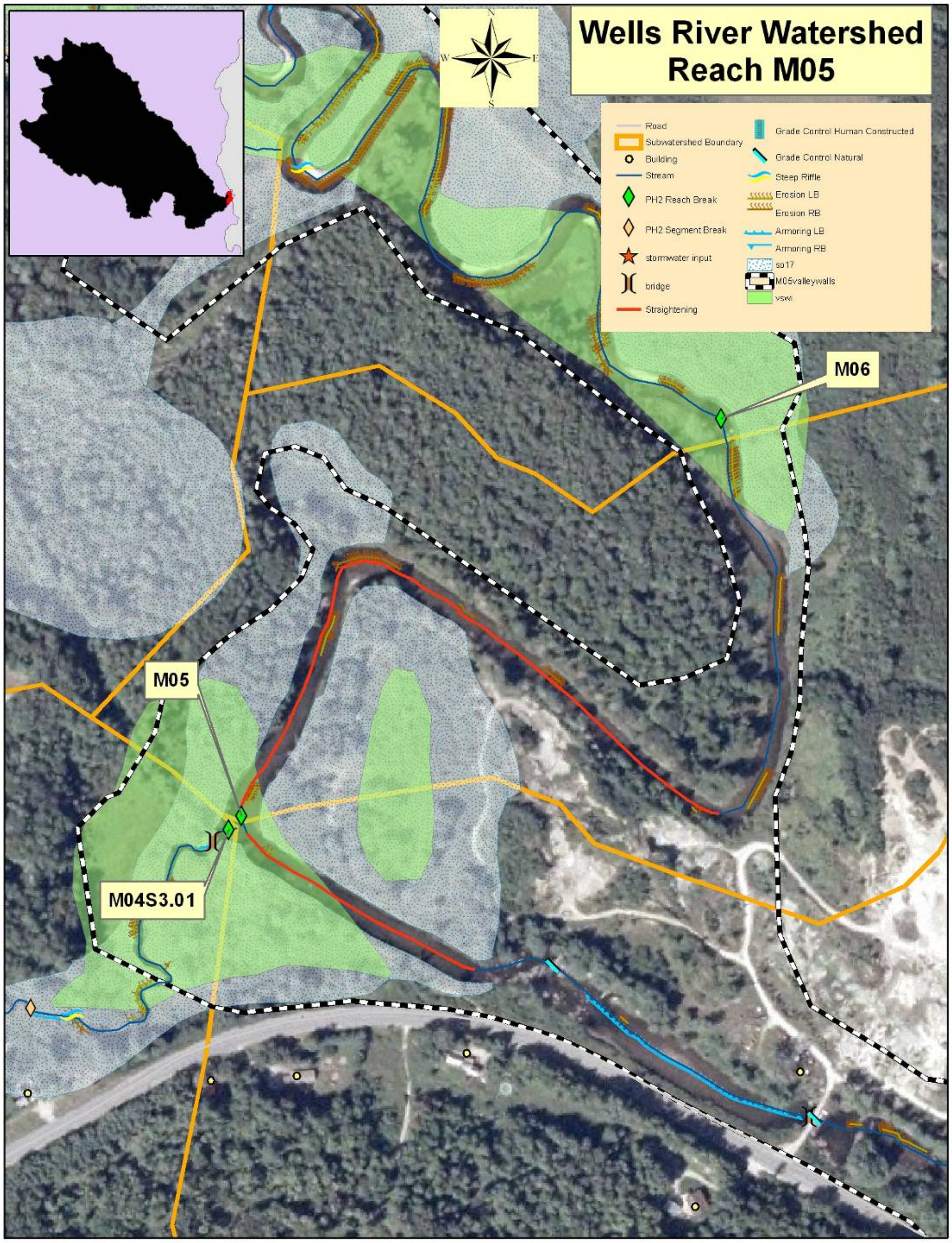

Figure 33: Wells River mainstem, Reach M05

Topographic maps from 1935 and 2009 (Figure 34) show distinct changes in form. Unfortunately, the 1935 map appears to be inaccurate, since the entire right valley wall along the present-day stream channel is steep and elevated to an extent that would preclude the possibility of a stream channel anywhere in this vicinity. The only possibility along the right bank lies where the railroad cut goes through the hill into a broad wetland valley to the north. There is clearly a connection from this area back to the mainstem location in the next reach upstream (see Figure 33). Having considered the possibility that historically the stream came through this cut in the hill, it was discarded due to the narrow shape of the cut (narrower than the Wells stream channel) and the difference in elevation between the cut through the hill and the Wells mainstem at the confluence of MO4S1. Along the left bank, in the vicinity of the upstream-most meander of M05, there is another possibility of a historic channel that could have continued straight (to the east) here, through the gravel pit area to the present-day location of the Wells somewhere in the vicinity of the gravel pit bridge (Figure 35).

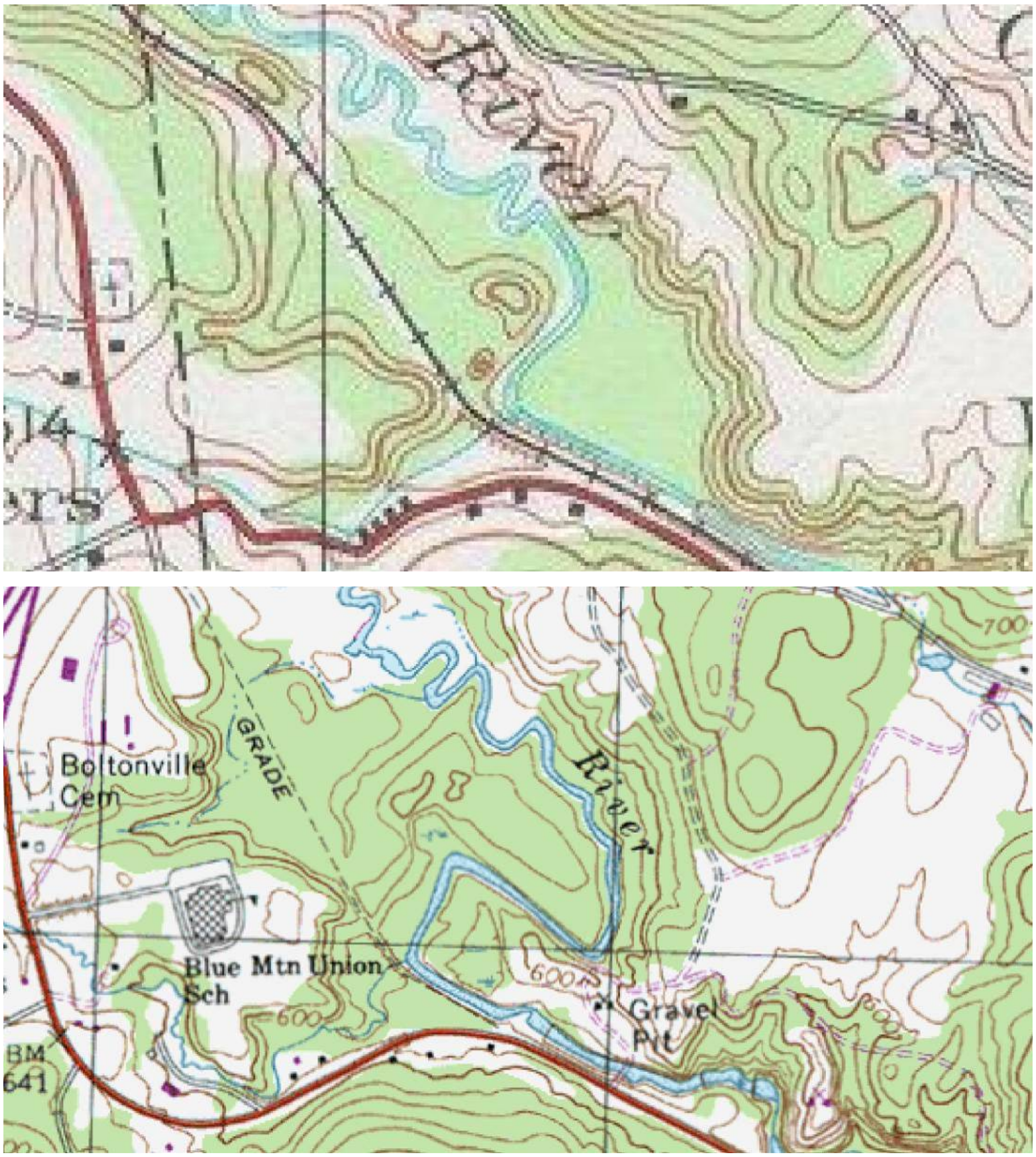

Figure 34: Topographic maps of M05 from 1935 (top) and 2009 (bottom) show distinct changes in the planform of this section of river. Unfortunately, for those of us trying to solve this mystery, the topography is such that the 1935 topo map is clearly incorrect. Nevertheless, the differences in these topos further support the supposition that the stream was re-routed.

Since so much material has been moved around in the gravel pit area, it is impossible to tell for sure, but there is no evidence to permanently refute this hypothesis. Another part of this mystery concerns the historic location of tributary MO4S1. There is wetland and hydric soil mapped in the area to the northeast of the confluence of this tributary and the mainstem, including areas that look like old channel. Pre-railroad building, was this area used by this tributary as it meandered north and east to the mainstem?

Figure 35: Reach M05: Potential historic route of the stream at the site of the upstream-most meander could have had the stream going straight (left to right) through this area that is now elevated road bed.

Key features of reach M05 include:

- Dominant buffers on both banks are >100 feet and forested.
- More then 50% of this reach has been straightened.
- There is no encroachment or development on the reach.
- Erosion is found for approximately 20% of the reach length, on the left side.
- There is a significant area of wetland and hydric soils in the lower portion of the reach and again at the very top of the reach.
- The reach is in stage II, with incision prominent but, in general, processes seeming somewhat arrested.
- Substrate is sand, sensitivity rating is Very High, and geomorphic condition is Fair.

Table 12. Wells River Reach M05: Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M05-0	Protect river corridor	High	High	N	The left bank of this section of stream is potentially unstable. Gravel pit activity has reduced the elevation close to the level of the stream (or lower in one instance) and the distance between the river and the pit is potentially not adequate protection in an extreme flood event or further meander migration.

6.1.1 Reach M06: Wells River mainstem from approximately 1,000 feet upstream of the most upstream meander of the unusual "dogleg" of M05, to approximately 150 feet upstream of the I-91 overpass (upstream of a small tributary confluence).

Reach M06 is 6,957 feet (1.32 miles) in length. It begins 1,000 feet upstream of the last meander on the M05 dogleg and continues upstream to just past a small tributary confluence that enters upstream of the I-91 overpass (Figure 35). This reach was characterized during the Phase 1 process as being an E-type stream with a dune-ripple bedform and sand substrates, in a very broad valley. The reach was segmented once.

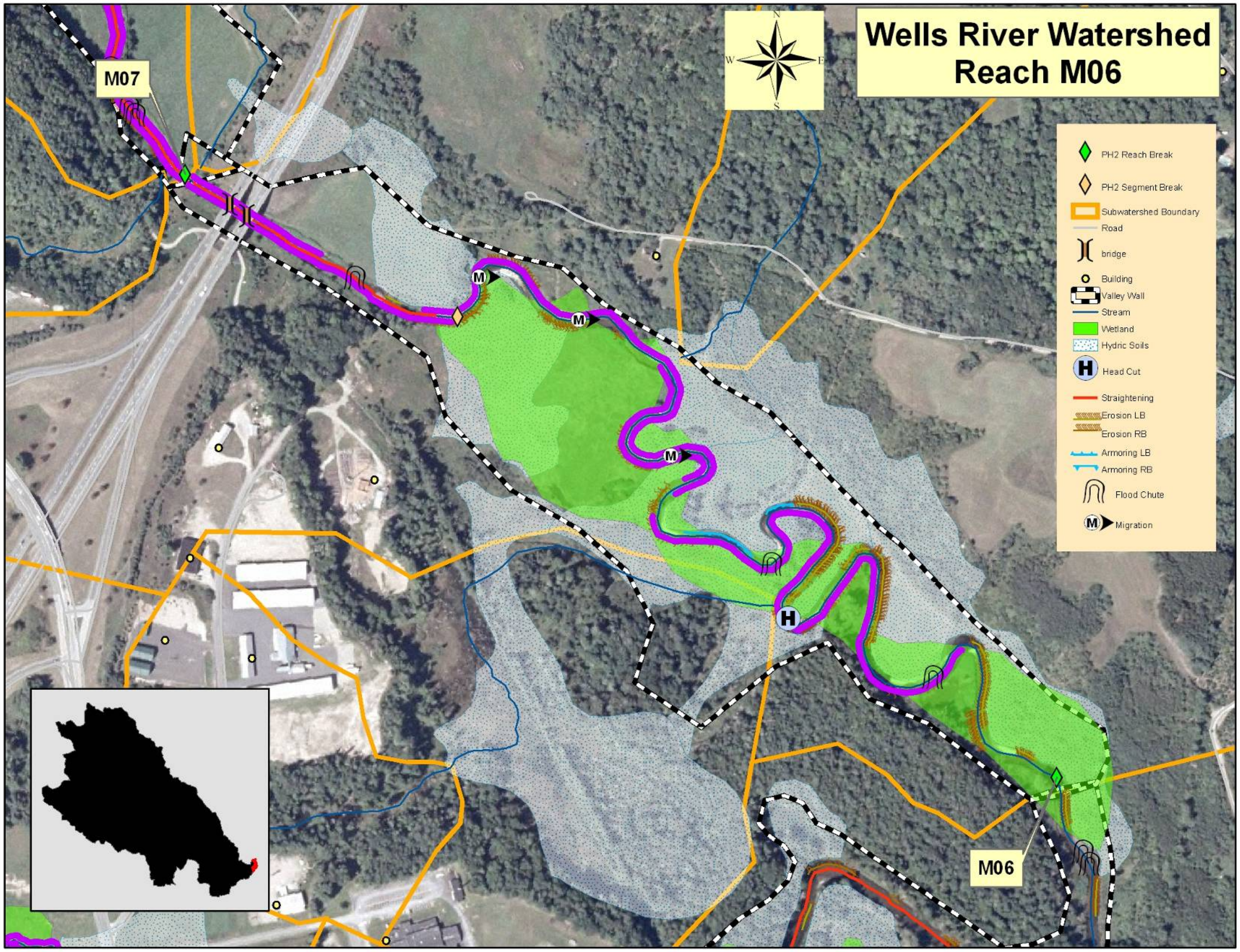

Figure 36: Wells River mainstem reach M06, Segments A and B.

Segment A comprises the dominant portion of the reach length: 5,779 feet. This segment retains the Phase 1 classification of stream and valley type and is characterized by having an unforested buffer, significant bank erosion (Figure 37), and deep meander bends. The entire valley for this segment is underlain by wetland and hydric soils, making this area extremely valuable as an attenuation asset. A D evolution model was used for this segment since lateral movement dominates stream processes. Processes tend to vary from the upstream to downstream portions of this segment. The upstream part of this segment shows more signs of incision. The downstream part has floodplain access between the deep meander bends. The cross-section taken for this segment best represents the downstream part and so indicates no incision. For the entire segment, however, widening appears to be the dominant process occurring, and there is signicant evidence of ongoing planform adjustments. Key features for Segment A include:

- Dominant buffer on the left bank and sub-dominant on the right bank are <25 ft., with a total of 5,770 feet of unbuffered bank.
- Buffer vegetation is almost entirely herbaceous (and often invasive species).
- Erosion is found along >30% of the length for both banks. Average height of erosion is 4-5 feet.
- Armoring is found along 10-20% of the segment along the left bank.
- Tributary rejuvenation was noted, and one head cut was mapped.
- This segment is in stage IIc of a D evolution model, where lateral movement of the stream dominates over incision processes, due to banks being more erodible than the bed.
- Substrates are sand, sensitivity rating is Very High, and geomorphic condition is Fair.

Figure 37: Reach M06 Segment A is characterized by having fine grained substrates and a large amount of bank erosion

Segment B is 1,177 feet in length and is characterized by having been extremely manipulated when Interstate 91 was built in the 1960s. A tributary coming in from the northwest was rerouted and a meander on the mainstem appears to have been eliminated

(Figure 38). This may have been done for agricultural purposes as well, since the re-routing freed up land which is currently agricultural (see Figure 36). The present-day channel is channelized and heavily armored. This segment and its valley were re-classified during the Phase 2 process as a C-type stream in a broad valley, with a plane bed bedform and a gravel substrate.

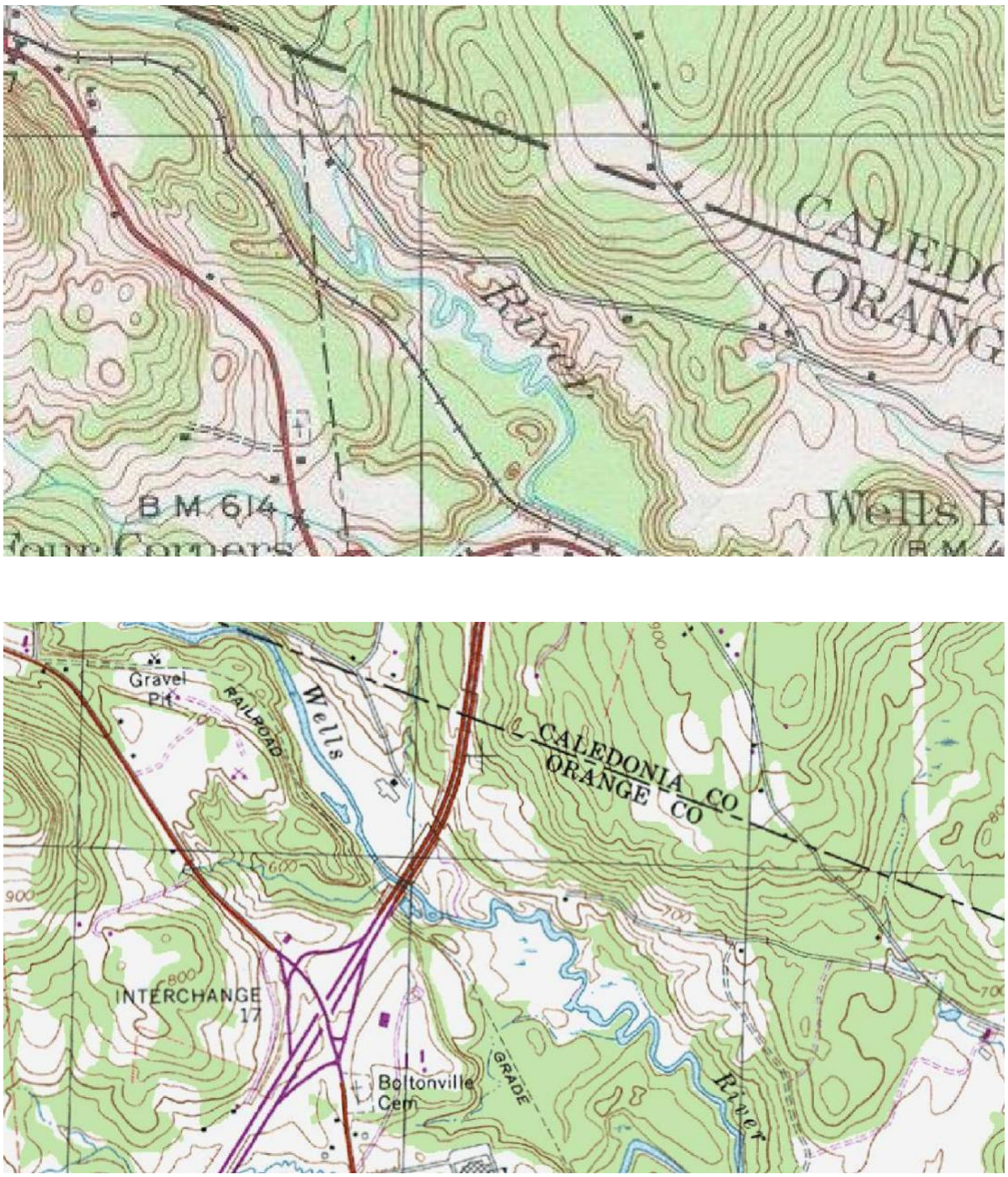

Figure 38: Topographic maps from 1935 (top) and 2009 (bottom) show that a tributary entering the Wells River mainstem was rerouted for the building of I-91. At the same time, a meander curve in the mainstem appears to have been eliminated.

Key features for Segment B include:

- Dominant buffer on the left bank and subdominant buffer on the right bank are <25 feet. In all, there is 1,879 feet of unbuffered bank.
- Buffer vegetation is limited to herbaceous plants (many are invasive).
- The entire segment has been straightened.
- Armoring is present along >50% of both banks.
- Tributary rejuvenation was noted.
- The segment is in stage II, with incision dominating stream processes. Widening is inhibited by armoring and there is localized widening where armoring is absent.
- Substrate is gravel, sensitivity level is Very High, and geomorphic condition is Fair.

Figure 39: Reach M06, Segment A has been channelized and straightened under Interstate 91.

Table 13: Wells River Reach M06: Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M06A M06B	Protect river corridor	High Moderate	High Moderate	N	This entire reach (and particularly the lower segment) is an important attenuation asset. Development potential on the agricultural fields in this valley is high.
M06A	Plant stream	High	High	Y	Low cost benefit potential. Both segments

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M06B (2)	buffer	High	Moderate		have very high to extreme sensitivity ratings, with major current adjustments.

6.1.1 Reach M07: Wells River mainstem from approximately 150 feet upstream of the I-91 overpass to the narrowing of the valley and the end of agricultural fields along the left bank, 2,349 feet upstream.

Reach M07 is 2,349 feet (0.44 miles) in length. Beginning upstream of the I-91 overpass, it continues upstream through primarily agricultural lands to a point where the valley narrows and agricultural uses cease. (Figure 39). This reach was characterized during the Phase 1 process as having a broad valley with an E-type stream, a riffle-pool bedform, and a gravel substrate. A historic landfill high up on the right valley is delivering leachate to the stream valley below. Efforts are being made by the State of Vermont to test the leachate from this source. The reach was segmented once.

Segment A is 1,551 feet in length. It was re-classified during the Phase 2 process as having a C-type stream, and a plane bed bedform. It retained the gravel substrate and broad valley. This segment is dominated by agricultural use along both banks. Straightening in this reach and some entrenchment upstream are leading to bank erosion where banks are unbuffered.

Key features for Segment A include:

- Buffers on both banks are <25 feet for almost the entire length of the segment. In all, there are 3,034 feet of unbuffered bank.
- Agricultural use dominates the valley: both pasture and hay.
- The entire segment has been straightened.
- Armoring is present along 10-20% of the left bank.
- Erosion is found along > 20% of the right bank.
- There is a stream ford.
- The segment is in stage II, with incision dominating stream processes.
- Substrate is gravel, sensitivity level is High, and geomorphic condition is Good.

Segment B is 798 feet in length. This section of stream was designated a subreach with a reference B-type stream in a semi-confined valley. Straightening of the stream in this reach appears to have led to incision to the extent that this particular segment has undergone a stream type departure from a reference B-type to an F-type stream, and a bedform change from riffle-pool to plane bed. Entrenchment is not particularly deep at this time, as witnessed in Figure 40. The bedform is plane bed, and the substrate is cobble. Slopes are also distinctly steeper in this segment (see Figure 40).

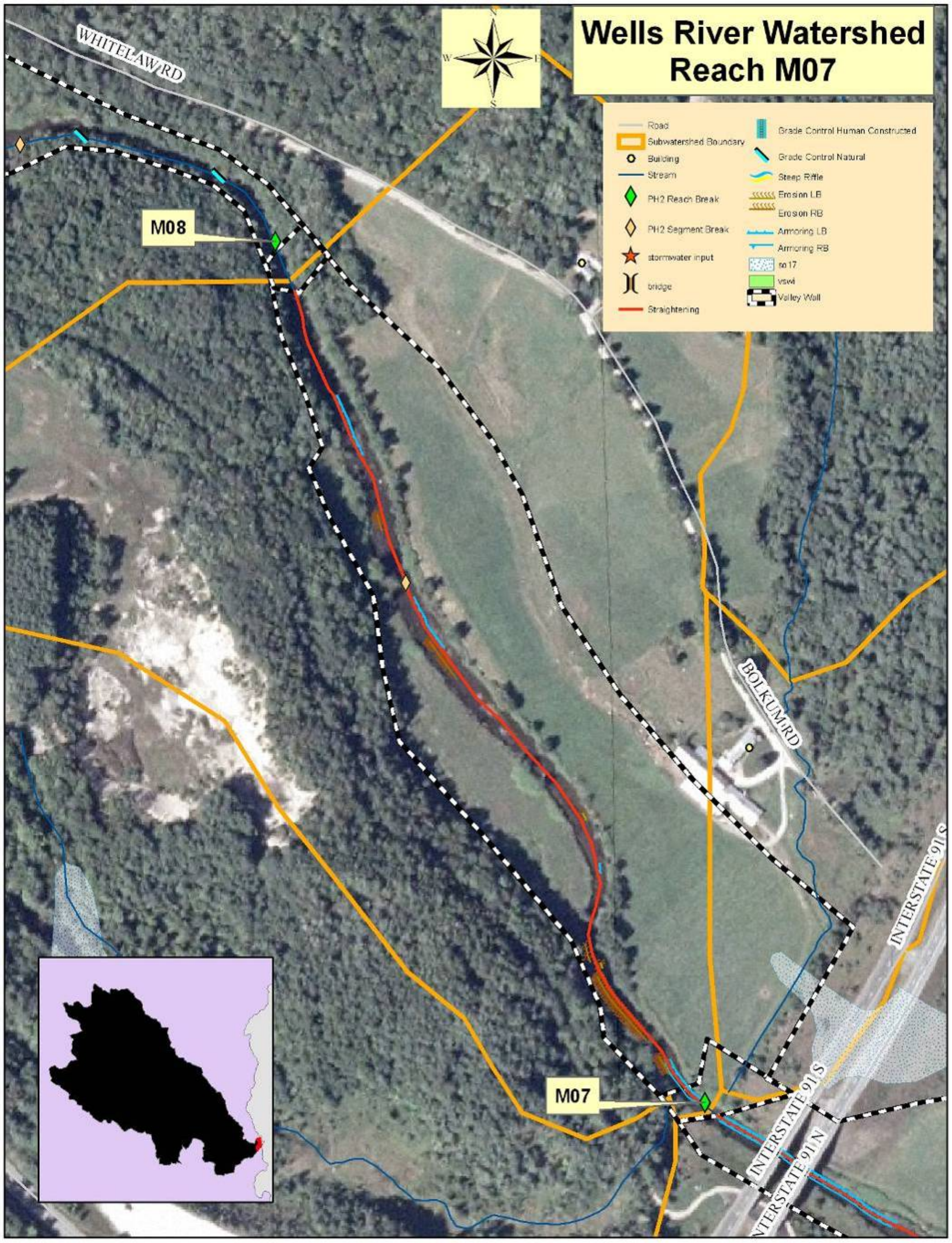

Figure 40: Wells River mainstem reach M07, Segments A and B

Figure 41: Reach M07 has a gentle slope and gravel substrate in Segment A (top left) that shifts to a steep grade and coarser substrate upstream in Segment B (top right). Segment B has undergone a stream type departure, but entrenchment is not extreme (bottom).

Key features for Segment B include:

- Dominant buffer on the left bank and subdominant buffer on the right bank are <25 feet. In all, there are 1,027 feet of unbuffered bank.
- Almost the entire segment has been straightened.
- Armoring is present along >20% of the left bank.
- The segment is in stage II, with incision dominating stream processes. Some erosion is occurring, but banks have coarse substrates and there isn't any sign of active widening.
- Substrate is cobble, sensitivity level is Extreme (due to stream type departure), and geomorphic condition is Fair.

Table 14. Wells River Reach M07: Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M07A M07B	Protect river corridor	High High	High Mod erate	N	Although no wetlands are present, the broad valley in Segment A provides important attenuation assets. Development potential on the agricultural fields in this valley is high.
M07A M07B (2)	Plant stream buffer	High High	High Mod erate	Y	Low cost benefit potential. Upper segment with extreme sensitivity due to stream type departure, and lower segment experiencing bank erosion due to increased flow.

6.1.1 Reach M08: Wells River mainstem from upstream of the Allen farm fields, where the valley narrows, to just upstream of the Boltonville Road bridge.

Reach M08 is 2,778 feet (0.53 miles) in length. Beginning at the top of the Allen farm fields, it continues to just upstream of the Boltonville Road bridge (which in turn is just upstream of the hydroelectric dam) (Figure 41). During the Phase 1 process, this reach was characterized as having a semi-confined valley, with a B-type stream, step-pool bedform, and cobble substrate. The reach was segmented twice during the Phase 2 process. Because the uppermost portion of the reach has been highly manipulated for the hydroelectric dam located there (Figure 41), it was not included in the Phase 2 assessment process. The omitted segment is 1,213 feet long. Soil and wetland maps show that this omitted segment is underlain almost entirely by wetland soils, something that might indicate that the installation of this hydroelectric dam in 1928 has greatly impacted the natural stream valley here. A historic landfill high up on the right valley wall is delivering leachate downslope to this reach. There is a leachate pool only feet from the stream bank, located at the upper end of Segment B. Efforts are being made by the State of Vermont to test the leachate from this source.

Figure 42: Reach M08, Segment C has a hydroelectric dam (above) and impoundment located at the top of the segment. It was not included in the Phase 2 assessment process.

Segment A is 819 feet in length. It retained the Phase 1 classification during the Phase 2 process, except that it has a narrowly confined valley. This segment is characterized by bedrock in the stream bed and the valley slopes. Key features of Segment A include:

- Buffers are >100 feet on both sides.
- There is no development along this segment.
- There is road encroachment for more than 75 ft of the left bank.
- There are two bedrock grade controls, one of which is 8 feet in total height.
- There is a bedrock channel constriction.
- The segment is in stage I, stable condition.
- Substrate is cobble, sensitivity level is moderate, and geomorphic condition is Reference.

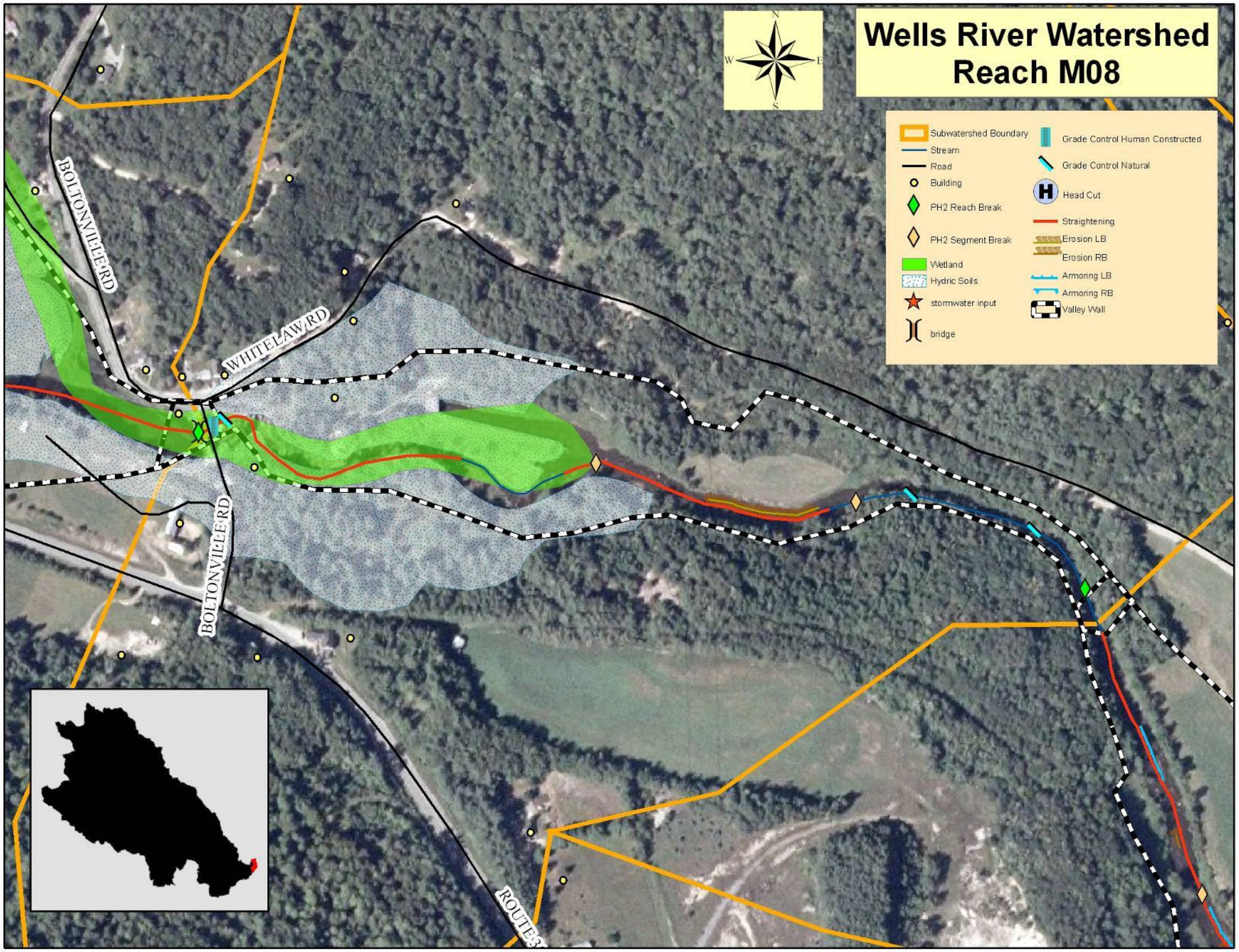

Figure 43: Wells River mainstem reach M08 segments A, B, and C.

Figure 44: Reach M08 Segment A is characterized by bedrock in the bed and banks, and a forested buffer.

Segment B is 746 feet long. It was re-classified in the Phase 2 process as a subreach with a reference C-type stream in a narrow valley. In reference condition, this stream would have a riffle-pool bedform, but due to straightening has degenerated to plane bed. The valley here broadens and the slope of the stream bed flattens. This segment represents a repository for fine sediments that are washed over the dam during high flows and drop out just upstream of the grade controls that moderate flow levels. Key features of Segment B include:

- The dominant buffer on the left bank is <25 ft. Almost 75% of this side is unbuffered.
- More than 75% of the segment has been straightened.
- There is erosion along approximately 40% of the left bank.
- The left bank valley is being used for crop agriculture.
- There is extensive development for a hydroelectric dam in the segment upstream.
- There is an impoundment upstream.
- The segment is in stage II, with incision being the dominant process. Some erosion is occurring where buffers are lacking and the stream is beginning to widen.
- Substrate is sand, sensitivity rating is Very High, and geomorphic condition is Fair.

Figure 45: Reach M08 Segment B is characterized by having a broader valley with agricultural uses in the left bank valley. Lack of buffer is causing bank erosion (left). A historic landfill high up on the right valley is delivering leachate downslope to the river (right).

Table 15. Wells River Reach M08: Projects and Practices Table used throughout the stepwise project identification process (VT ANR RCPG, Ch. 6 step numbers).

River Segment (step no.)	Project	Reach Priority	Watershed Priority	Completed Independent of Other Practices	Next Steps and Other Project Notes
M08A M08B	Protect river corridor	Moderate High	Moderate High	N	Segment B provides a valuable attenuation area and has a high development potential. Segment A's steep slopes make it vulnerable to upslope development.
M08B (2)	Plant stream buffer	High	High	Y	Low cost benefit potential. Severely eroding left bank speaks to the importance of a buffer here. Sand substrates are conducive to erosion.

6.1.1 Reach M09: Wells River mainstem from just upstream of the Boltonville Road bridge to a point 0.75 miles upstream, approximately 350 feet upstream of where the railroad track (now a farm road) starts to run tight to the right bank.

Reach M09 is 2,922 feet (0.75 miles) in length. Beginning just upstream of the Boltonville Road bridge, it continues 0.75 miles upstream to a point approximately 350 feet past where the old railroad bed approaches the stream along the right bank. This reach is characterized by being a Very Broad valley with agriculture as a primary use along much of the right side. Wetland and hydric soils are abundant in this valley. The Phase 1 process classified this as an E-type stream with a dune-ripple bedform and sand substrate. The reach was segmented once during the Phase 2 process. Because the lower portion of the reach has been highly impacted by the hydroelectric dam impoundment downstream, it was excluded from the Phase 2 assessment process. This omitted segment is 1,679 feet long.

Segment B is 2,257 feet in length. It retained the Phase 1 classification during the Phase 2 process, except that it has a gravel substrate. This segment is characterized by having agricultural cropland use for most of its length on the right side. Wetland is common on the left side. There is some incision in evidence at the upstream end of this segment, but overall it appears to be fairly stable. The downstream hydro-dam impoundment is likely a significant modifier of degradational processes. There are some signs of aggradation and widening in the segment. Key features of Segment B include:

- Dominant buffer on the right bank is <25 feet. 1,077 feet of stream bank on this bank is unbuffered.
- Buffer vegetation on both sides is dominated by herbaceous plants.
- There is road encroachment for more than 30% of the left bank.
- There is railroad bed (now farm road) encroachment along >40% of the right bank.
- Erosion is found along 10-20% of both banks (average height of 4+ feet).
- 10-20% of the length has been straightened.
- The segment is in stage I, stable condition. There is a moderate amount of aggradation occurring and some erosion where banks are unbuffered.
- Substrate is gravel, sensitivity level is High, and geomorphic condition is Good.

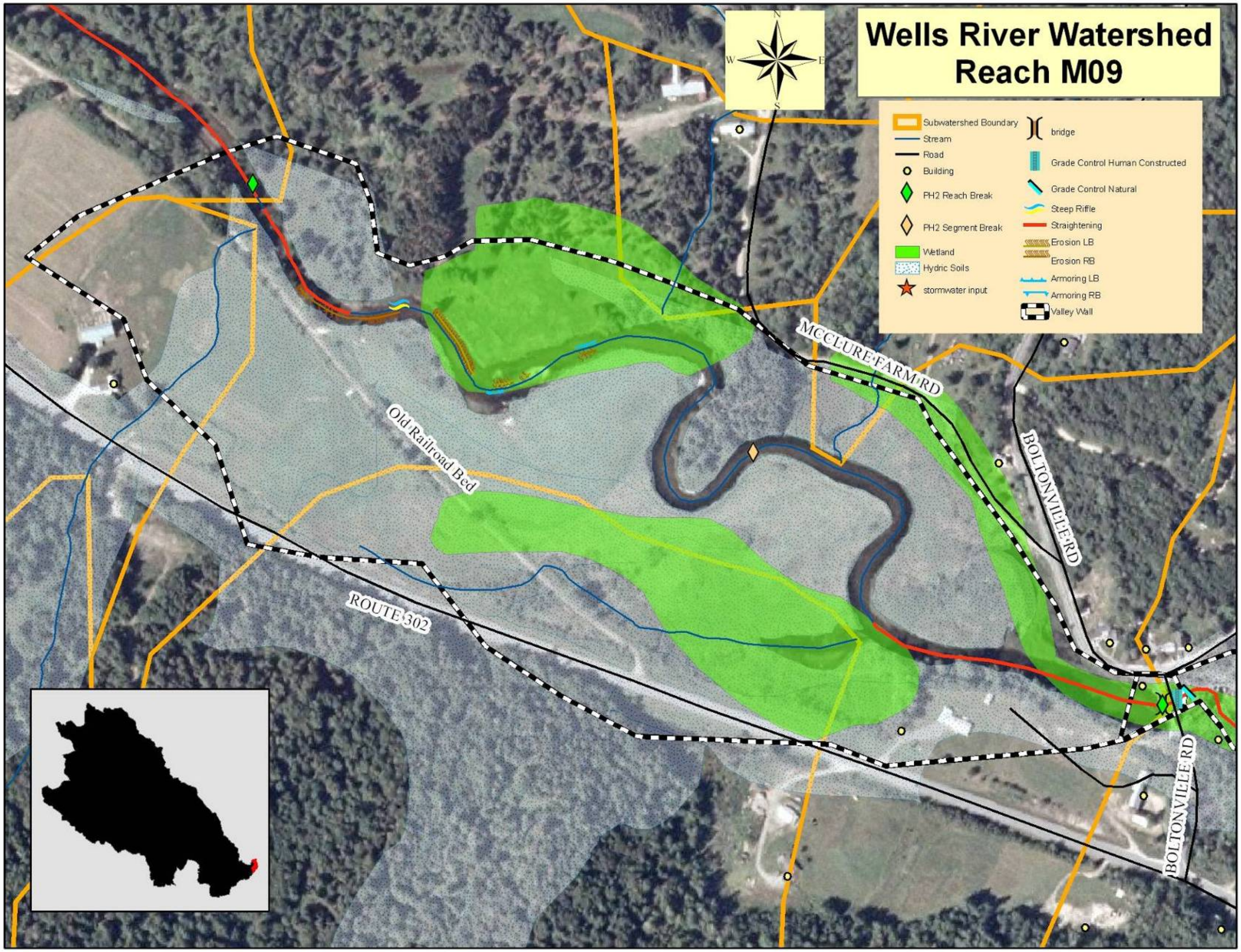

Figure 46: Wells River mainstem Reach M09, Segments A and B

6.1.1 Reach MO4S1.01: Wells River tributary to mainstem reach M04 begins at the confluence and continues upstream to a private road crossing approximately 850 feet upstream of the town garages.

Reach MO4S1.01 is 3,361 feet (0.64 miles) in length. Beginning at the confluence located at the top of mainstem reach M04, this tributary reach extends upstream to a private road crossing that is approximately 850 upstream of the town garages. The Phase 1 process characterized this reach as having a Very Broad valley. It was classified as an E-type stream with a dune-ripple bedform and sand substrate. This reach was segmented 3 times to create four segments. Segments A and D were assessed during the Phase 2 process. Segment B was not evaluated because of access problems (unwilling landowner), and Segment C was not evaluated because it is dominated by active beaver impoundments. Segment B is 1,200 feet in length, and Segment C is 860 feet in length.

Segment A is 1,024 feet in length. It retains the Phase 1 classification of an E-dune-ripple-sand stream in a Very Broad valley. This section of stream is very sinuous and runs through old beaver meadow wetland. At the beginning of the assessment process there was a partial beaver dam at the railroad bed bridge; this dam was gone a month later. Lacking topographic maps that show pre-railroad information, it is not possible to determine whether or not this tributary mouth was rerouted. Key features of Segment A include:

- Dominant buffers on both banks are >100 ft, but are exclusively herbaceous plants.
- There is no encroachment or development (other than the bridge) on this segment.
- There is a bridge at the downstream end of the segment, very near the mouth, that constitutes a major channel constriction.
- There is erosion along 5-20% of both banks.
- This segment is in stage IIc of a D evolution model, where lateral movement of the stream dominates incision processes due to the banks being more erodible than the bed.
- Substrate is sand, sensitivity level is Very High, and geomorphic condition is Fair.

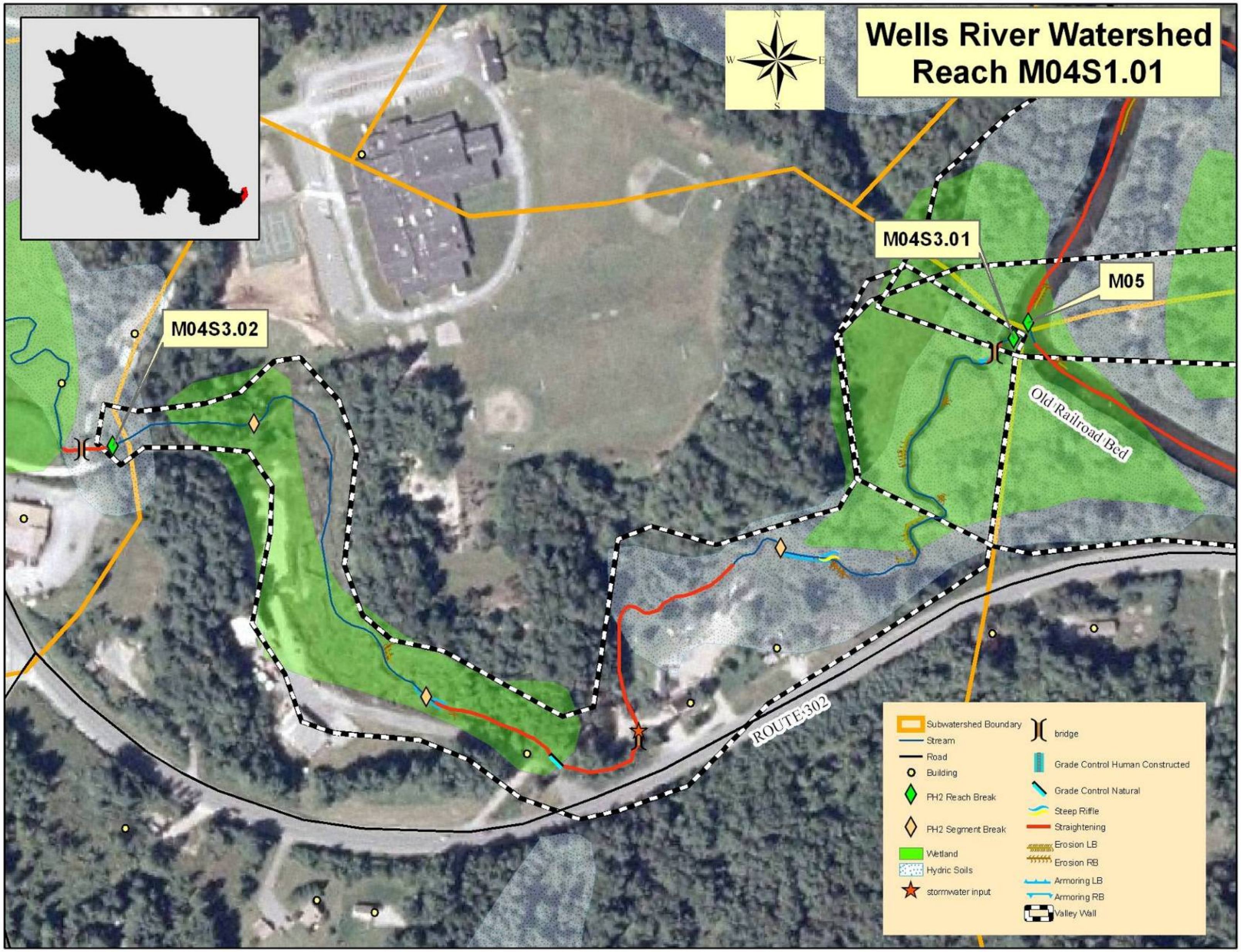

Figure 47: Wells River Tributary to Wells River mainstem reach M04: Reach MO4S1.01

 

Figure 48: Tributary Reach MO4S1.01 Segment A is characterized by a Very Broad valley with historic (and some current) beaver use (left). The bridge for the railroad bed trail at the mouth of the tributary constitutes a significant constriction (right).

Segment D is only 277 feet long and is located at the very top of the reach. This section of stream was designated a subreach with a reference B-type stream in a narrowly confined valley. The slope for this segment is >4%, fitting an “a” slope classification. Key features for Segment D include:

- Buffers are >100 feet on both sides.
- There is no development or encroachment.
- The segment is in stage I; stable.
- The substrate is cobble, the sensitivity rating is Moderate, and the geomorphic condition is Reference.

Figure 49: Tributary reach MO4S1.01 Segment D is characterized by having a steep slope and coarser substrate, in a narrowly confined valley.

6.2 PROJECT PRIORITIZATION

Reaches selected for inclusion in the Wells River watershed 2008 Phase 2 assessment range greatly in sensitivity rating. The breakout for sensitivity is as follows:

- 1 Very Low: M04A
- 2 Moderate: M08A, M04S3.01D
- 4 High: M01, M02, M07A, M09B
- 5 Very High: M04B, M05, M06B, M08B, M04S3.01A
- 2 Extreme: M06A, M07B

For reaches with high to extreme sensitivity, passive geomorphic restoration projects, which leverage these inputs and use the river's own energy to facilitate a return to equilibrium conditions, are generally preferred for prioritization due to the likelihood of rapid stream evolution. Lower investments associated with this approach are desirable, considering an inherent degree of uncertainty in the success of engineered approaches in an active system, and the Wells River watershed can be characterized as a fairly active system.

Currently, a primary problem in the Wells River watershed is the significant increase in stream power resulting from long-term impacts of extensive straightening and consequent loss of floodplain access. Extensive straightening has encouraged subsequent development and agriculture in many historic floodplains, such that key attenuation assets are a rapidly dwindling resource. With continued significant development pressures, high priority is recommended for protection of these assets as a basis for reducing flood hazards and land-use conflicts.

The use of belt-width corridors, created during the FEH corridor approach being developed by the State of Vermont River Management Program, offers a science-based refinement and added measure of protection over corridors that are based only on a predefined width or similar method (VT ANR, 2007a). The width of this corridor is based on over 30 years of research and data collected from hundreds of streams around the world, and approximates the extent of lateral adjustments likely to occur over time in a meandering stream type (VT ANR 2007 Protocols, Appendix H). "Human investments within the belt width inevitably result in structural constraints placed on the channel adjustment process to protect those investments and address associated threats to public safety. These threats will be largely avoided by recognizing the hazards created by development, incompatible with channel adjustments, within the critical belt width" (VT ANR 2007 Phase 2 Protocols, p.17).

Key attenuation assets available to provide significant amounts of floodplain access in this watershed are found in portions of all reaches in the study area, starting with M04B and continuing upstream. Eight of the fourteen segments in the project area are listed as having value as attenuation assets. Due to erodible materials being frequently present along the banks of the streams in these areas, ample buffer establishment will be critical to permitting these functions without continuing to lose large amounts of fine sediments and valuable nutrients.

In addition to protecting attenuation assets, efforts to reduce increased direct hydrologic inputs to the stream from stormwater inputs and addressing this problem in development and transportation planning throughout the watershed will help with avoidance and mitigation of flood hazards and will permit stream reaches out of equilibrium to begin to regain a balance between flow and sediment transport. In the 2008 project area, there was only one reach (M01) with significant stormwater inputs. In the village of Wells River, stormwater management to ensure percolation and distribution over well vegetated surfaces can be enhanced to reduce the rate of stormwater flow. Maintenance and enhancement of woody buffers to mitigate surface flow impacts and flood hazards is also important.

A primary objective for watershed stability is ensuring sediment continuity so that bed load sediments can work their way through the stream network and contribute to the rebuilding of floodplains and meanders. Deposition of coarse bedload sediments is vital to the reestablishment of meanders, pools, and a variety of stream features that are currently not well distributed in the watershed. For the Wells River, coarse sediments are largely being recruited from the tributaries and occasional bedrock and till areas along the mainstem. Within the project area there are two barriers to the movement of coarse materials in the form of hydroelectric dams. This means that access to coarse material is somewhat limited for many reaches. Erodible bank materials found in many of the project mainstem reaches (upstream of M04A), as well as in tributary reach M04S3.01, are the primarily contributors of fine sediments (gravel, sand, and silt) to the system. These finer sediments are generally transported long distances downstream. Due to the presence of dams, however, transport of even these finer sediments (particularly gravels) may be inhibited except during the highest flow events. This explains the relatively modest number of large depositional features found in the project area (small depositional features are more frequent). In addition to the extreme effects of dams on sediment transport, sediment continuity is further broken (although to a lesser extent) whenever stream flow or sediment inputs are increased or decreased. Straightened reaches, stormwater inputs, bridge and culvert channel restrictions, and destabilized stream banks all contribute to the disruption of a sediment regime in equilibrium.

Sediment regime departure analysis (see Section 5.1.4 of this report, especially Fig. 23) currently indicates significant deposition in several reaches of the Wells River. Very few of these deposits are mid-channel bars or steep riffles; the majority being point and side bars. Point bars, in general, are a relatively stable form of deposition, and as such, less an indication of stream instability. Bridges and culverts have frequently been identified as constrictions restricting sediment transport to reaches farther downstream. Signs of deposition related to bridges are found in M01, M04B, and M04S3.01. Removal or replacement with structures of adequate size to permit transport of both sediment and water in high flows will benefit these dynamics (sizing guidelines and recommendations are currently being developed by a number of cooperating partners, including VT Fish & Wildlife, VT Agency of Transportation, Better Backroads, and other organizations).

With these considerations as a general backdrop, Table 16 lists potential projects in the Wells River corridor planning Project area in recommended order of priority. Project prioritization should be considered preliminary and will need to be adjusted based on further information and community interest. Buffer establishment and augmentation will be an important component of many of these projects, although planting conditions will be difficult in areas of extensive road encroachment. Buffer establishment and/or augmentation could be conducted independent of other project implementation in most instances. Maps of specific potential project areas follow the table.

It is important to understand that the Phase 2 assessment was completed on only a very small piece of the watershed. While it is useful to examine the base of the watershed, particularly since that is the location of valuable and vulnerable infrastructure (village of Wells River), it important to acknowledge that adjustments and stability in these reaches are likely a reflection of impacts in upstream reaches. Additional Phase 2 assessment in this watershed is recommended to shed further light on the impacts and adjustments outlined in this report.

Table 16: Potential project prioritization for the Wells River corridor planning Project area

Wells River Watershed 2008 Phase 2 Prioritized Project and Strategy Summary								
Project No.	Reach/ Segment Condition Sensitivity	Site Description Including Stressors and Constraints	Project or Strategy Description	Technical Feasibility & Priority	Other Social Benefits	Costs	Land Use Conversion & Landowner Commitment	Potential Partner Commitments
1	All of Project Area	Extensive straightening and frequent loss of floodplain access, escalating erosion conflicts due to adjustments	FEH and belt-width-based corridor planning, protection of attenuation assets	Feasible, high priority; delineation process largely developed. Development pressures in watershed likely to continue; upstream impacts affect success of projects	Flood hazard reduction, fisheries protection, prime farmland protection, viewshed preservation, water quality protection, oversight of management activities affecting stream function	Development of FEH corridor; outreach and educational materials; policy development and implementation	Depends on options chosen; see VT ANR Municipal Guide to Fluvial Erosion Hazard Mitigation (Literature Cited section of this report)	Towns of Newbury, Village of Wells River, CCNRCD, ANR-RMP
2	Numerous reaches High Priority (In order of priority): M06A, M07A, M07B, M09B, M08B, M06B, M04B	Bank erosion, encroachment leading to bank destabilization and increased flows	Buffer protection and enhancement and corridor easement projects	Feasible, high priority; data available; inexpensive; easy to promote with landowners; funding available for easement projects	Water quality protection, fisheries protection, flood hazard reduction	Outreach; materials and planting costs; easement development costs	Landowner commitment critical. Potential land use conversion of buffer areas	Private landowners; CCNRCD, VT ANR-RMP, CREP
3	M01	Bank erosion and ongoing flow pressure on bank, threatening shed and property above	Stabilize streambank; redirect stream flow with rock vein	Feasible; financial responsibility needs to be worked out	Water quality protection	Riprap and vein boulders, installation costs	Landowner commitment needed, Wells River village commitment needed	Wells River village, landowner at site, CCNRCD, RMP
4	In order of priority: M04B, M04S3.01A, M01	Deposition and scour upstream and downstream of channel constrictions	Remove or replace current structures with structures that don't constrict channel and allow for some lateral movement	Feasible; financial responsibility needs to be worked out, potentially expensive in M01	Water quality protection, flood hazard reduction	Removal of existing structure, expense of new structures (if any) and site stabilization work	Landowner commitment needed: private owner, Wells River village, and VT Fish and Wildlife	Wells River village, Landowner of gravel pit area, CCNRCD, RMP

Project maps for Project Priority 3 can be found in Figure 50. For projects involving multiple reaches (1-2), refer to reach scale maps in Section 6.1 Reach Descriptions.

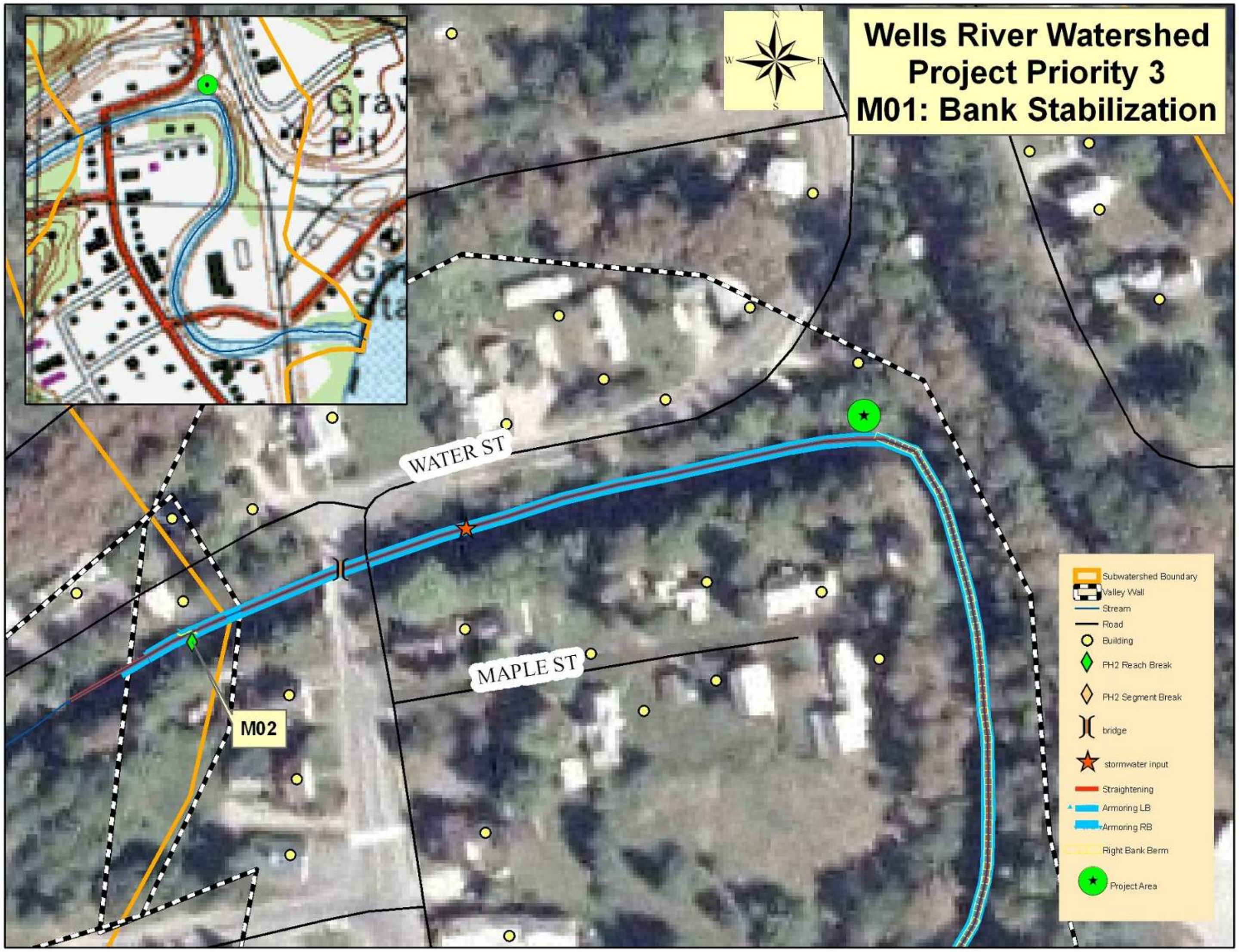

Figure 50: Priority Project 3: Bank stabilization at meander bend on M01.

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