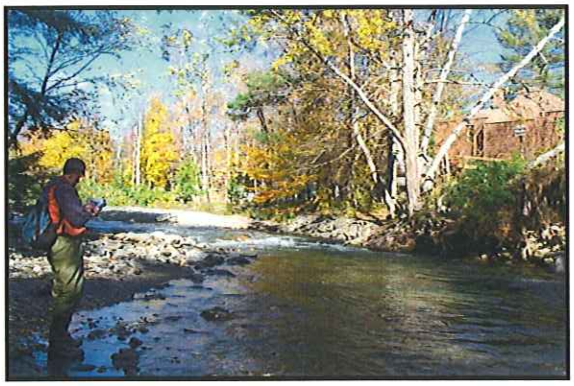
West Branch of the Little River
Corridor Management Plan
Stowe, Vermont



Prepared by:
The Lamoille County Planning Commission

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Executive Summary

The West Branch of the Little River in Stowe has been extensively studied. A multitude of resources have been spent on protecting property adjacent to the river and restoring the natural characteristics of the river. According to Chuck Mitchell of the United States Department of Agriculture, Natural Resource Conservation Service (USDA NRCS), more money has been spent maintaining the West Branch than any other river in Lamoille County, and possibly, the entire state.

Beginning in June of 2005, fluvial geomorphic assessments of the West Branch, using Vermont Agency of Natural Resources (ANR) protocols were conducted by the Lamoille County Planning Commission (LCPC) and Bear Creek Environmental (BCE). These assessments studied the condition of the river, and made predictions about how the West Branch will continue to evolve. The results provided by the assessments were used in determining management strategies to help make good decisions about land use within the river corridor.

These assessments concluded that the West Branch is undergoing active adjustment processes. On the majority of the West Branch, historic down cutting has lowered the elevation of the river bed leaving the floodplain inaccessible. As a result, high flows that would normally access the floodplain are contained within the channel; causing extensive bank erosion, channel widening, loss of aquatic habitat, and general channel instability. Highly erodible soils are a major contributor to these dynamics of the channel adjustment process. In an attempt to control this erosion, bank armoring (rip-rap), was employed on the West Branch. Bank armoring, however, lead to further instability in the system. Also, there are many encroachments to the river corridor from residential and commercial development, as well as roads and the Stowe Recreation Path. The result is a decreased amount of area that is capable of reestablishing equilibrium through lateral channel migration and the creation of a lower floodplain. It is important to protect the few areas that still have the space for the river to move; otherwise management of the river will become increasingly difficult and expensive.

This report makes management recommendations to restore the West Branch to a stable condition. The recommendations are combinations of regulatory and non-regulatory policy as well as specific restoration projects that will help the town manage the river corridor in a manner that is beneficial for property owners by decreasing fluvial erosion hazards.

1.0 Project Overview

This report will describe the setting of the West Branch of the Little River, including the river's flood history, land use history, past river management, and past studies. The stages of channel evolution, sensitivity, condition, and major adjustment process for each section of the West Branch are considered to determine effective management strategies. Restoration goals and management alternatives are then described for different segments of the river. This report will make recommendations to restore stable channel conditions, decrease the amount of money spent on maintaining the West Branch, and shift the focus of management projects from short term improvements to long term stability.

1.1Goals and Objectives

The goal of this river corridor management plan is to restore the West Branch of the Little River to a stable state with long-term planning in mind. This will be accomplished by managing the river toward a more sustainable equilibrium condition that will reduce fluvial erosion hazards and nutrient and sediment loads, as well as protect and restore aquatic habitat. Utilizing the results of stream geomorphic studies will help design and implement effective restoration strategies. Management alternatives include:

- Riparian lands conservation – permanent protection of undeveloped corridor through easement acquisition
- Avoidance of new development within corridor through land use regulations
- Removal or relocation of encroachments
- Passive / active redevelopment of floodplain and stable river

1.1.1 Manage for geomorphic stability

Without an understanding of how a river evolves over time, management efforts may be ineffective. Water within a river is a powerful force; the approach towards managing a river should respect this fact and focus on how land use can accommodate the river's dynamic needs rather than attempting to control the river in a static state. The later mindset has dominated development and land use decisions for many years, has increased erosion hazards, and often proves costly and counterproductive. River restoration projects must recognize the river's stage of evolution, and be compatible with channel and floodplain morphology to which the river is evolving.

The stages of river evolution have been established by the Schumm Channel Evolution Process (see Figure 8, page 20). The stages of channel evolution are generally incision (headcutting, or a lowering of the river bed), aggradation (sediment buildup), and channel widening, and gradual stabilization as the river establishes a floodplain at a lower level. Most of the West Branch has incised and is currently undergoing aggradation and channel widening as it erodes its banks to re-establish a new floodplain. Rivers evolve through these stages to achieve equilibrium conditions. Channel and floodplain management activities that work with or accommodate channel evolution processes are usually most successful.

1.1.2 Protect and Enhance River Corridors and Riparian Buffers

A river corridor includes lands adjacent to and including the course of a river. The width of the corridor is defined by the lateral extent of the river meanders when the equilibrium channel slope is achieved. Providing space for sediment deposition, floodplain and meander development, and slope reduction serves to maximize channel stability and minimize fluvial erosion hazards.

A riparian buffer is the land adjacent to a river either within or adjacent to the river corridor. The riparian buffer serves a number of functions that are important to a healthy river. Vegetation on a river bank improves both the quality and quantity of runoff entering the river. Vegetation physically slows the velocity of water entering the river allowing roots to have more time to absorb nutrients in the runoff. This decreases the amount of water, along with any nutrients it contains, entering the river. Roots stabilize soil on the banks of the river which reduces erosion and flood damage. Vegetation that makes up a riparian corridor also provides habitat for terrestrial communities and shade for aquatic organisms. This improves aquatic habitat by lowering water temperatures which increases the amount of dissolved oxygen available to aquatic organisms.

1.1.3 Improve Aquatic Habitat

The steps that are taken to reestablish a stable river often have a secondary impact of improved fish habitat. Stable, equilibrium channels erode and deposit sediment into pools, steps, and riffles that form the physical cover for aquatic organisms (ANR Riparian Buffer Guidance, 2006). Healthy riparian buffers help protect property from flood and erosion hazards, and also provide shade for fish. As leaves and debris fall into the water, they provide food for bugs which are then eaten by fish (Barg 2004). As erosion decreases, so does the amount of sediment in the water. This keeps pools free from sediment and aquatic habitat healthy. Streams that lack a riparian buffer have higher water temperatures, less debris, increased erosion, and fewer pools for aquatic habitat.

2.0 Project Background Information

2.1 Scope of Study Area

The 11 mile West Branch River accommodates a 27.7 square mile watershed (see Figure 1, page 8). The West Branch joins the Little River, which flows into the Winooski and drains into Lake Champlain. The Mountain Road and the Stowe Recreation Path parallel the West Branch for most of its length.

The chin of Mount Mansfield is the highest point in the watershed and Vermont at approximately 4395 feet above sea level. At the confluence with the Little River in the Village of Stowe, the elevation is about 695 feet above sea level. The lower portion of the river (below the confluence with Ranch Brook) has a slope of just less than 1% with riffle-pool morphology. Upstream of Ranch Brook, to where the main channel leaves Route 108 (north of Big Spring), the channel slope averages approximately 4.5% with a step-pool/cascade-pool morphology. The steepest part of the channel drains the summit of Mount Mansfield and has a slope of approximately 41% (cascade-pool morphology) for less than a mile.

A detailed Geographic Information System (GIS) analysis of 24.2 square miles of the West Branch watershed (upstream of the Rusty Nail) found the watershed was primarily forested and agricultural. The majority of impervious cover results from transportation, including ski trails and road works, commercial and residential development (Barg 2004).

The scope of the Phase 1 and Phase 2 studies, which provide the bulk of the data for this plan, is from Ranch Brook to the confluence with the Little River. This portion of the river was divided into six reaches to account for variations in stream type and geology (see Maps 1-5, pages 47-53). The six reaches were further divided into subreaches by Bear Creek Environmental (BCE) to account for more subtle variations in channel confinement, stability and condition of the river corridor.

Land use adjacent to the river is predominately agricultural, commercial, residential, and recreational. The Stowe Recreation Path is also adjacent to most of the river and accounts for many encroachments to the river.

This area has undergone extensive development as an economic response to the ski resort industry over the past 50 years, and the river is adjusting to loss of historic floodplain, channel modifications (straightening and gravel mining), and changes in runoff. The result has been a lowering of the river bed, impaired sediment movement, and widespread bank failure.

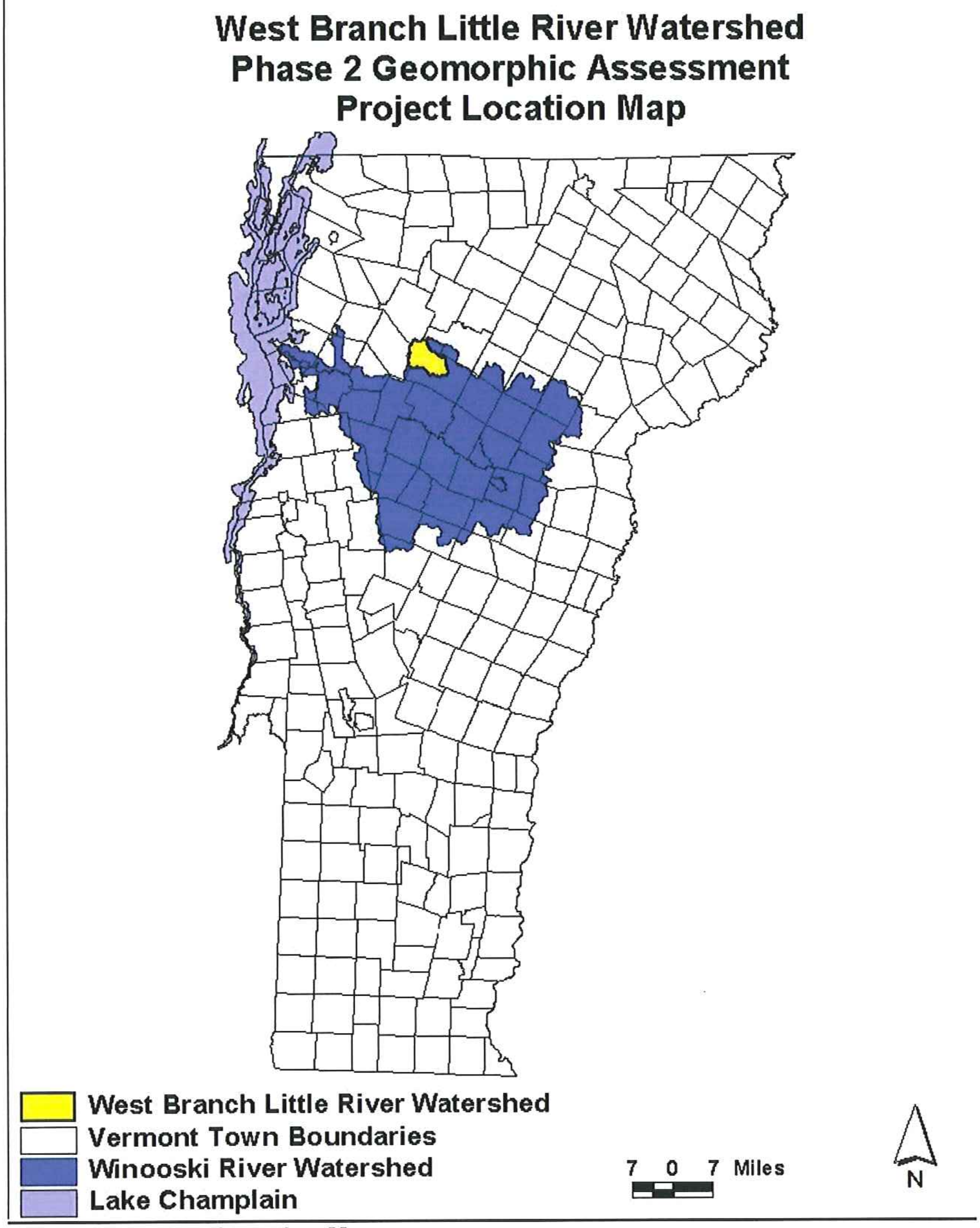

Figure 1. Project Location Map

2.2 Geologic and Geographic Setting

The West Branch drains the highest mountain in Vermont, Mount Mansfield. Bedrock geology consists of the Cambrian age (~550 million year old) Hazens Notch and Ottoqueechee Formations. These rocks consist of metamorphic phyllites, schists and gneisses (Springston 1997).

The valley contained a high level glacial lake that left well-drained highly permeable soils up to high elevations. Delta gravels are found up to ~2000 feet elevation above the State Ski Hostel (Stewart 1969). The glacial lake(s) also left behind extremely deep deposits of silt, sand and gravel. Glacio-lacustrine sands and glacio-fluvial gravels are found to upstream of Luce Hill Road and Kame terraces flank the West Branch to upstream of Bingham Falls. The Town of Stowe benefits from these deep, glacial deposits. Its two public water wells and numerous private water supplies have high yields and are located in deep gravel deposits (Barg 2004).

2.3 Land Use History

Founded in 1763, Stowe would not get its first permanent inhabitant until 1794. By 1800 the town boasted a population of 300, a penny tax rate, a hotel and a schoolhouse. It was an important gateway into the eastern side of the Green Mountains. Since its early days Stowe has been characterized by its village centers, forested mountains and scattered farmsteads. It has the largest land area of any town in the state of Vermont. It has thousands of acres of mountains, forested woodlands and valleys. The mountains rise up on the East and West side of the town. Forming the boundary of the town on the west is the highest peak in the state, Mount Mansfield. Along the hillsides, the once cleared landscape at the turn of the 19th century has gradually reforested. As a result most of the open space is in the valley that runs north and south. The valley was once a rich and fertile landscape for farming with the Little River running through it.

Commerce in Stowe covered a wide spectrum from grist mills to dairy farms. By the turn of the century (1900) the more marginal farms and lumbermen were having difficulty making a living from the land. Soils and forests were severely depleted and the difficult access to markets was more pronounced as competition edged them out. Stowe would fall back on its history of hospitality.

The town has a long history of hospitality. Its first hotel, established in the village of Stowe, is still the location of one of Stowe's premiere hotels. The first tavern was established in 1811 and the town opened its doors to visitors. The local economy would prosper due to the influx of seasonal visitors. By the late 1800's trolley service from Stowe to its neighbor Waterbury was established to bring supplies and tourists from the railroad, which was 15 miles to the south. The trolley service would continue for years but eventually was phased out as a cement highway was built between Waterbury and Stowe (1932). Some years later in the 1950's, access would again be improved with the building of the Interstate. The Interstate would follow much the same route as the railroad and would have an exit in Waterbury. This too, would bring tourists to the town.

Mount Mansfield, the highest mountain in the state, was the centerpiece for the small New England style village of Stowe. It would draw visitors for hiking and the fresh mountain air. In 1857 a road was built up the side of the mountain and shortly thereafter the Mount Mansfield Hotel was built atop the Mountain.

The early part of the 20th Century was not kind to Stowe's tourist trade and it wasn't until the advent of skiing that the economy would turn around. In 1933 the Civilian Conservation Corps cut the first ski trails on Mount Mansfield. The Corps worked from a camp base and built lean-to's to shelter them from the elements. Those lean-to's are still part of the landscape as is the first "base" lodge and ski dorm built by the CCC to protect skiers from the elements and provide a place of refuge between ski runs. From these simple beginnings, Stowe "The Ski Capital of the East" had its origins.

In the 1950's the community transitioned to a service based economy to support the ever increasing popularity of the ski resort. Small lodges, restaurants and retail establishments sprang up along the ten mile road that separated Stowe Village from Mount Mansfield. Cross country ski trails would also start to crisscross the town and one of the most extensive systems of trials in the northeast would be established. Maria Von Trapp would move her family to Stowe and create a lodging and cross country skiing empire overlooking the Village of Stowe.

With the increasing tourist popularity would come seasonal visitors in increasing numbers. Many of those visitors would relocate in Stowe and the amenities that attracted tourists now attracted year round residents as well. The town started to grow and with it came impacts from that growth. In the 60's and 70's land speculators began buying up land. Outside money would pour into new commercial establishments and that small, cozy, family style lodges would become at risk. The first Planning Commission was established in 1972 and their first chore was to adopt zoning regulations in an attempt to preserve much of what the residents considered special. This was followed by subdivision regulations. The first town plan was adopted in 1964 and was a generic attempt to identify the essence of Stowe.

The tourism industry in Stowe spawned the development of hotels and other businesses along the Mountain Road which is paralleled by the West Branch. The scope of the studied area on the West Branch includes twelve reaches. The percentage of developed land within the river corridor is greater than ten percent in nine of these reaches.

2.4 Flood History

Understanding the flood history of a river will help to implement effective and appropriate management approaches.

The West Branch watershed averages 53" annually of precipitation (USGS, Scott Olson, pers. comm. 2004). The top of Mount Mansfield averages over 78" of precipitation annually. Mount Mansfield has a long-term record of precipitation with 1.07 inches of precipitation at the 90% interval (CWP, 2002 Center for Watershed Protection, September 8, 2000 Memo No. 2: Recommendation and Justification for Stream Channel Protection Criteria). Precipitation increases with elevation, at about an inch per 1000 feet of elevation (Wemple, 2002). Mount Mansfield receives more precipitation than most areas in the State.

Mount Mansfield creates an orographic effect. Thunderstorms form over mountains by convection off of a sunny slope. As the air rises, it is shifted downwind, increasing precipitation 'downwind' onto the opposite (east) slope.

The prevailing winds in the Green Mountains are from the west. Extreme rainfall events occur when moisture-laden air arrives from the south. Storms that come from the north or northwest typically have dry air.

Between 1995 and 1998 Vermonters suffered nearly $60,000,000 in flood damage; much of these losses were avoidable. The majority of large twentieth century floods have occurred during the summer months of June through August and are associated with intense cloudbursts, which stay in the mountains producing high rainfall amounts. The remainder is divided quite evenly between fall floods (September through November) which are often associated with hurricanes. Winter/spring floods (January through April) are associated with rain on snow events or snowmelt. Summer and fall floods are associated with greater flood damage than winter snowmelt floods. A flood in July 2004 in Stowe dropped as much as 4 inches of rain in one hour causing almost $500,000 in flood damage according to the Federal Emergency Management Agency (Barg 2004).

2.5 Channel and Floodplain Management History

An anthropogenic attitude has lead to the mismanagement of many of our country's natural resources as the human population grew. This is especially true in the context of the management of rivers; little consideration was given to the river's needs to sustain stability and most rivers have been maintained to accommodate development along the banks. Rivers were transportation corridors before there were roads and also provided flat, well drained, fertile soil for agriculture, so infrastructure developed along the same corridor. Towns and villages grew on the banks of rivers, whose role in power generation and transportation at first outweighed flood risks. The legacy of this landscape manipulation is rivers and streams which are unstable and prone to fluvial erosion.

> "The history of the West Branch of the Little River in Stowe provides an educational case history. Back in the 1940s and 50s, the West Branch valley was primarily agricultural with forested uplands. At this time, examination of aerial photos and other historical evidence indicate that the river morphology allowed for access of flood flows to the floodplain on a frequency of approximately once every 1.5 years. This is a common

characteristic of natural, stable alluvial stream systems (McCrae and Rosgen). Large scale conversion of land use through economic development occurred along the river, its tributaries, and the uplands from the 1960s until the present. Floodplain encroachment and channel alteration through dredging and bank armoring accompanied the development to protect it from frequent overbank flooding. This resulted in almost complete isolation of flood flows from access to the previous floodplain. Consequently, all the energy of a flood is concentrated within the channel. Literally hundreds of thousands of dollars of both public and private funds have been expended to protect the investments along the river from a condition that is directly a result of past watershed and river channel mismanagement."

-Options for a State Flood Control Policy, ANR, Feb. 1999

2.6 Recent Restoration Projects

Organizations that have been involved in restoration or management projects on the West Branch include Vermont Fish and Wildlife, Vermont Agency of Natural Resources-River Management Program, U.S. Fish and Wildlife Service-Partners for Fish and Wildlife Program, USDA NRCS, the Federal Emergency Management Agency (FEMA), the Army Corps of Engineers, the Lamoille County Planning Commission, the Lamoille County Natural Resources Conservation District, local municipal officials, private landowners, and angler groups.

Many restoration projects have been implemented on the West Branch. The Lamoille County Natural Resources Conservation District, the Vermont Agency of Natural Resources, FEMA, and U.S. Fish and Wildlife conducted natural channel restoration projects coordinated by the Lamoille County Planning Commission, and have been monitoring them over a period of four years. These projects were implemented at ten sites and included riparian plantings, grade control structures to prevent headcutting, tree revetments, rock vanes and weirs, and riffle-pool structures. Over the four year monitoring period, the project integrity was maintained and riparian plantings established themselves well.

3.0 Stream Geomorphic Assessments

The focus of the geomorphic assessments is to understand how to accommodate the river to achieve equilibrium, or a stable state, by working within the river corridor. The geomorphic assessments and this report do not address other issues commonly associated with water quality such as storm water, waste water, or other watershed wide issues. The Vermont Agency of Natural Resources has developed protocols for conducting geomorphologic assessments of rivers.

A goal of Vermont's stream and river corridor conservation programs is to resolve or avoid conflicts between human investments and river systems in a manner that is technically sound and both economically and ecologically sustainable. The purpose of the stream geomorphic assessment protocols is to provide a method for gathering scientifically sound information that can be used for watershed planning and detailed characterization of riparian and instream habitat, stream-related erosion, and flood hazards (VANR 2005). Various trainings have been held to provide consultants and regional planning commissions with the knowledge necessary to make accurate and consistent assessments of Vermont's rivers.

The stream geomorphic assessments are divided into three phases. The Phase 1 assessment is a rough analysis of the condition of the stream through using aerial photographs, maps, and preliminary field data collection. The Phase 2 assessment is a more detailed analysis of the stream by determining what adjustment processes are taking place and predicts how the river will continue to evolve in the future. Phase 3 is the identification and implementation of restoration projects. A Phase 3 assessment, however, is not always necessary for project implementation. Phase 3 assessments are usually only necessary on projects that require more in-depth analysis. For example, a Phase 3 assessment was performed on the Luce Hill Bridge section of reach 2 on the West Branch. Replacing the bridge is a costly restoration project, and an in-depth analysis of the geomorphology of the site and analysis of alternatives is required to ensure successful and economical restoration objectives.

To account for variations in topography and other geographic characteristics of the river corridor, the stream was divided into six segments, or "reaches" exhibiting similar characteristics. Two of the reaches were then divided further into subreaches by Bear Creek Environmental (BCE) during the Phase 2 assessment.

3.1 Phase 1 Geomorphic Assessment

Phase 1 assesses a number of characteristics of the river. These include reach locations, stream type, basin characteristics, land cover and reach hydrology, instream channel modifications, planform changes and floodplain modifiers, bed and bank survey, stream impact ratings, stream geomorphic condition assessment.

There are various components to each characteristic that is assessed. For example, valley slope and width are assessed as part of the stream type. Land cover and hydrology assessment involves determining riparian buffer width and small tributary inputs. Instream channel modifications include bridges, culverts, bank armoring, channel straightening, and dredging and gravel mining history.

The bed and bank survey was done in a more extensive manner on the West Branch than the protocols outline. The protocols suggest a "windshield" survey, in which various sections of the river are viewed from a convenient location such as a bridge. Staff from the Lamoille County Planning Commission (LCPC) walked the entire river determining bed material and measuring bank erosion. This was helpful due to major erosion on the West Branch that would not be captured in a regular Phase 1 survey. The Phase 1 assessment of the West Branch river was conducted by the LCPC during June and July of 2005. Extensive riprap and erosion were the main features mapped during the Phase 1 study of the West Branch. The findings of the assessment concluded that the river was not in a stable condition, and more detailed assessments were necessary.

3.2 Phase 2 Geomorphic Assessment

A Phase 2 geomorphic assessment was conducted by Bear Creek Environmental (BCE) during September and October of 2005. The Phase 2 assessment provides detailed analysis of stream type, stage of channel evolution, geomorphic condition and habitat conditions of the river. Details of the findings of this assessment are available in Appendix A.

Figure 2. Cross section performed during Phase 2 assessment

3.3 Phase 3 Geomorphic Assessment

The Phase 3 geomorphic assessment is the site specific project implementation component of geomorphic assessments. Not all Phase 1 and 2 assessments require a Phase 3 assessment, and projects can be designed and implemented without the utilization of a Phase 3 assessment. To date, one specific Phase 3 project has been identified on the West Branch. Milone and MacBroom, Inc. performed a Phase 3 geomorphic assessment, conceptual design, and alternatives analysis for the Luce Hill Bridge Area on the West Branch. The Luce Hill Bridge was identified as being a major constrictor of the stream's evolution; specifically its ability to widen and create a new floodplain. The results of the assessment are located in Appendix B (page 45).

4.0 Geomorphic Stressors

4.1 Channel Evolution Stage

Rivers evolve through a known sequence of stages that have been documented by the Schumm Channel Evolution Process (see Section 5.1 (page 20) and Appendix A (page 42)). The stages of evolution can be accurately predicted when the initial stream type is determined which is part of the Phase 2 assessment. In the case of the West Branch, the stages of evolution for most of the river are degradation (headcutting, or a lowering of the river bed), widening as the lowered river erodes its bank while trying to access the lost floodplain, aggradation (the buildup of sediment from eroding banks), and a change in planform as the lowered river establishes a new floodplain at a lower elevation and meander bands may change location. The stage of evolution varies slightly at different points along the river. This channel evolution sequence is helpful in determining river management practices, as the river's characteristics can be predicted, and adjacent land use can be planned accordingly.

4.2 Watershed Scale Stressors

The West Branch is a stream with a naturally high bed load, meaning a lot of sediment moves through the system. High bed load systems are particularly sensitive to channel adjustment and movement.

While there are occasional bedrock outcrops (often near bridges), downstream of Ranch Brook, there is no channel-spanning bedrock to act as a grade control (Barg 2004). The lack of a bedrock grade control allows the river bed to incise or cut down when the energy of the stream is increased. Increases in stream energy may occur naturally, but in recent decades, increases in both depth and slope of the West Branch channel have made it a more powerful stream. In some areas, the channel has lowered as much as twelve feet in the last fifty years (VAOT1949). Most importantly, the incision process cuts the river off from its floodplain where it attenuates both the increase flows and sediments loads that occur during floods.

The building of roads, ski trails, driveways, and houses alter the hydrology of the West Branch watershed. As the area of impervious surfaces increases, so does the amount of runoff entering the river rather than infiltrating into the soil. A study conducted by the United States Geological Survey (USGS) and the University of Vermont (UVM) shows that the amount of runoff is significantly greater on the West Branch side of the watershed that drains trails on Spruce Peak than on the mostly forested Ranch Brook side. Water is quickly funneled into the river instead of allowing it to be soaked up by the ground. This increases the amount of water in the river, along with nutrients and other pollutants carried by the runoff. The large projects underway in the headwaters of the West Branch will likely alter the hydrology through an increased amount of impervious surface that reduces infiltration of water into the soil adding significant runoff to the river. Stormwater issues in this area should be processed as efficiently as possible locally. Otherwise, the potential increase in the volume of the water and sediment will put additional pressure on an already stressed downstream system.

4.3 Reach Scale Stressors

On the West Branch, the majority of reach-scale stressors are encroaching residential and commercial development and transportation infrastructure. The major transportation encroachments are Route 108 (The Mountain Road), and the Stowe Recreation Path, both of which parallel almost the entire river (see Figure 5 and 7, page 18 and 19). These encroachments limit the ability of the stream to attenuate sediment loads, undergo planform adjustment, and redevelop critical floodplain areas.

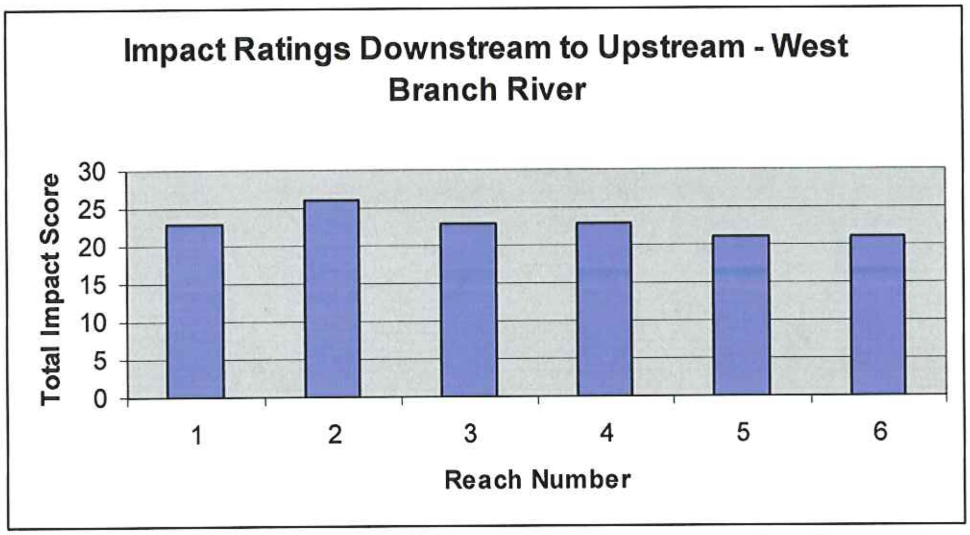

Figure 3. Total Impact Ratings for the West Branch – Downstream to Upstream Note: The ANR set an impact score of 16 as the state-wide high score in its 2005 Phase 1 Assessment Protocol Handbook.

Channel encroachment and adjacent land use have also led to extensive channel straightening and bank armoring (see Figure 5, page 18). Both of these activities tend to increase stream power and sediment transport and the vulnerability of downstream reaches to catastrophic erosion and deposition. An example of this is the erosion and deposition occurring upstream of the Luce Hill Bridge. The incised straightened and armored reaches upstream have the increased power to move a higher sediment load. When the flood water slows, due to backwater conditions above the bridge, the sediment drops out and the river pushes or erodes into adjacent lands.

Figure 4. Luce Hill Bridge

Many reaches on the West Branch also lack an adequate riparian buffer. This impacts many different aspects of the river, including decreased erosion resistance, increased runoff with higher nutrient and sediment loads, and warmer water temperatures which are unfavorable for a cold water fishery.

Historic dredging has also been documented along the West Branch. Extensive dredging and gravel mining often results in a channel that is both steeper and deeper, thereby increasing stream energy and power. If the excess stream power erodes the coarse armor layer of the river bed, then the channel incision process may be accelerated. This has been especially problematic in the West Branch given the highly erodible, silty, glacial lake deposits that lie just below the gravel-cobble armor layer of the river bed (see geologic-setting section).

Figure 5: Reach Scale Stressors

Reach #	Channelization	Dredging	Berms & Roads	Corridor Development
1	62%	yes	18%	5%
2	45%	yes	76%	29%
3	46%	yes	64%	18%
4	64%	yes	95%	10%
5	42%	yes	55%	11%
6	81%	no	32%	63%

Rip-rap, which was placed to protect stream banks, has been undermined and collapsed multiple times. 45% of the West Branch is armored on one side or the other; no other stream in Vermont has this amount of bank armoring. This practice is not cost effective as is perpetuates instability problems and inevitably fails and needs replacement. Barry Cahoon, River Management Program Director and civil engineer for the Vermont Agency of Natural Resources, says that some rip-rap has been replaced and rebuilt as much as four times (pers. comm. 2004). Due to the lack of bedrock grade control and proposed land use changes, it is likely that the West Branch will continue to lower its bed elevation. As the banks erode and the elevation of the bed lowers, the sediment load carried by the river increases.

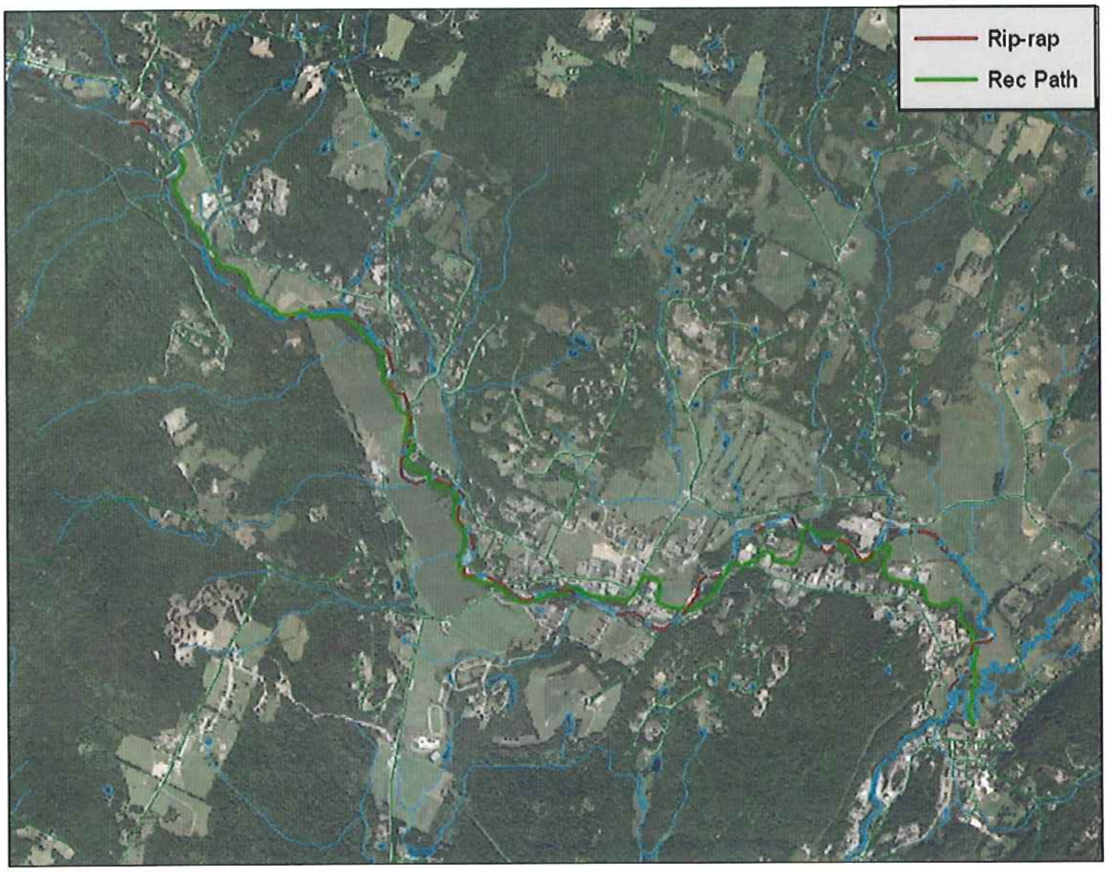

Figure 6. Stowe Bike Path and Rip-rap on the West Branch

Figure 7. Bike Path on bank of river

5.0 Fluvial Erosion Hazard Mapping, Stream Adjustment, and Sensitivity

5.1 Fluvial Erosion Hazard Mapping

An important step in a River Corridor Management Plan is to identify the width of the river corridor necessary to accommodate the river's meanders and channel slope as it moves towards an equilibrium condition. For rivers which have been significantly altered from a slope and planform standpoint and are highly sensitive to adjustment and change, like the West Branch, it is critical to understand the minimal area the river may require to achieve a natural equilibrium. The Vermont River Management Program, based on river studies worldwide, has developed the process for delineation this area, or fluvial erosion hazard (FEH) zone. This is also the area along the river where flood losses caused by fluvial erosion are most likely to occur. Minimizing encroachment within the FEH zone will help to minimize flood losses and protect public safety by enabling the West Branch to adjust toward equilibrium.

Along the West Branch, based on the stream sensitivity and channel evolution stage identified by BCE during the Phase 2 geomorphic assessment, the width of the FEH zone is six times the reference bankfull channel width. For example, the FEH zone at the lower end of the West Branch is 414 feet wide, centered on the meander center line. In some areas, along the West Branch, commercial, residential, and transportation infrastructure encroachments already limit the ability of the stream to adjust within the FEH zone. A fluvial erosion hazard map, combined with a knowledge of the existing encroachments, can be used by the town to manage and plan land use along the West Branch in a way that is consistent with river processes (See section 6.3 Implementation).

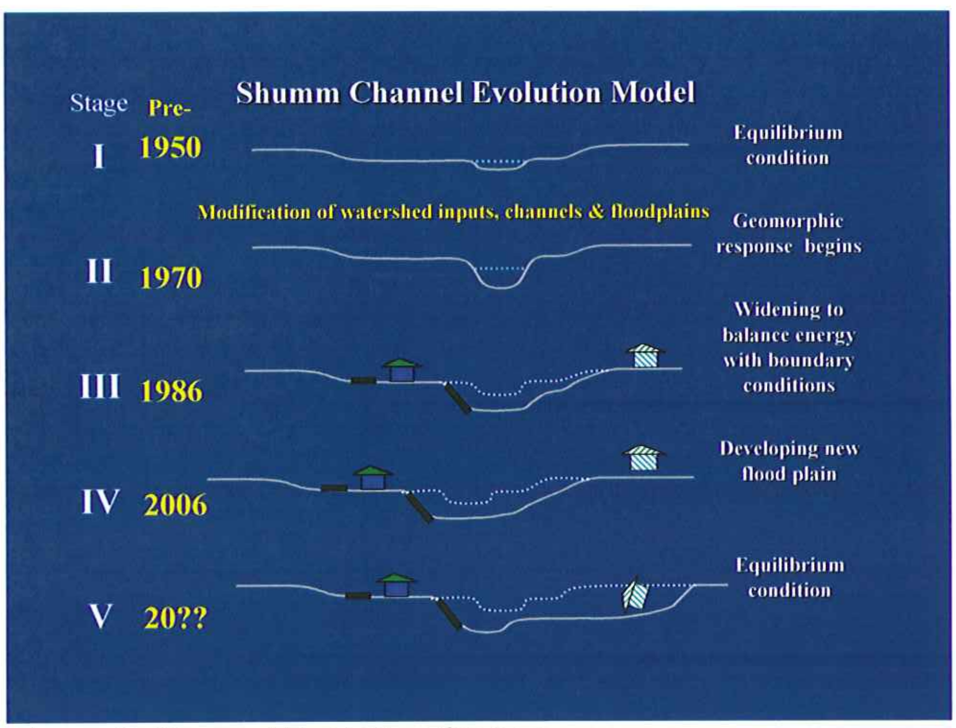

Figure 8. Channel Evolution Stages

5.2 Channel Evolution of the West Branch

Primarily as a result of flood plain encroachments and historic channel management activities including straightening, gravel mining, and bank armoring; combined with the highly erodible glacial-lacustrine soil layer underlying the riverbed, the West Branch has been markedly unstable in the vertical dimension. The Phase 2 Geomorphic Assessment report by Bear Creek Environmental confirms that the majority of the West Branch is in Stage III or IV of the channel evolution model shown above.

In brief, the channel evolution process is simply a physical expression of the river corridor, energized by the flow of water down the valley, to balance the erosive force of water with the resistance of the channel and flood plain boundaries.

As the river flow is confined by channel straightening, flood plain filling, gravel mining, and bank armoring, the force of the water is greatly magnified and erodes away the channel boundaries at the weakest points. Because of the extensive channel armoring (45% of the lower 6.2 miles of the West Branch has armoring on at least one bank), the point of least resistance becomes the river bed which is generally composed of a thin layer of gravel and cobble overlying an 80 ft. deep layer of unconsolidated, highly erodible gray silt.

Through the 1970's and 1980's, particularly downstream of the Top Notch lower meadow, the West Branch dramatically incised (Stage II), losing complete access to its historic floodplain; this in addition to those portions of the flood plain which had not already been filled for development purposes. As the river corridor evolved from Stage II into Stage III, a paroxysm of channel armoring and gravel mining ensued to protect the threatened land use investments within the river corridor.

These channel management activities created a vicious feedback loop wherein the river would either transfer its energy from an armored bank to erode an unprotected area, or simply incise more deeply, thereby cycling the channel evolution process back to Stage II. This served to undermine and outflank much of the bank armoring that was performed. It is estimated that as much as 75% of bank armoring constructed since 1973 has failed and been replaced at least once; and as much as 33% failed and has been replaced more than once. In today's dollars, public and private expenditures on bank armoring along the West Branch would total upwards of $1.5 million. This cost should be considered in addition to the extensive erosion and inundation related property damages that have been experienced along the West Branch over the past quarter century.

Where development encroachments and bank armoring preclude the formation of a new flood plain at a lower elevation within and adjacent to the active channel (Stage IV & V), the balancing of the energy of the flowing water and the resistance of the channel boundary conditions becomes impossible without extremely expensive investments in channel bed stabilization.

The good news, however, is that in the 20 years since gravel mining ended as a channel management practice, the active rate of vertical channel incision appears to have been significantly reduced. The river has redeveloped, through bank erosion and sediment deposition (early Stage IV), a limited but significant amount of floodplain within and adjacent to the active channel. This has served to substantially enhance the stability of the West Branch in comparison to the 1986 condition.

But Stowe and the owners of property along the West Branch are not out of the woods yet. This is still a highly confined river corridor, deeply incised, draining a hydrologically dynamic watershed, with a tremendous land use investment endangered by catastrophic flooding and erosion hazards.

Stowe also has the opportunity here to build on the success of the past 20 years in re-defining its relationship with the West Branch. For 2 or 3 decades, the West Branch was treated and perceived as primarily a liability to the community. When Stowe's relationship with the river can be characterized as "allowing the river its space" and accommodating its physical imperatives, the West Branch can and will become an immeasurably valuable economic, social, and ecological asset to the entire community.

Figure 9. Rip-rapped erosion threatening residential structures on the West Branch

5.3 Sensitivity Analysis – Dominant Adjustment Process

When determining the most effective method of stream restoration, it is important to consider the current condition and sensitivity of a segment. Otherwise, restoration efforts may adversely affect other segments of the stream, or fail altogether. Stream sensitivity is pertinent because, in addition to knowing which vertical and lateral adjustments are ongoing, the analysis often gives an indication as to the *rate* of channel evolution.

The stream condition and sensitivity were determined by BCE in the Phase 2 assessment. Stream condition refers to the stream's exhibition of predicted geomorphic conditions, depending on the stage of the stream's evolution. For example, in Stage III of stream evolution, after it has incised, bank failure and channel widening is expected to occur so that a new flood terrace at a lower elevation can be established.

Consideration is given to the expected equilibrium condition of the stream, whether the current adjustment processes are moving the channel form away form or toward this condition, and how fast the process is occurring. The management alternatives considered and their feasibility will depend on the costs and benefits of intervening and/or accommodating the channel evolution process underway within an appropriate and effective spatial and temporal contexts. For instance, trees planted along the top of the bank of a stream undergoing widening after deep incision are likely to be washed into the river. In this scenario, planting efforts might be better aimed further back from the river in anticipation of erosion. See Figure 10 (page 31) for the stream adjustment process for each reach on the West Branch.

6.0 Project Identification and Prioritization

6.1 Restoration Approaches

There are different approaches that can be taken to achieve a stable river depending on its current condition and adjacent land use practices. Some segments require an active, sometimes aggressive restoration approach, while others may self-adjust given enough space and time. The decision of what type of restoration approach is made by the degree of degradation, stage of channel evolution, stream sensitivity, and social-economic factors such as costs and risks of failure. An important component to a successful restoration project is monitoring it over regular time intervals. The type of restoration project that is implemented determines the intervals at which a project is monitored and the characteristics that are measured to quantify a projects success or failure.

<u>Active Geomorphology</u>: This approach seeks to restore or manage rivers to a geomorphic state of dynamic equilibrium through an **active** approach that may include human constructed meanders, floodplains, and bank stabilization techniques. This approach tends to have high upfront cost. Typically, the active approach involves the design and construction of a management application or river channel restoration project in an attempt to achieve stability in a relatively short period of time. This approach may involve restoring sections of river to their reference condition or may involve recognizing new valley conditions imposed by human constraints and working within those constraints. Active riparian buffer revegetation and long-term protection of a river corridor is essential to this alternative (Vermont Agency of Natural Resources 2005).

<u>Passive Geomorphology</u>: A **passive** geomorphic approach is targeted at allowing rivers to return to a state of dynamic equilibrium by removing constraints from a river corridor thereby allowing the river, utilizing its own energy and watershed inputs to re-establish its meanders, floodplains, and self maintaining, sustainable equilibrium condition over an extended time period. This approach is typically less expensive, however, may take much longer to achieve desired results. Active riparian buffer revegetation and long-term protection of a river corridor is also essential to this alternative (Vermont Agency of Natural Resources 2005).

An active restoration approach may be necessary for streams that are highly degraded with many encroachments. The stream may have no room for lateral migration needed to restore stable conditions. Encroachments from development rule out the possibility of a passive restoration approach to many sections of the West Branch. In this scenario, the restoration may involve the design of channel forms that would exist in more naturally confined settings. For instance, the low gradient channel, that would otherwise form wider meanders, sediment deposition forms, and floodplain, would be restored to a stream type typical of a stream found in a narrower, steeper valley where little sediment is deposited and only minor floodplain features are formed. In making this transformation, however, the restoration design must also include the attenuation of the sediment load that is now being transported instead of stored in the transformed reach. Finding and protecting these sediment attenuation areas, in a river corridor, such as the West Branch, with limited room for floodplain development, is a critical restoration component.

Various methods exist for restoring sediment attenuation areas (floodplains and deposition zones) of a watershed. Some involve active restoration practices, but often times the most cost effective method is to define the corridor, limit the encroachments (future conflicts), and passively allow these features to be restored by the river over time.

Most of the West Branch is undergoing the phase of channel evolution in which widening and aggradation are the main adjustment processes. This stage generally exhibits extensive bank failure as the river widens, which is clearly evident on the West Branch. During this stage, bank stabilization projects often fail. Once this stage is complete and a floodplain is reestablished, the establishment and protection of riparian buffers should be the main focus of restoration efforts. In the meanwhile, buffer planting projects may take place in the corridor away from the top of the river bank. Beginning to replant these areas now will provide a long term buffered corridor on the West Branch and will encourage natural regeneration of the eroding banks and new floodplain.

6.2 Policy Options

6.2.1 Riparian Corridor Widths

Maintaining an adequate river corridor width will allow the West Branch to evolve unimpeded by adjacent land use. The river's evolution should be monitored to adjust management practices as needed. In many segments of the West Branch, however, the riparian corridor is already developed to the point where it has confined the river's movement. Identifying and protecting undeveloped sections of the riparian corridor is essential to manage the river. As more of the river corridor is developed, the costs associated with maintaining the river and protecting property from flood and erosion hazards will increase. Avoiding development in sensitive areas will not only improve the quality of the habitat and water, it will also save money.

6.2.2 Encourage Maintenance and Re-establishment of Open Floodplains

Development within the floodplain or corridor of a river is a major factor in the amount of money spent on flood damage and river management. Floodplains are tempting places to build a house or commercial structure; they generally consist of flat, well-drained soil, and offer pleasant scenery and higher property values. The decision to build within an active floodplain or river corridor is accompanied by certain flood damage costs as well as costs associated with the often futile flood damage mitigation.

According to the Stowe 2005 Pre-Disaster Mitigation Plan, the town of Stowe has 62 structures located within the floodplain. This represents 2.4% of the total number of structures in the town, and also is a potential flood loss of $13,187,400. The majority of the Stowe Recreation Path is also located in the floodplain (see figure 6, page 29), as well as a number of roads; primarily the Mountain Road.

A high priority initiative for restoration and protection of the West Branch is the development of zoning bylaws that regulate building on undeveloped land adjacent to the river as depicted by the river corridor map and FEH zone. This is land that is capable of allowing lateral migration of the channel and can allow banks to erode to create a lower floodplain. Given the current restrictions on the release of flood energy from encroachments, land that is still undeveloped is a valuable resource in the effort to maintain a manageable river.

6.3 Implementation Options

6.3.1 Regulatory

The Town of Stowe has a variety of regulatory options to aid in accomplishing the objectives of this report. These options include the adoption of a new overlay zoning district to avoid encroachment in FEH zones, as well as modifications of existing zoning ordinances and town program.

Fluvial Erosion Hazard (FEH) Overlay District
The adoption by the Town of Stowe of an overlay district that would prevent encroachment in undeveloped portions of the FEH zone is one significant way to work toward the objectives of this plan. The Vermont Department of Environmental Conservation has developed model language for a stand-alone FEH Overlay District, independent from and complementary to Stowe's existing flood hazard zoning, which was based upon National Flood Insurance Program (NFIP) maps and standards. It may also be possible to incorporate both inundation hazards and fluvial erosion hazards into a single overlay district. In either case, the purpose of the FEH Overlay district is to minimize the economic losses and public safety risks associated with fluvial erosion by limiting inappropriate land uses within the identified fluvial erosion hazard zone. Limiting encroachment in this area will allow the West Branch to adjust toward equilibrium, minimizing erosion hazard along the entire stream.

As the FEH District will be an overlay district, it will be superimposed over any other zoning district. All lands to which the FEH district applies should meet the requirements of both the underlying zoning district and the FEH district. Where there is a conflict between the underlying zoning district and the FEH district, the more restrictive regulations shall apply (VANR 2005).

Modifying Existing Regulations
Modifications to existing zoning regulations can also be effective in working toward the goals of this plan. These modest changes would have far reaching effects on the development of land in the FEH area. For most of these the FEH zone would need to be adopted as a part of the official zoning map.

- Strengthen existing flood hazard zoning. The Town of Stowe currently has flood hazard zoning which meets the minimum NFIP requirements. Stowe could develop and adopt more restrictive flood hazard zoning in order to provide even more protection for both the West Branch and Stowe residents.
- Double setback and buffer requirements for the West Branch. In current zoning the setback and buffer requirements for streams and rivers are 50 feet. Due to the unstable nature of the West Branch a wider setback and buffer are necessary to avoid conflict and allow the West Branch to adjust toward equilibrium. It is therefore recommended that a 100 foot setback and buffer be enforced on the West Branch. Additionally, a revision to the buffer requirement to remove landscaping as an exemption (either in all or part of the buffer zone) could be pursued in order to achieve water quality and habitat goals (1.1.2 and 1.1.3).
- Make the FEH zone a "sending area" for the purpose of Stowe's Transfer of Development Rights (TDR) Program. This will allow owners of land in the FEH zone to sell development rights to individuals developing properties in the "receiving zones".
- Continue to allow Planned Unit Developments (PUDs) to remove development rights from the FEH zone. Whenever strict regulations regarding land use are involved, it is best to allow the rights to develop to be moved to more appropriate locations. In this way property owners are not denied an economic use of their lands in the FEH zone. In a PUD, the development rights are shifted from the undevelopable lands (in the FEH zone) to developable portions of the property. Stowe already allows this but it will become more important if additional restrictions on development are adopted.
- Continue to enforce other zoning criteria that may impact the FEH. Many provisions currently in effect have a positive effect on the stream corridor. The Flood Hazard Area provisions require that all development in the FHA receive conditional use approval. All conditional uses are required to incorporate appropriate storm-water management measures [Section 4.7(2)(B)(9)] therefore all projects in the FEH will require storm-water management controls.

Fortunately, the Town has a Transfer of Development Rights (TDR) program. Areas within the FEH Overlay District can be added to the Town's designated "Sending Areas" and revisit "Receiving Areas" to make sure there is no need for modification.

6.3.2 Non-Regulatory

Property (or Structure) Buyouts

The Town should prioritize certain properties, and in particular structures, that pose either a high safety risk or a potentially high reoccurring investment, or whose encroachment is causing such a significant impact on the fluvial system that the consensus is it should be removed, as candidate properties for being bought out. Funding for such action could come from a range of sources, such as local town funds, state emergency management funds, or federal (pre)disaster mitigation funds.

Purchase or Donation of Development Rights
The Town should prioritize certain properties that pose either a high safety risk or a potentially high reoccurring investment, as candidate properties for purchasing or donating development rights, using a conservation or river corridor easement to protect such properties and the river. Depending on the reach or site issues, such easements may only need to be as big as necessary to create a riparian buffer or they may need to include an entire property or combination of properties. Potential resources for such action include the local conservation commission, Stowe Land Trust, statewide organizations like the Vermont Land Trust and the Vermont River Conservancy, as well as similar federal organizations.

Add River Restoration and Land Conservation Projects to Stowe's existing Capital Program and Budget
Capital programs and their associated budgets are typically used to plan for the substantial capital needs of a community, such as traditional infrastructure improvements like roads and bridges, or for the purchase of expensive equipment. For example, planning and budgeting for any local costs associated with the Luce Hill Bridge replacement (one of the recommendations of this Corridor Management Plan) would be a standard item in a capital program and budget. At the same time, the town should also be including river restoration and conservation projects as a part of its capital program and budget. Maintaining the town's "green infrastructure" is as equally important as maintaining the town's built infrastructure; especially when it comes to restoring river ecosystems. By adding river restoration and land conservation projects to the town's capital program and budget, the town will be ensuring it has the necessary resources in the future to implement the projects it has prioritized. If the town anticipates needing additional funding resources beyond the town's tax base to supplement the implementation of any of the items in the capital program, the town should also identify any additional funding sources for these types of investments.

6.3.3 Planning and Research
The management of stormwater runoff is both a simple concept and a complex problem. Precipitation runs off impervious surfaces rather than infiltrating naturally into the soil. The cumulative impact resulting from the increased frequency, volume, and flow rate of stormwater runoff events can lead to destabilization of downstream channels and can also result in increased wash-off pollutant loading to receiving waters (VANR 2005). A stormwater retrofit survey is also recommended to ensure that stormwater is processed as efficiently as possible within the watershed as not to cause unnecessary volume increases during high flow events.

The bike path is an encroachment along much of the West Branch. In such places, consideration should be given to relocating the bike path to a site outside of the floodplain as not to encroach on the river corridor and cause maintenance issues, particularly bank armoring (see figure 6). It is recommended that the Town of Stowe revise its Recreation Plan and Recreation Lands Management Plan to place higher priority on realignment and relocation over channel armoring in response to erosion conflicts with the river, and avoidance of facilities investments within the corridor.

6.3.4 Education and Training

An effort should be made to educate landowners and other interested people as to the importance of maintaining a stable river. As more people become aware of the dangers and expenses associated with developing land within the river corridor it will be easier to implement policies that protect both the river and property. Fewer resources will be wasted on counterproductive river management and proper management for long term stability will become more efficient. Local landowners that understand the importance of managing the river corridor will make implementation of recommended management easier.

6.4 Administration of the Corridor

It is recommended that the Town of Stowe develop a list of protocols that guide procedures such as field surveys and repairs or maintenance after damage is done to the river system from storms or other events. This will help organize procedures and create efficient operation of town officials and emergency responders to document current and future flood events.

The Regional Pre-Disaster Mitigation Plan was funded by the Federal Emergency Management Agency through Vermont Emergency Management (VEM). All Lamoille County Towns have an officially adopted Pre-disaster mitigation plan, and all plans include conducting a Fluvial Geomorphic and Landslides Hazard Assessment as an Identified Hazard Mitigation Project/Activity. This plan, as well as the Town Plan, should incorporate any changes made to accommodate the river corridor.

7.0 Project and Program Recommendations - Reach and Site-scale Initiatives

Higher priority should be given to restoration projects that are easy to implement, low cost, and require little or no further analysis ("low hanging fruit").

There are a few segments that are not as degraded as others on the West Branch, and have high recovery potential. These are the areas that have a healthy riparian buffer, good bed form, sediment storage potential, or floodplain access. Any segment with one or more of these characteristics should be given high priority for protection through conservation. For example, reaches 4C (Map 4, page 50) and 5 (Map 5, page 51) are high recovery reaches that still have access to their floodplain, and should be protected from potential degradation by protecting this undeveloped floodplain and healthy buffer.

7.1 Short-term – Designs for Immediate Actions

Due to the lack of floodplain access on the West Branch, projects that result in or allow for the re-establishment of floodplain should be a high priority to prevent further degradation and channel widening. Reach 1 (Map 1, page 48) is one of the few areas capable of storing sediment. This is an area where removal of rip-rap should be considered, as this would help the creation of a lower floodplain and improve geomorphic stability.

Reach 5 (Map 5, page 52), the second uppermost reach of the assessments, has a low incision ratio, retains a weak riffle-pool bed form, a generally healthy riparian forest, and adequate room to migrate laterally to reestablish equilibrium. This reach has a high recovery potential. This area is an example of where restrictions on development within the river corridor and permanent conservation easements to obtain channel management rights, combined with passive restoration through protection strategies will be beneficial. This reach is also capable of storing sediment that comes from upstream where storage capacity is minimal.

Just downstream is another reach with high recovery potential. This reach, 4C (Map 4, page 51), also has some access to its floodplain which should be protected through zoning bylaws or permanent conservation of undeveloped areas. This will also protect the intact riparian buffer. A healthy aquatic ecosystem was noted by BCE scientists in this area.

The Luce Hill Bridge is the cause of major sediment deposition and erosion upstream of the bridge (Figure 4, page 18). This is due to the undersized width of the bridge, which is approximately half of the bank-full width of the stream. There is a proposal to either replace or refit the bridge to a proper width to curtail the effects it has on the stream. The Brook Road Bridge is another undersized structure that should be replaced.

7.2 Long-term Restoration and Protection Plan

A high priority of long term restoration is the creation of a river corridor that regulates land use adjacent to the river to allow the stream room to migrate laterally and regain equilibrium. This area will include the floodplain in which zoning bylaws regulate development. Any undeveloped areas within the corridor should be permanently protected from future encroachments. This will greatly reduce the amount of money spent on flood damage and erosion mitigation. Rip-rap should not be installed unless it is absolutely necessary to protect an existing structure.

Riparian buffers should be established or protected to control erosion and manage the quantity and quality of runoff. Aquatic and riparian habitat will also benefit from stable buffers. One priority that applies to the entire river is the preservation of undeveloped areas within the river corridor. Long term stability reduces the amount of resources necessary to maintain a healthy river.

7.3 Management Recommendations

See the attached Maps 1-6 (page 48-53) for locations of the reaches on the West Branch.

Menu of river corridor segment management alternatives:

1. Avoidance of new development encroachments within the river corridor through land use regulatory means. (FEH Overlay District)
   -permitted and conditional uses
   -clustering options
   -density bonuses
   -set backs
   -buffers
   -transfer of development rights
2. Riparian corridor conservation through easement acquisition of channel management rights within the river belt width.
   -donation of development and channel management rights
   -purchase of development and channel management rights
   -transfer of development and channel management rights
   -outright fee purchase of property
   -capital budget / program
3. Restore the river corridor through the removal or relocation of existing development constraints (either pro-actively or in response to fluvial erosion conflicts) as a preferred alternative to bank armoring.
4. Allow passive geomorphic adjustments and redevelopment of an equilibrium (stable) channel condition (generally consisting of new flood plain).
5. Construct an equilibrium (stable) channel (may be modified from what would be the natural condition).
6. Combinations of 1-5 above.
7. No treatment.

Reach	Channel Evolution Stage	Major Adjustment Process	Recommendations	Rec. Path Relocation / Floodplan Reconstruction Sites	Who	Potential Funding Source
1	III	Aggradation, Widening, Planform	•Relocate Rec. Path and Quiet Path •Reconstruct floodplain and buffer •Permanently protect / restrict new development and channelization within undeveloped corridor	1, 2 (Quiet Path)	Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	VT CREP Program Town of Stowe FEMA Clean and Clear
2	IV	Aggradation, Planform	•Replace Luce Hill Bridge •Relocate Rec. Path •Reconstruct floodplain and buffer •Permanently protect / restrict new development and channelization within undeveloped corridor	3, 4, 5, 6, 7, 8	Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	VT CREP Program PDM-C FEMA Town of Stowe VTRANS Clean and Clear
3A	II	Aggradation	•Allow for passive geomorphic adjustments •Permanently protect / restrict new development and channelization within undeveloped corridor		Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	VT CREP Program PDM-C Town of Stowe Clean and Clear
3B	III	Aggradation, Widening	•Allow for passive geomorphic adjustments •Relocate Rec. Path •Permanently protect / restrict new development within undeveloped corridor	9	Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	Town of Stowe Clean and Clear
4A	IV	Aggradation, Widening, Planform	•Reconstruct floodplain and buffer •Relocate Rec. Path •Permanently protect / restrict new development within undeveloped corridor	10, 11, 12	Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	Town of Stowe Clean and Clear
4B	II	Aggradation, Widening	•Relocate Rec. Path •Permanently protect / restrict new development and channelization within undeveloped corridor •Allow for passive geomorphic adjustments	13	Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	VT CREP Program Town of Stowe Clean and Clear
4C	IV	Aggradation, Planform	•Permanently protect / restrict new development within undeveloped corridor •Allow for passive geomorphic adjustments		Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	Town of Stowe Stowe Land Trust VT Land Trust River Conservancy
5	IV	Planform	•Monitor Brook Road Bridge •Relocate Rec. Path •Permanently protect / restrict new development and channelization within undeveloped corridor •Allow for passive geomorphic adjustments	14	Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	PDM-C Town of Stowe VTRANS Stowe Land Trust VT Land Trust River Conservancy
6	II	Aggradation, Widening	•Improve stormwater management •Permanently protect / restrict new development and channelization within undeveloped corridor •Allow for passive geomorphic adjustments		Town of Stowe, LCPC, Stowe Conservation and Planning Commissions	Town of Stowe Clean and Clear

Figure 10. West Branch Projects (See maps in Appendix C)

Reach 1
Reach 1 begins at the confluence of the West Branch and the Little River in the Village of Stowe and ends where the river passes by Percy's (just above Weeks Hill Road).

This segment has incised to the point that it has lost access to its historic floodplain. It is creating a new floodplain at a lower elevation by eroding its banks and widening. Approximately 50% of both banks were failing, and where active erosion was absent, riprap was generally present. Once the new flood bench is established, the channel will narrow and the banks will stabilize.

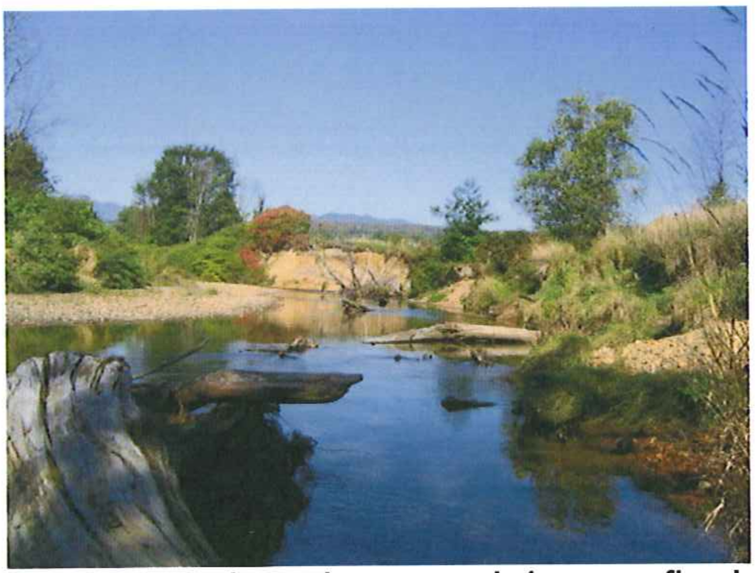

Figure 11. Bank erosion on reach 1 as new floodplain develops

This reach is unconfined by topography or geology and is incised but not as deeply as upstream reaches 2, 3, or 4. The floodplain is accessed at infrequent, high discharges in lower half of reach. There is very limited redevelopment of flood plain only in one short segment.

The corridor is generally constrained only by recreational development. Adequate space appears available to move the path away from the channel in response to erosion threats. There is an opportunity along the Mayo Farm at the Quiet Path to allow the river space and actively construct a new floodplain.

<u>Recommended Corridor Management Alternatives (see Map 1):</u>

- Provide regulatory restriction on new development within the undeveloped corridor.
- Obtain easements enabling future relocation of the Recreation Path and Quiet Path, where not already available.
- Provide permanent protection against the ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the belt width.
- Construct a new floodplain and plan a buffer along the Quiet Path.

Reach 2
Reach 2 begins at Percy's (just above Weeks Hill Road) and continues until half way between Cottage Club Road and Houston Farm Road.

This segment is also exhibiting signs of widening and creating a floodplain at a lower elevation, and is extensively armored with rip-rap, similar to reach 1. The Luce Hill Bridge is the cause of significant obstruction of sediment movement in this reach (see Figure 4, page 18). The riparian corridor in this segment is dominated by commercial and residential land uses.

Figure 12. Sediment upstream of Luce Hill Bridge
This is another segment where erosion is currently widening the river and a new floodplain is being established at a lower elevation. This process should be allowed to proceed on its own where possible and may be encouraged through active floodplain creation where landowners are agreeable. However, in some areas, encroachments from the bike path, residential and commercial development, and transportation infrastructure will not allow the river to widen to achieve stability. Where it is possible, riparian plantings can help curtail erosion, but erosion and the creation of a new floodplain should be left unimpeded where it is possible. Riparian plantings can provide stability on sections where further erosion is establishing a new floodplain. The right bank (right and left bank are always determined looking downstream) especially needs an enhanced riparian buffer, as it is currently less than 25 feet wide.

Recommended Corridor Management Alternatives (see Map 2):

- Provide regulatory restriction on new development within the undeveloped corridor.
- Replacement / redesign of Luce Hill Bridge with a wider structure that allows for the movement of sediment.

- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.
- Obtain easements enabling future relocation of the Recreation Path, where not already available.
- Analysis of alternatives for floodplain reconstruction including removal of rip-rap and enhancement of riparian buffer.

Reach 3A

Reach 3A begins roughly half way between Cottage Club Road and Houston Farm Road and ends about 550 feet upstream at a large rock.

This segment has become over-widened, featureless, and is extensively riprapped. There is very little sediment storage.

This segment would benefit from the creation of floodplain. Restoring floodplain access and the meander geometry of this segment may help to improve habitat, reduce erosion and fluvial erosion hazard and decrease the need for bank armoring in the future. The left bank has a riparian buffer of less than five feet which can be increased by plantings.

<u>Recommended Corridor Management Alternatives (see Map 3):</u>

- Provide regulatory restriction on new development within the undeveloped corridor.
- Plant riparian buffer after stream stabilizes
- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.
- Allow for passive geomorphic channel adjustments.

Reach 3B

Reach 3B begins at the end of 3A and continues until bike path parking lot near corn maze.

Figure 13. Reach 3

This segment has reestablished a small floodplain and sediment is being stored in point bars. It is further along in channel evolution than the segment downstream, and is relatively wide and shallow.

This segment should be monitored as the right bank reestablishes its flood bench. This process has been successful thus far, and zoning could ensure that it can continue unimpeded into the future. The right bank would benefit from riparian plantings after the new floodplain is established.

Recommended Corridor Management Alternatives (see Map 3):

- Provide regulatory restriction on new development within the undeveloped corridor.
- Obtain easements enabling future relocation of the Recreation Path, where not already available.
- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.
- Reconstruct floodplain. This includes removal of rip-rap where private and public structures are not being threatened and geomorphic adjustments are anticipated.

Reach 4A
Reach 4A begins near bike path parking lot near corn maze and ends about 3000 feet upstream.

This segment is also starting to reestablish a small floodplain and channel bars. The left bank has a narrow riparian buffer of only 5-25 feet.

This segment has lost its historic floodplain. The left bank, which is dominated by commercial land use and Route 108 would benefit from riparian plantings, as there is very little room for the river to move laterally. Currently, the left riparian buffer is less than 25 feet wide and could be enhanced after the floodplain is reestablished.

Recommended Corridor Management Alternatives (see Map 4):

- Provide regulatory restriction on new development within the undeveloped corridor.
- Obtain easements enabling future relocation of the Recreation Path, where not already available. The segment of the path that was recently relocated should be extended.
- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.
- Allow for passive geomorphic channel adjustments.

Reach 4B
Reach 4B begins about 3000 feet upstream of the beginning of reach 4A and ends approximately where the hay field ends on the left.

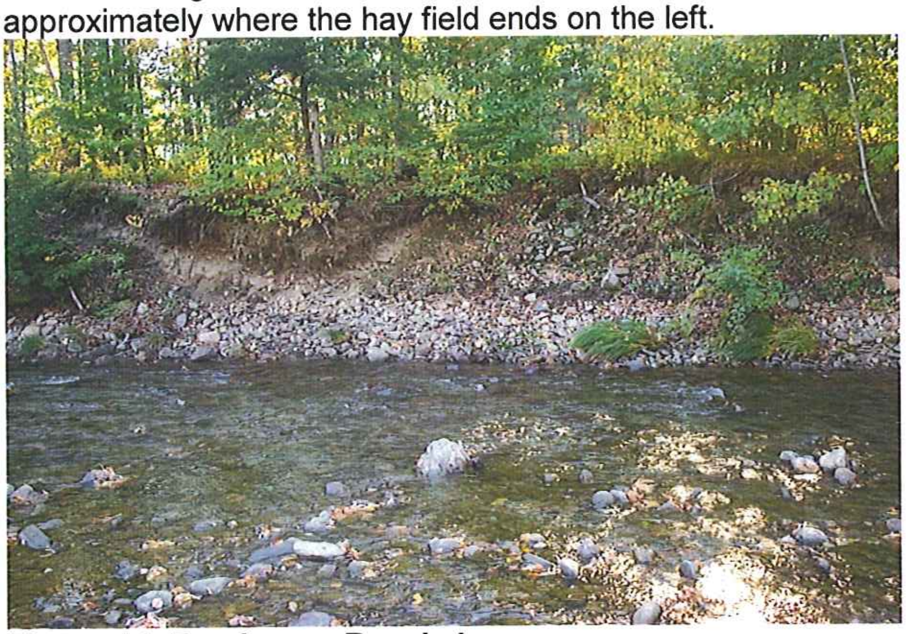

Figure 14. Erosion on Reach 4

This segment is highly entrenched. There is high bank erosion and very little sediment storage. This segment would benefit from the creation floodplain to help prevent further degradation and widening. Although many sections of this reach have a healthy riparian buffer that should be protected, continued erosion and loss of streambank trees can be expected unless a floodplain bench is created.

Recommended Corridor Management Alternatives (see Map 4):

- Provide regulatory restriction on new development within the undeveloped corridor.
- Reconstruct floodplain and enhance buffer through incised reach.
- Obtain easements enabling future relocation of the Recreation Path, where not already available.
- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.

Reach 4C

Reach 4C begins at the end of 4B and continues until approximately where Brookdale Lane intersects Mountain Road.

This segment was less entrenched than many others and had a wide riparian buffer made up of mixed trees. This was the first segment that BCE scientists noticed fish utilizing the favorable habitat conditions. Conservation of the riparian corridor in this segment should be a high priority.

This segment is in better shape than many others on the West Branch. It has some riffle-pool features, and still has access to most of its floodplain. The riparian buffer was over one hundred feet wide on most of the segment. This buffer and floodplain should be high priority for protection through zoning bylaws. The extreme sensitivity of the segment just downstream is important to acknowledge.

Recommended Corridor Management Alternatives (see Map 4):

- Provide regulatory restriction on new development within the undeveloped corridor.
- Preservation of the floodplain and riparian buffer
- Obtain easements enabling future relocation of the Recreation Path, where not already available.
- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.
- Allow for passive geomorphic channel adjustments.

Reach 5
Begins approximately where Brookdale Lane intersects Mountain Road and continues until approximately 1500 feet downstream of the Route 108 Bridge.

This segment generally had a healthy riparian forest of adequate width, despite a couple encroachments from Brook Road, Route 108, and some commercial and residential structures. This is another segment that still retains some riffle-pool characteristics and should be protected from further degradation. The areas with a healthy riparian buffer should be protected to make up for the few spots of encroachment by Brook Road and Route 108. Passive restoration approaches can be applied to this reach by protecting the assets through zoning.

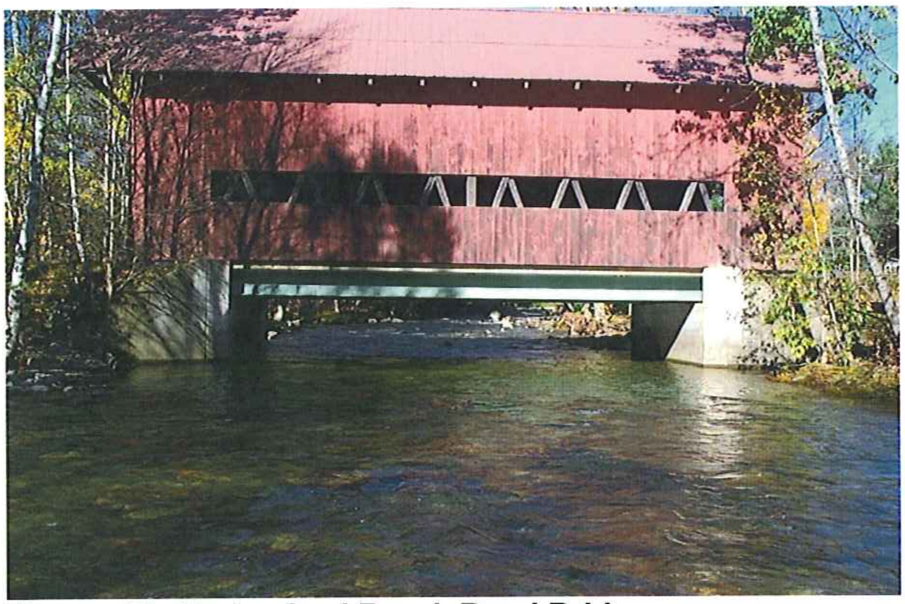

Figure 15. Undersized Brook Road Bridge

Recommended Corridor Management Alternatives (see Map 5):

- Provide regulatory restriction on new development within the undeveloped corridor.
- Monitor undersized Brook Road Bridge
- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.
- Allow for passive geomorphic channel adjustments.

Reach 6
Reach 6 begins approximately 1500 feet downstream of the Route 108 Bridge and ends at the confluence of Ranch Brook near Notchbrook Road.

This segment has been affected by historic channel straightening and floodplain encroachment especially on the left bank. Opportunities for reducing these encroachments and reestablishing floodplain should be explored. Considering the amount of existing development in the left corridor, the right side of the corridor should be given higher priority for conservation to compensate for the lack of room on the left. Also, plantings should be a priority for the left bank to protect structures that are very close to the river.

Figure 16. Reach 6
This is a steep, bouldery, partially channelized reach that is providing no sediment storage and may even be producing sediment from active incision and bank erosion. It is very dynamic and has resulted in a number of significant erosion threats to developed property located within the corridor in the past. It is a high priority to avoid additional development within the undeveloped corridor.

Recommended Corridor Management Alternatives (see Map 6):

- Provide regulatory restriction on new development within the undeveloped corridor.
- Improve stormwater management for development on left bank
- Provide permanent protection against ongoing channelization within the undeveloped portion of the corridor through easement acquisition of channel management rights within the river belt width.

7.4 Recommendation Conclusions

There are many opportunities on the West Branch to restore the river to a stable condition. Generally, relocation of the bike path, preservation of the undeveloped areas within the corridor, and passive restoration of the river are the actions that will benefit the stability of the river. Addressing these issues would reduce flood hazards, avoid conflicts regarding land use, and save money spent on flood damage and river maintenance.

The town can adopt a Recreation Path and Recreation Lands Management Plan that places higher priority on realignment and relocation over channel armoring in response to erosion conflicts with the river, and avoidance of facilities investments within the corridor. There are a number of options to permanently preserve undeveloped portions of the corridor. Utilization of the Stowe Land Trust or Vermont Land Trust to acquire the development and channel management rights in these undeveloped portions, either through donation, transfer, or purchase, would be an enormous benefit to the town. Also, bank armoring is a costly practice that prolongs the river's evolution towards stability. Erosion that is not threatening permanent development should be left to proceed rather than being armored. Funding can be solicited to replace the Luce Hill Bridge, the Brook Road Bridge, and relocation of the bike path.

The river needs the space within the corridor to move and achieve stability. Given the space and time, the West Branch will establish equilibrium on its own. Maintenance of the stable channel will be less costly and easier than trying to maintain the unstable channel that currently exists. Flood and erosion hazards would also be reduced once the channel stabilizes. It is in the town's best interest to take all reasonable measures to stabilize the West Branch. If the community of Stowe can recognize these opportunities, the West Branch would be a wonderful resource for the town rather than a liability.

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Appendix A: Channel Evolution Models

F-Stage Channel Evolution Process

The capital letters used throughout the following discussion refer to the stream types (Rosgen 1996) typically encountered as the channel form passes through the different stages of channel evolution. The F-stage adjustment process typically begins in unconfined, low gradient valleys where the streams are not entrenched and have access to their floodplain at the 1-2 year flood stage. Moderately entrenched, semi-confined "B" streams may also go through an F-stage channel evolution. This channel evolution model (CEM) is based on the assumption that the stream has a bed and banks that are sufficiently erodible so that they can be shaped by the stream over the course of years or decades. Streams beginning this process are typically flowing in alluvium or other materials that are easily eroded by an increase in stream power. As the incision process continues, they may degrade into bedrock or materials of glacial origin. When a stream with a low width to depth ratio ("E" stream types) goes through this process, the sequence of stream types may be **E-C-F-C-E** (other forms may include **E-C-G-F-C-E** or **C-G-F-C** or **C-F-C** or **B-G-F-B** or **B-G-F**).

Stage I – Channel in regime with access to floodplain or flood prone area at discharges at and above the average annual high flow. Planform is moderate to highly sinuous; supportive of energy dissipating bed features (steps, riffles, runs, pools) essential to channel stability (B, C, and E Stream Types). Channel slope (vertical drop in relation to length) generates flow velocities and stream power in balance with the resistance of stream bed and bank materials. Sediment transport capacity in equilibrium with sediment load.

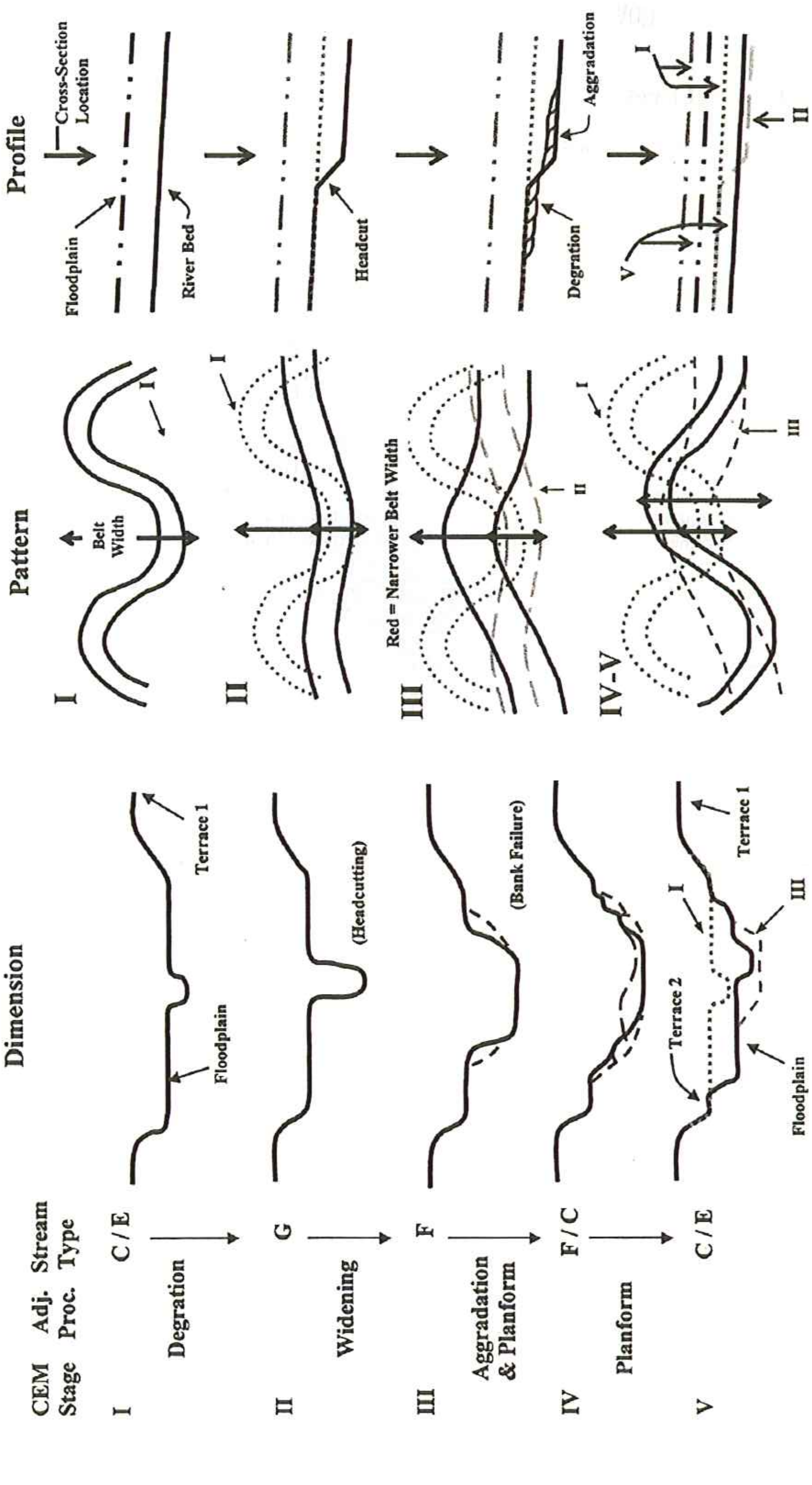
Stage II – Channel has lost access to its floodplain or flood prone area through a bed degradation process or floodplain build up. Stream has become entrenched as discharges in excess of the annual high flow are now contained within the channel (G or F Stream Type). Channel slope is increased with commensurate increase in velocity and power to erode the stream bed and banks (boundary materials). The result of preventing access to the floodplain and containing greater flows in the channel is to increase the stream's power that must be resisted by the channel boundary materials; i.e., the rocks, soil, vegetation, or man-made structures that make up the bed and banks of the river. Plane bed may begin to form as head cuts move upstream and step/riffle materials are eroded.

Stage III – Channel is still entrenched, widening and migrating laterally through bank erosion caused by the increased stream power (G or F Stream Type). The system regains balance between the power produced and the boundary materials as sinuosity increases and slope decreases. There are profound physical adjustments that occur upstream and downstream from the site of alteration as bed degradation (head cuts) migrates up though the system and aggradation in the form of sedimentation occurs downstream. Stream bed largely becomes a featureless plane bed.

Stage IV – Channel dimension and plan form adjustment process continues. Channel width begins to narrow through aggradation and the development of bar features. The main channel may shift back and fourth through different flood chutes, continuing to erode terrace side slopes as a juvenile floodplain widens and forms. Weak step/riffle-pool bed features forming. Transverse bars may be common as planform continues to adjust. At Stage IV, erosion may be severe. Historically, channels have been dredged, bermed, and/or armored at this Stage pushing the process back to Stage II or III.

Stage V – Channel adjustment process is complete. Channel dimensions, pattern, and profile are similar to the pre-adjustment form but at a lower elevation in the landscape (B, C and E Stream Types). Planform geometry, longitudinal profile, channel depth, and bed features produce an energy grade that is in balance with the sediment regime produced by the stream's watershed.

F-stage Channel Evolution Process (VTDEC-Modified from Schumm, 1977 & 1984 and Thorne et al, 1997)



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Appendix B: Phase 3 Geomorphic Assessment Results

Comparison of Project Alternatives
West Branch Rehabilitation, Luce Hill Bridge Area

Alternate	*Increase sediment continuity*	*Reduce erosion hazards*	*Improve channel stability*	*Reduce bridge scour*	*Improve aquatic habitat*	*Towards natural process*	*Short or long-term solution*	*Initial relative cost est.*	*Comments*	*Rec.*
Conceptual Watershed Alternatives										
No action	x	x	x	x	x	x	n/a	none	not desirable, many local erosion hazards, system-wide instability	
Limit sediment supply	+	+	+	o	+	+	long	very high	not feasible, high bedload, developed corridor, dispersed sources	
Restore natural discharge	+	+	+	o	+	+	long	very high	not reversible, altered hydrology, developed corridor, accepted risks	
River Corridor Protection Alternative										
Passive channel recovery	o	+	+	+	+	+	long	medium	space to meander, floodplain creation, decreases corridor conflicts	✓
Luce Hill Road Bridge Alternatives										
No action	x	x	x	x	x	x	n/a	none	not desirable, bridge prone to scour, mechanism of sediment bottleneck	
Increase bridge width	+	+	o	+	o	+	long	high	allow ample lateral migration, flood bench creation, increase safety	✓
Add overflow culvert	o	o	o	+	o	+	short	medium	reduce high-flow backwater, flood bench creation, multi-use	✓
West Branch Channel Alternatives										
No action	x	x	x	x	x	x	n/a	none	not desirable, unstable channel, inc. lateral erosion, poor habitat	
Passive adjustment	o	o	o	o	o	+	long	low	adjustment likely with bridge change, track monumented sections	✓
Adjust cross sections	o	o	o	x	+	+	short	medium	assist towards flood bench creation, compound stable channel	✓
Increase channel slope	+	x	x	x	x	x	short	medium	oppose natural process of decreasing slope	
Stabilize raw banks on site	x	o	o	x	x	x	short	medium	not presently working at site, need hard toe, improve flow path	✓

+ Good
o Moderate to fair
x Poor

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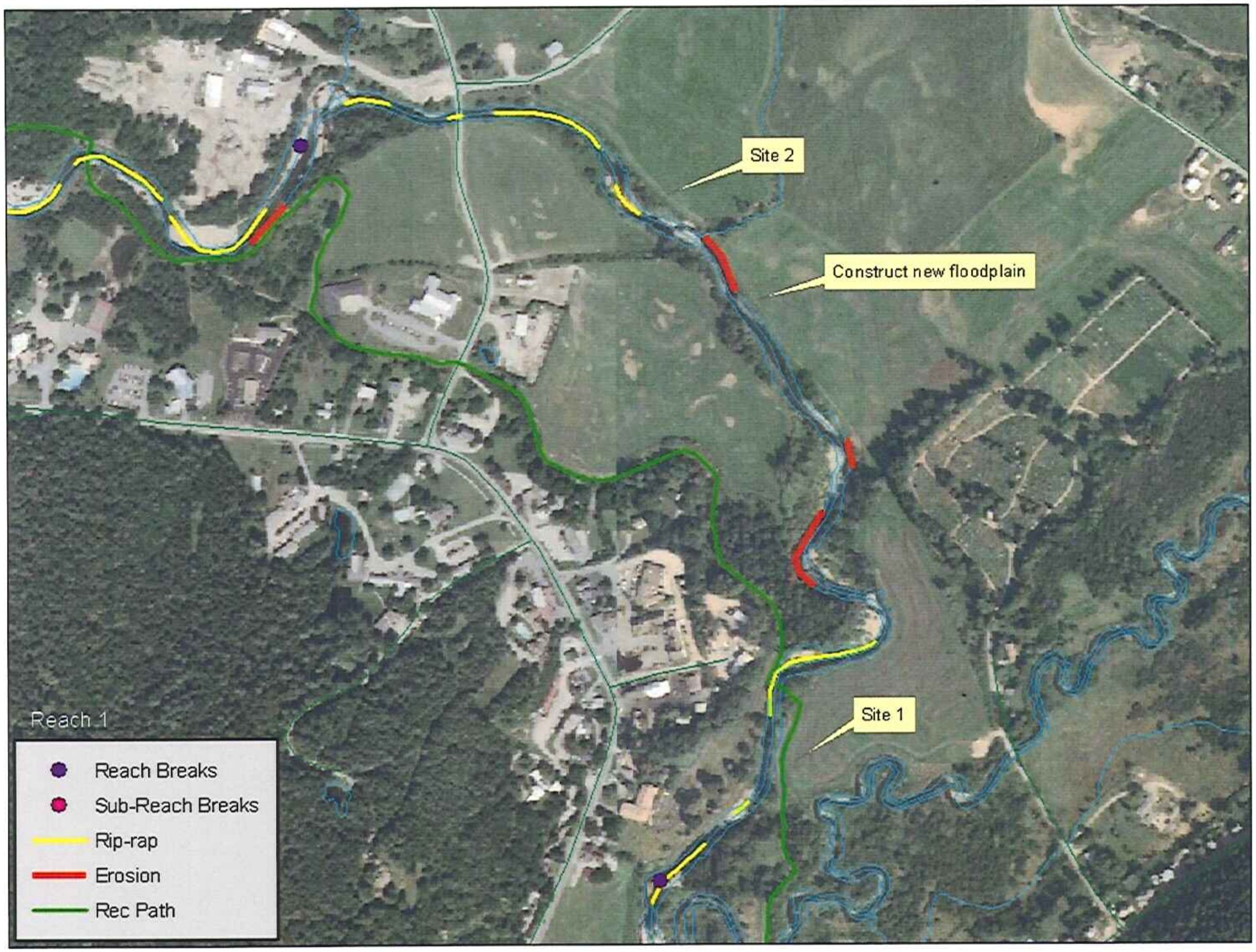
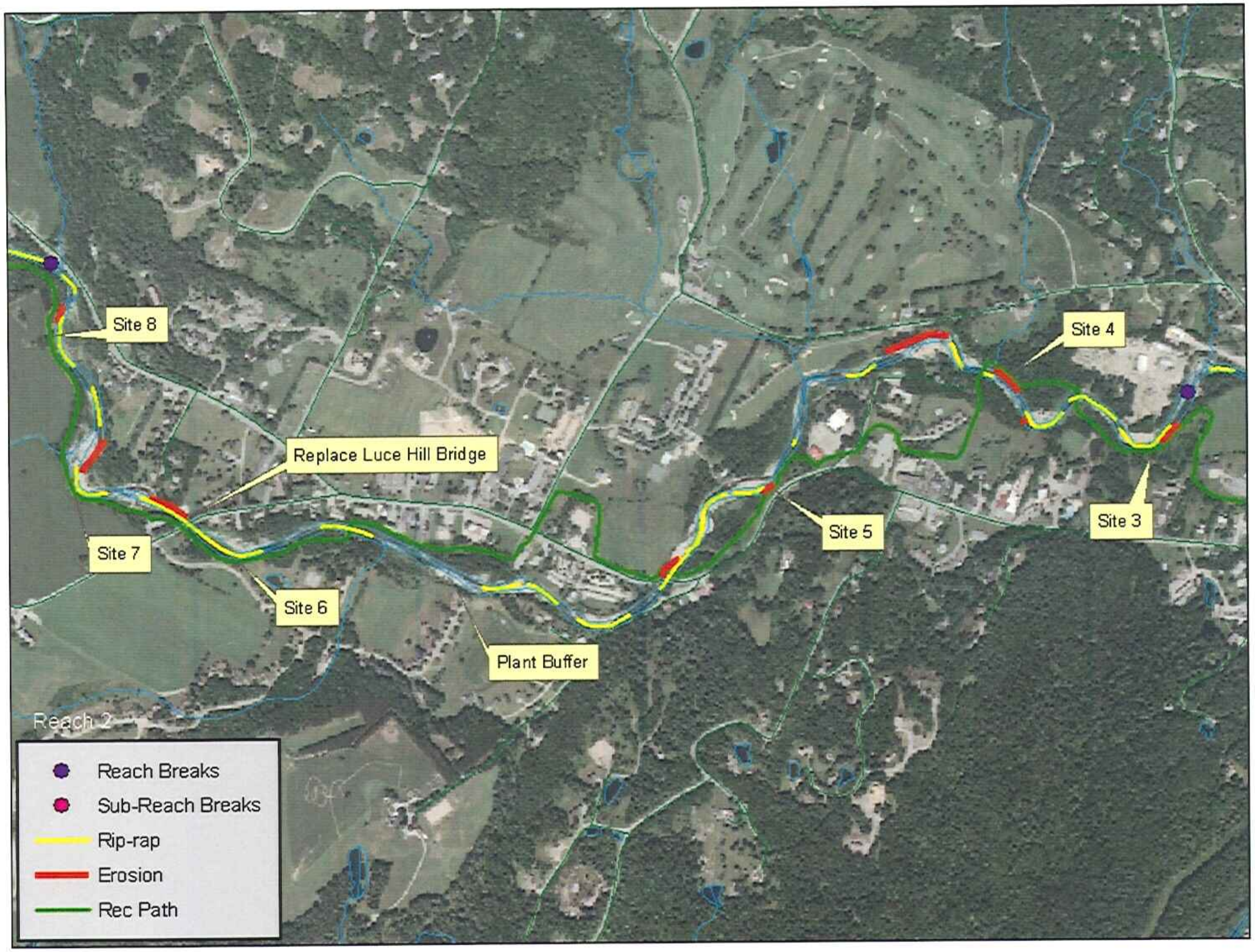
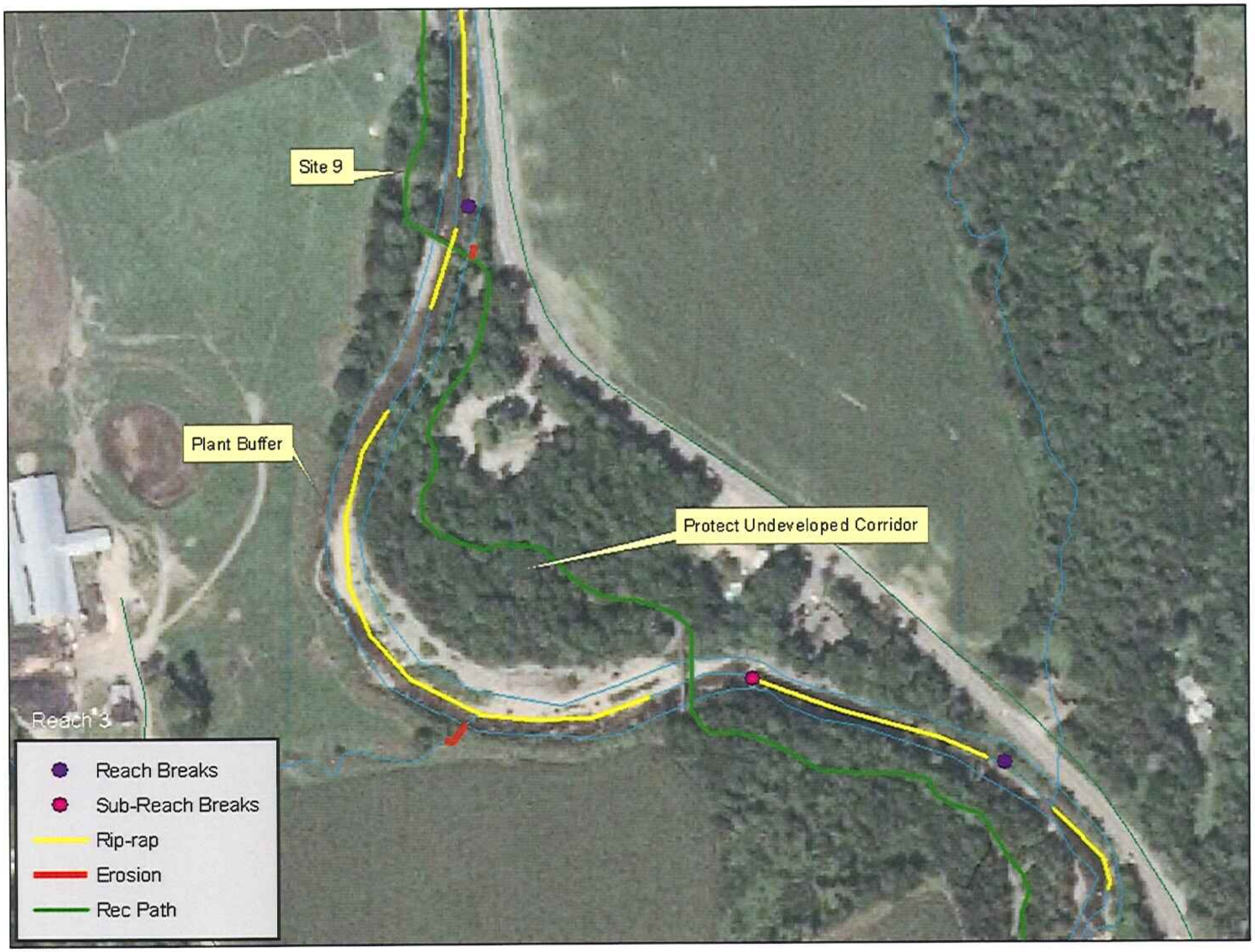
Appendix C: Reach Maps


Site 2
Construct new floodplain
Site 1
Reach 1
Reach Breaks
Sub-Reach Breaks
Rip-rap
Erosion
Rec Path

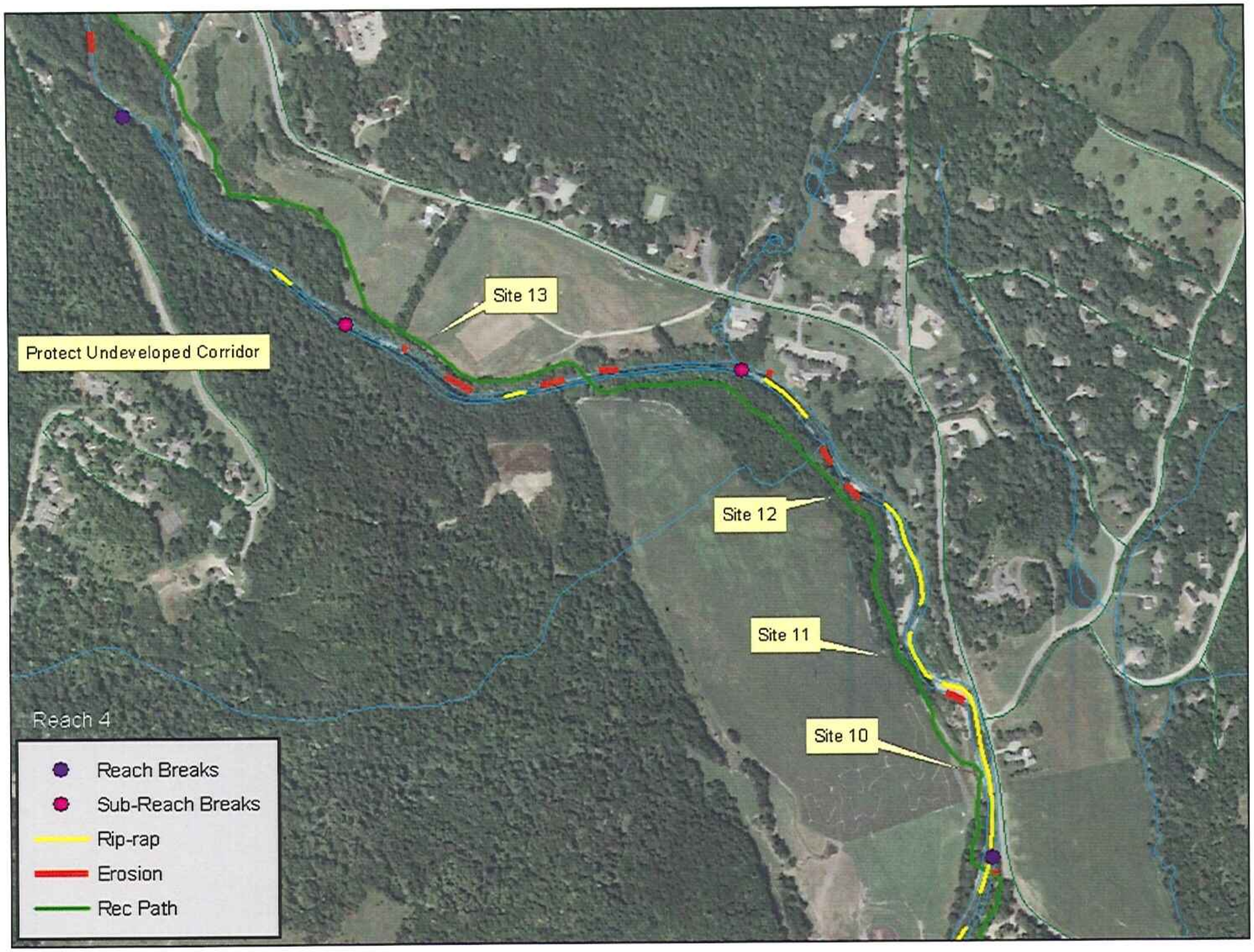
Map 1


Site 8
Site 4
Replace Luce Hill Bridge
Site 5
Site 3
Site 7
Site 6
Plant Buffer
Reach 2
Reach Breaks
Sub-Reach Breaks
Rip-rap
Erosion
Rec Path

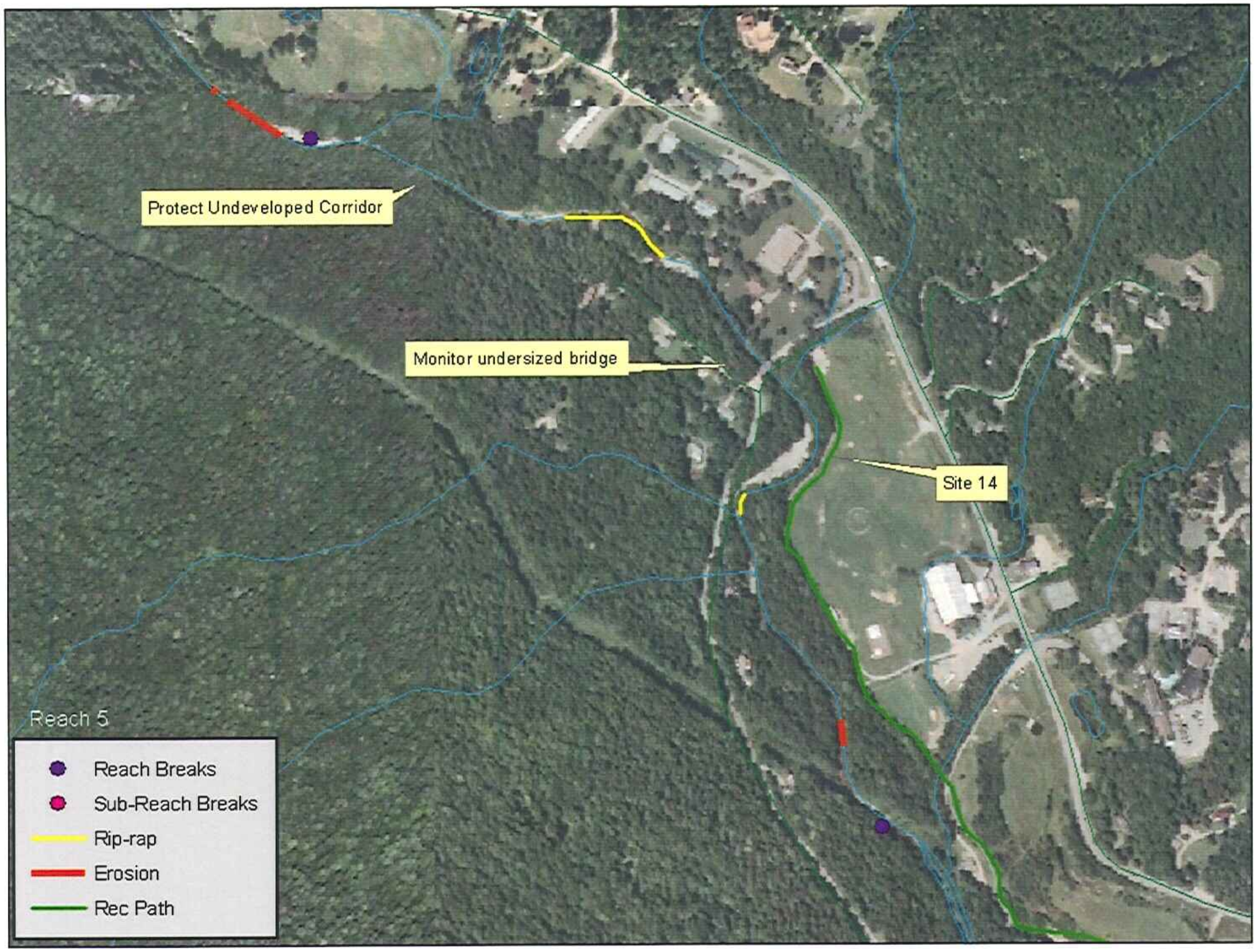
Map 2


Site 9
Plant Buffer
Protect Undeveloped Corridor
Reach 3
Reach Breaks
Sub-Reach Breaks
Rip-rap
Erosion
Rec Path

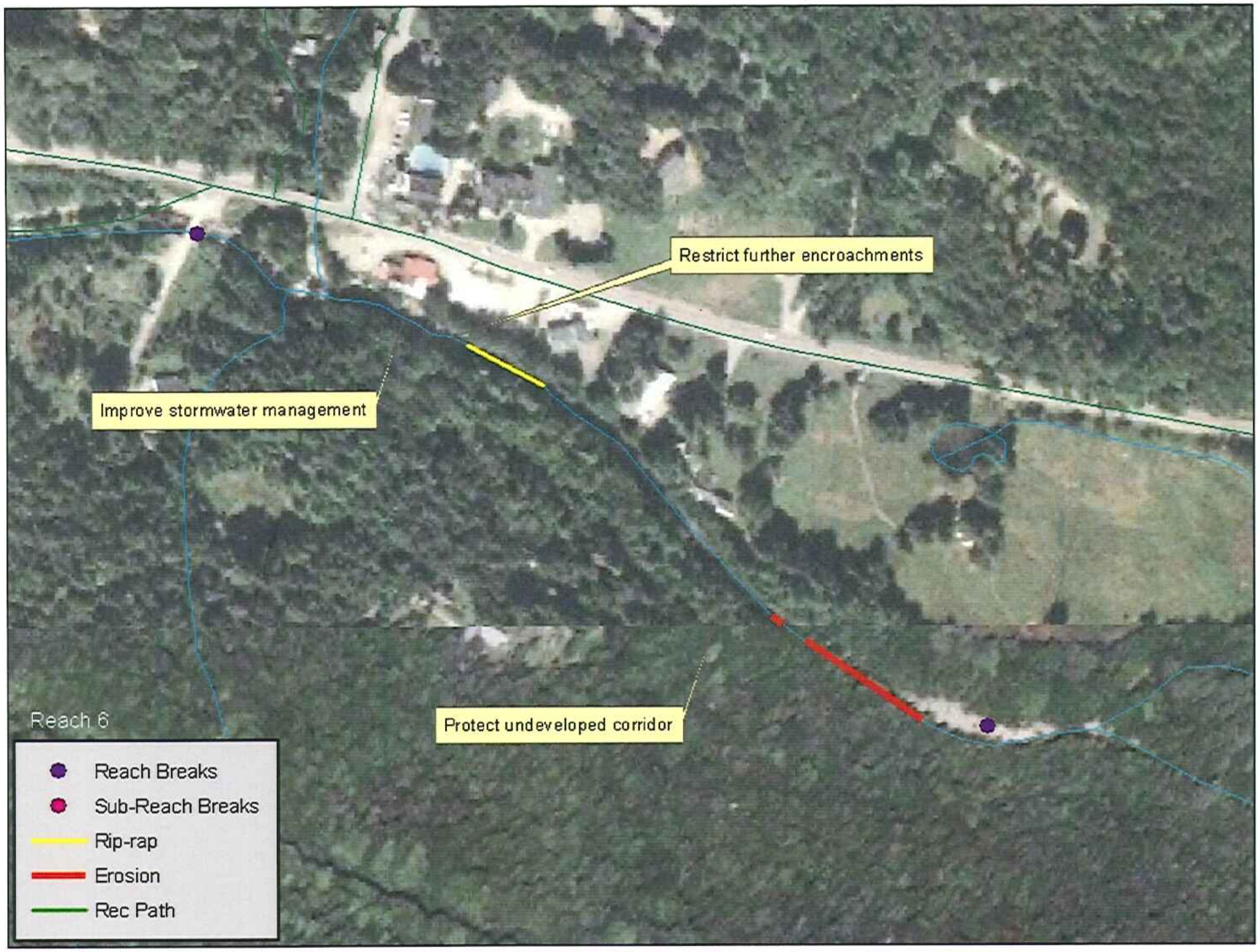
Map 3


Protect Undeveloped Corridor
Site 13
Site 12
Site 11
Site 10
Reach 4
Reach Breaks
Sub-Reach Breaks
Rip-rap
Erosion
Rec Path

Map 4


Protect Undeveloped Corridor
Monitor undersized bridge
Site 14
Reach 5
Reach Breaks
Sub-Reach Breaks
Rip-rap
Erosion
Rec Path

Map 5


Restrict further encroachments
Improve stormwater management
Protect undeveloped corridor
Reach 6
Reach Breaks
Sub-Reach Breaks
Rip-rap
Erosion
Rec Path

Map 6