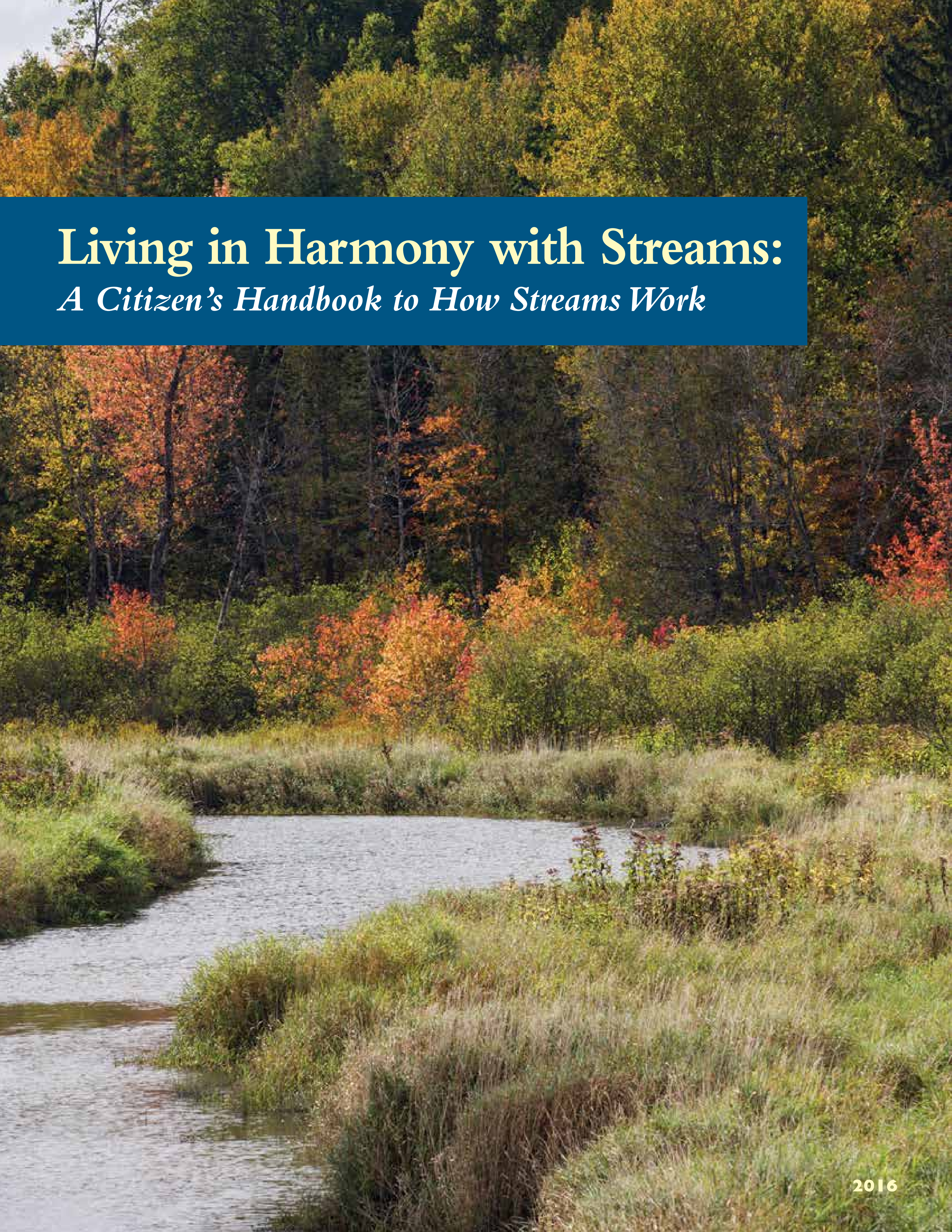
Living in Harmony with Streams:

A Citizen's Handbook to How Streams Work



2016


Courtesy of Colin McCaffrey

Coits Pond; headwaters of the Winooski River.

Cover photo: Black River, © Elinor Osborn

In 2012, Ann Smith, Director of the Friends of the Winooski River and Abbey Willard, Director of the Winooski Natural Resources Conservation District at the time, observed that landowners and others would benefit from a document that discussed stream processes and protection techniques. The Friends of the Winooski River, The White River Natural Resources Conservation District, and the Winooski Natural Resources Conservation District received generous grant funding from the Vermont Rivers Program, the Vermont Ecosystem Restoration Program, and the Lake Champlain Basin Program to write the 2012 *Living in Harmony with Streams* guide.

The *Living in Harmony with Streams* document was written by Linda Henzel, enhanced with case studies, and refined and checked for accuracy with input from many reviewers and scientists. Special thanks to Mike Kline, Director of the Vermont Rivers Program, and others at the Department of Environmental Conservation at the time, including Gretchen Alexander, Shannon Pytlik, Shayne Jaquith, Staci Pomeroy, and Kari Dolan for their work on the document. Special thanks also to Janet Thigpen, CFM, who developed *Stream Processes: A Guide to Living in Harmony with Streams* for the Chemung County Soil and Water Conservation District, Southern Tier Central Regional Planning and Development Board in New York. We borrowed heavily from many sections of the Chemung County guide.

Thank you to the following individuals for reviewing the 2012 handbook: Kerry O'Brien, Caledonia County Natural Resources Conservation District (NRCD); Justin Kenney, VT DEC, (formerly Winooski NRCD); Karen Bates, VT DEC; Cynthia Scott, Missisquoi River Basin Association; Julie Moore, Stone Environmental; Charles Fish, author of *In the Land of the Wild Onion;* Kevin Geiger, Two Rivers-Ottauquechee Regional Commission; Nanci McGuire, Rutland NRCD; Mary Nealon, Bear Creek Environmental; Daniel 'Rudi' Ruddell, Redstart Forestry; Marli Rupe, VT DEC; Mary Russ, White River Partnership; Clay Whitney, resident of Winooski basin. And thank you to Joanne Breidenstein, Leslie Haines and Kim Jensen (Lamoille County Conservation District), for proofreading the original document.

2016 Update

The first printing of the *Living in Harmony with Streams* guide was so successful that by 2015 there were only a few guides left for distribution. Watersheds United Vermont (WUV), formed in 2013 as a state-wide network of local watershed groups, received a generous grant from the Lake Champlain Basin Program* and additional support from Lake Champlain Sea Grant to revise and reprint the *Living in Harmony with Streams* booklet in 2016. Mike Kline, Vermont DEC Rivers Program updated the language in the guide to better reflect current terminology and practices. In addition, Mike wrote a section on Lessons Learned since Tropical Storm Irene. We would like to acknowledge Ann Smith for helping to shepherd this project forward and to Tim Newcomb, our designer, who helped make the guide so visually appealing to read. We would also like to thank Linda Henzel, Lyn Munno (WUV), and Corrina Parnapy (Winooski NRCD) for reviewing the 2016 version and to Joanne Breidenstein for proofreading the 2016 document.

The following organizations were partners in the development of this guide:

Friends of the Winooski River
Vermont Rivers Program
Watersheds United Vermont
Winooski Natural Resources Conservation District

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Lake Champlain Basin Program* (2012 and 2016)
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Friends of the Winooski
Vermont Ecosystem Restoration Program
Lake Champlain Basin Program
Winooski Conservation District
WUV
Watersheds United Vermont
Sea Grant Lake Champlain
River Management
Vermont Rivers Program

Goals of this Handbook

The overarching purpose of this handbook is to help Vermont's stressed stream and river systems recover more quickly by engaging communities in improving the health of Vermont's rivers. To this end the handbook is designed to:

- Encourage people and agencies to change their relationship with streams so that responses to conflicts are most conducive to river health, human enjoyment, and property protection;

- Provide community members with information about how streams work; and

- Highlight incentive programs available to landowners.

A Few Explanatory Notes

People are not likely to read this handbook through cover to cover. So, to make the handbook as accessible as possible, there is some repetition of terms and their definitions throughout the document. A glossary is also provided in Appendix A. There is a list of acronyms in Appendix B. Appendix C offers additional references for people who would like a summary of this type of information.

One fundamental term is stream "geomorphology," "*geo*" referring to the earth as in "geology," and "*morphology*" to the shape or structure of the stream channel and nearby environment. The physical processes of streams are a product of the interaction of running water and the characteristics of the land over which it flows.

The handbook concentrates on physical conditions with limited mention of key biological references and no attention to chemical processes. In addition, the primary focus is on the science of sediment in streams rather than woody debris. Many of the processes described for sediment also apply to woody materials. However, woody debris processes will only be mentioned when important to do so.

The words "rivers" and "streams" are used interchangeably throughout this handbook. In fact, within the study and planning for streams and rivers in Vermont, both terms are being used. For example, an assessment of a river system, or parts of a system, is referred to as a Stream Geomorphic Assessment (SGA). The findings of the SGAs are then incorporated into what is referred to as River Corridor Management Plans.

The River Corridor Plans described in this document are not to be confused with Vermont's tactical basin planning process. There are seventeen major watershed drainages in Vermont, and each is required to have a plan to address water quality by dealing with the complete range of physical, chemical, and biological stressors. The new Surface Water Management Strategy developed by the Vermont Department of Environmental Conservation, Water Quality Division explains that the findings and recommendations made in the River Corridor Plans will be incorporated into the appropriate basin plan as they are developed.

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Courtesy of Tim Newcomb

Preface

By Mike Kline, Vermont DEC Rivers Program Manager

Vermont's rivers and streams have many friends. These are people who know their watersheds, the rocky gorges, the meandering confluence, and the communities that live, work and play along the river banks. We owe a great debt to their stewardship—a labor of years to build a bridge between people, human livelihood, and the ever-moving, ever-changing rivers we cherish. It is truly an honor to work with groups like the Friends of the Winooski River, the White River and Winooski Conservation Districts, and their counterparts statewide. The "riparian ethic" (Naimen, 2005) grows in Vermont because these organizations exist. It is their problem solving with the local road foreman and farmer; their tireless efforts to keep rivers safe to swim and play in; and, as this handbook demonstrates, their endless work to tell us a story of the river and stir an ethic to conserve what we have in our riparian lands.

I highly recommend that every person who loves or lives next to a Vermont river or stream take the time to read, "A Citizen's Handbook to How Streams Work." You will learn about river behavior and why many Vermont Rivers have changed and will continue to change. You will learn that a stream bank along the back field may be eroding from changes that took place on the land decades or centuries ago, or just because streams are naturally dynamic—they move. You will also learn practices large and small that can make a lasting difference to something as mighty as the river.

Read this handbook, and then take a drive around your watershed. You'll see the river and its floodplains in a new light. You will see the river stressors described in this handbook, but you will also see that Vermont's rivers are not so confined and permanently constrained by human development that the benefits of stream equilibrium cannot be attained. This cannot be said in other areas of the country. The river's friends are speaking here: we must seize the opportunity and protect our river corridors and floodplains in Vermont, before they are lost.

Naimen, R.J., H. Decamps, and M.E. McCain, 2005. Riparia: Ecology, Conservation, and Management of Streamside Communities. Elsevier Academic Press, Burlington, Massachusetts.

1. Introduction

One landowner recently shared a river experience. "I love living near a stream and owned my land for more than a decade before seeing any flooding. But things started to change after a neighbor put riprap on a section of the bank upstream from me. A couple years later I wondered why the flow seemed more powerful, why there was more erosion, and why I started losing a few feet of my land it seemed every couple of years. Then I found out there is a connection between what happens upstream and changes that occur downstream due to attempts to control a river."

"…ten thousand river commissions, with the mines of the world at their back, cannot tame that lawless stream, cannot curb it or define it, cannot say to it 'Go here,' or 'Go there,' and make it obey; cannot save a shore which it has sentenced, cannot bar its path with an obstruction which it will not tear down, dance over, and laugh at."
— Mark Twain

Rivers and streams are very complicated, and different sections of the stream are related to each other in ways that we're learning more about as we study them. Over the years, people have tended to think about flood damage, washed out bridges, and eroded banks as a malfunction of the stream. While Mark Twain's experience with a river's power likely happened from his observations of the "mighty Mississippi" as shown in the sidebar, these same observations might also be made of Vermont streams.

But streams and their corridors are also our friends, indeed, necessary friends. They enhance the beauty of the landscape and the quality of our lives through scenic and recreational experiences. They provide vital breeding, resting, and feeding areas for fish, birds, and other wildlife species. They provide water for drinking and bathing, generating electricity, powering machinery, irrigating crops, transporting goods, and receiving wastewater. Healthy streams can even purify water and moderate floods and droughts.

Because the destructive action of streams is often dramatic and publicized, people may focus on that aspect. This guide explains that these "bad behaviors" are examples of normal stream function and, in many cases, reactions to human interference with natural processes. The Vermont Rivers Program has developed a scientific method for evaluating streams. Studies done between 2002 and 2016 of more than 2,000 stream miles throughout the state indicate why these efforts are important. Nearly three-quarters of Vermont streams have lost connection with their historic floodplains during the typical annual flood. A stream's lack of access to its floodplain creates an unstable condition where the stream no longer has its "release valve" or ability to dissipate energy out of the stream channel and onto the surrounding landscape. Excessive streambank erosion, depositing of sediments (sedimentation), and damage to infrastructure are all potential outcomes of a stream that has lost connection with its floodplain.

The take-home message here is that land along river shores and the lands adjacent to them should not be developed. This enables a river to flow beyond its floodplain when necessary and not cause damage to structures there. Towns are being advised to develop zoning bylaws that discourage development in floodplains and stream corridors—taking an "avoidance approach." Helping individuals and businesses make this transition to better practices, wherever feasible, is a goal of many Vermont organizations.

Here is a quick summary of the contents of the following chapters and the appendices.

Courtesy of the Vermont Rivers Program

Many landowners lose land every year due to collapsing and undercut banks. This guide explains why that happens and what can be done about it.

Miller Run in Vermont's Northeast Kingdom: How the New Approach Got Started

During the 1990s the Vermont DEC Rivers Program, the Natural Resource Conservation Service (NRCS), and the Caledonia County Natural Resources Conservation District worked as a team to restore Miller Run, a tributary to the Passumpsic River in Lyndon, Sheffield, and Wheelock, Vermont. The Miller Run was eroding along much of its length, and the team worked under the premise that erosion was "bad" and should be stopped. Agreements were reached with landowners to pioneer and apply bioengineering techniques along ten miles of the Run. The goals were to improve water quality, restore aquatic and riparian habitat, and help landowners keep their land.

After three years of work, a six-inch rain resulted in a large flood, and much of the work was undone. At a post-mortem conference on the banks of the Miller Run, the team acknowledged that they never really understood why so much of the stream was unstable and eroding in the first place. From the ashes of the Miller Run Project, was born a determination in Vermont to develop a rigorous scientific approach to assessing stream conditions, structures and processes to determine why a stream is eroding before any actions are devised to try and control or change the erosion processes.

Courtesy of Caledonia County Natural Resources Conservation District

A line of willows was planted on an eroding bank of Miller Run in the 1990s. They are seen in the photograph years later (and today). However, they are no longer on the bank of the river but further away now. This stretch of river is on a flat, open valley with a lower gradient and prone to natural lateral migration. If the geomorphic assessments being used now had been possible in the 1990s, this outcome would have been predicted. So the expense of planting willows to control erosion on the bank could have been avoided. In a situation like this where the river is re-establishing its sediment regime, the recommended action would be to allow the river to have a wider lateral flow area to do its work.

Chapter 2: How Do Streams Work? provides an overview of stream energy dynamics and channel structures and processes under what could be termed "natural" conditions.

Chapter 3: Human Activities and How They Affect Streams explains what happens to streams when human influences occur.

Chapter 4: How Vermont Protects River Corridors offers the perspective of recent research and activities by the Vermont Rivers Program and local partners in protecting a stream corridor as a connected system both upstream and downstream.

Chapter 5: Undertaking Stream Restoration Projects offers practical information and referrals to references for what people can do to restore streams.

2. How Do Streams Work?

This chapter presents general information about watersheds, the structure of streams, and the physical processes at work when water flows across the landscape.

Streams are complex systems that do complicated work. In their natural state, streams gather, store, and move water. However, it is important for understanding stream processes to realize that streams and rivers are not only moving water. Streams are also moving sediment and woody debris. The work of streams is the collection and movement of water and sediment from the surrounding landscape.

A. Streams Come From Watersheds

A watershed is the area of land from which surface and subsurface waters drain to a common receiving body or outlet. A stream is the product of this land, the watershed, which supplies both water and sediment to the stream system. The physical characteristics of a watershed—climate, topography, soils, bedrock, and vegetation—affect how water reaches its streams and how those streams behave. These features also influence the potential for soil erosion and the delivery of sediment into the stream channels. A portion of the rain that falls, along with melting snow (precipitation), soaks into the ground and fills depressions. The excess water flows downhill into streams as surface runoff and subsurface flow.

Valley Slope

In hilly or mountainous watersheds, water flows quickly down steep slopes, producing "flashy" streams in which water levels rise rapidly. The steep slopes also facilitate the transport of sediment into the stream. In areas with gentler slopes, the storm flow enters streams over a longer period and will thus have peak flows that are lower.

Soils

Different types of soil absorb water differently. If the soil allows large amounts of rainfall to pass through it or infiltrate into the ground, then less water will run off as storm flow and more will enter the stream later as base flow. Soils with high clay content and frozen soils are less able to absorb water and thus cause more rapid runoff into streams.

Figure 1. ***Illustration of the Hydrologic Cycle***

Hydrologic Cycle

The transfer of water from precipitation to surface water and groundwater, to storage and runoff, and eventually back to the atmosphere is an ongoing cycle called the hydrologic cycle. In a climate like the northeastern United States, about 30-34 percent of precipitation runs off into surface waters; about 50 percent is returned to the air by evaporation from land and water and by plants emitting water vapor (transpiration); and about 16-20 percent seeps into the ground and recharges the groundwater supply.

The water in our streams, the chief concern of this manual, is part of a vast natural loop called the hydrologic cycle.

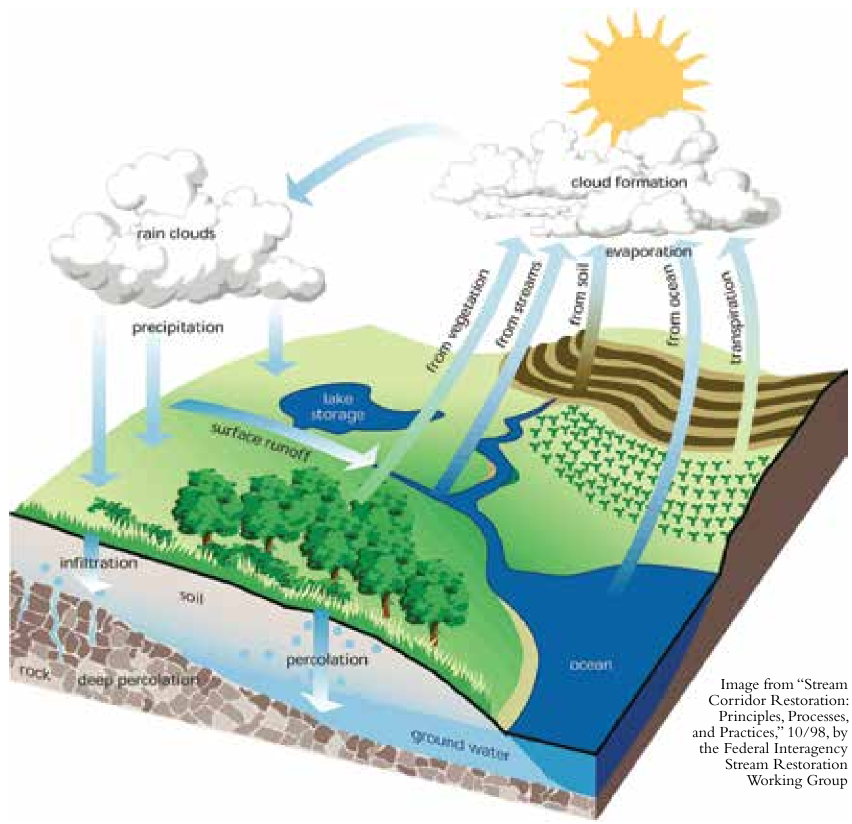


Image from "Stream Corridor Restoration: Principles, Processes, and Practices," 10/98, by the Federal Interagency Stream Restoration Working Group

Vegetation

Plants play a vital role in moderating the flow of water into streams and protecting against soil erosion. A rainstorm or heavy shower drops millions of tons of water on the land. When soil is exposed, the force of raindrops beats away at the surface, loosening soil particles and moving them downhill. When vegetation is present, leaves and stems intercept and reduce the impact of both falling and running water. This allows the water to either soak into the soil or to safely run off in a controlled manner. Forest soils are particularly porous and absorbent. Some of the water that infiltrates into the soil is drawn up by plant roots and transpired, or given off through the leaves as water vapor. This, in turn, renews the soil's ability to absorb water.

Land Uses

Many land uses leave soil more vulnerable to the effects of precipitation. The erosion that occurs increases the amount of sediment delivered to a stream. This changes the pattern of water and disrupts the stream's natural patterns of movement or equilibrium (to be explained more later on). If a disturbance, whether natural or man-made, is large enough, there can be impacts on the watershed that go beyond the initially affected area. It may take years, decades, or even centuries for a stream to reach a new equilibrium.

B. The Structures of Streams

Stream characteristics range from steep, swift-flowing mountain streams to flat, slow-flowing streams. The character of a stream is influenced by the amount of water it carries, the geology and soils it flows through, and the shape and slope of its valley.

Each stream channel is formed, maintained, and altered by the stream itself through the processes of erosion and deposition of sediment. If something changes the conditions that have shaped the stream, then its channel will change in response to those different conditions. A number of figures and photographs below will help illustrate the concept.

Streambed and Channel

The streambed is the foundation of a stream and supports its banks. Streambeds are composed of a variety of materials, ranging in size from bedrock, large boulders, and rocks, to gravel, sand, silt, and clay particles. The scouring and depositing of these materials shape the stream channel and its floodplain. The courser layer of sediments that forms on the streambed protects against excessive scour and helps keep the stream naturally stable.

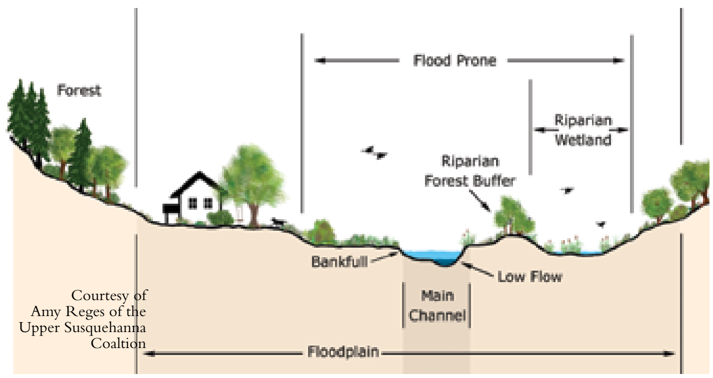
The banks within which low and moderate stream flows occur define a stream's channel. The deepest areas are generally connected, forming a low flow channel. In the unaltered stream, the term "bankfull" is used to describe the state at which the flow of the water completely fills the channel, just before it spills into the floodplain.

The structure of a channel is described by the following:

- Width and depth of the channel (dimension);
- Length of meandering or curving; and
- The degree of slope (change in elevation) or stream profile.

Some channels are relatively stable, while others actively adjust and change their shape. For example, the channel of a stream that is flowing through bedrock will change at a much slower rate (relatively stable) than one flowing through a sandy or highly erodible area (more actively depositing, adjusting or changing shape). Otherwise, adjustments in channel shape usually occur in response to changed conditions, such as increased water flow or a modification made within the stream channel or to the surrounding landscape. Most natural streams are dynamic; they may move around, and still maintain the same basic dimensions, meander pattern, and slope.

Figure 2. ***Cross Section Image of a Stream Channel with Depiction of Stream Structures***



Slope

The slope is the change in elevation or steepness of a streambed. The slope of the streambed contributes to how fast the water moves and, therefore, determines how much sediment of what size the water can carry. The steeper the slope, the faster the water moves and the more sediment bedload (i.e. sediments, silt, sand, gravel, boulders, and organic materials) can be moved through the channel. The term sediment is a general term to describe material that ranges in size from silt to sand to gravel to boulders. In flatter sections, the water will move more slowly, allowing finer sediment to deposit, referred to as "deposition." The stream adjusts to the slope of the valley through this process of erosion and deposition.

Pools, Steps, and Riffles

Streams alternate between concentrated (convergent) flows and flows which are more spread out (divergent). Convergent flows are deeper, faster and more erosive. Pools are deeper areas that are scoured out during flood events. Sediments that are eroded from a pool will fall to the bottom of the stream when flows are shallower and slower, with less energy to move the sediment, forming a riffle. This alternating between bed erosion and deposition creates up and down "bed forms" that dissipate the energy of a flood and help maintain channel stability. In steeper streams, high-energy flows scour pools and move larger sediments, such as cobbles and boulders, downstream to form rocky steps rather than riffles.

Andrew Nemethy

A nice example of riffles and pools on the Dog River.

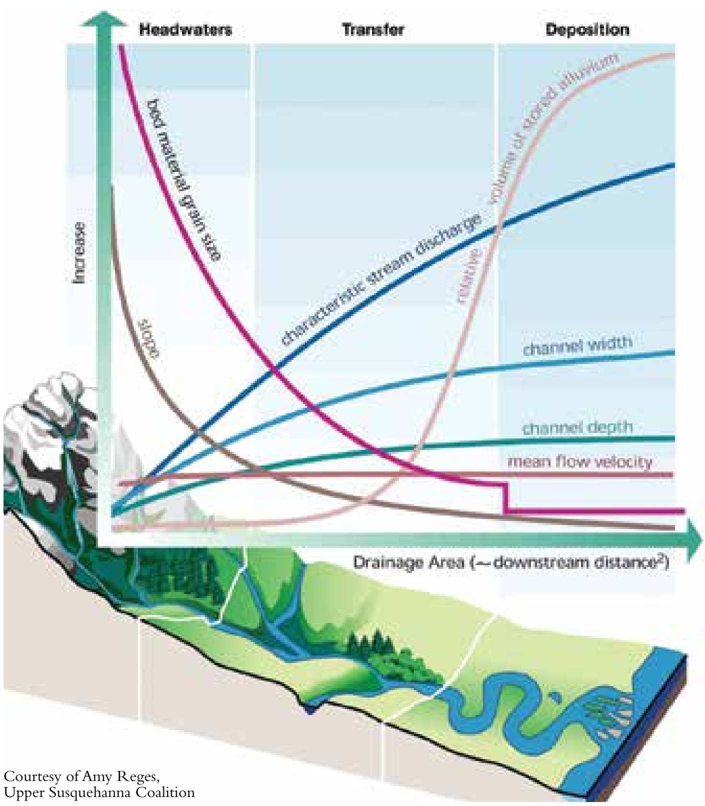
Streams are often classified or named from the type of bed forms they have, for example riffle-pool or step-pool streams. Pools provide shelter and resting areas for fish. The oxygenated, swift-moving water in riffles provides spawning and feeding areas for fish and other aquatic life.

Meanders

The processes of erosion and deposition serve to lengthen a channel through a curving process known as "meandering." Almost all streams naturally meander. Curves slow down the water and absorb energy, which helps reduce the potential for erosion. The velocity of a stream is greatest on the outside of a bend. The increased force of this water frequently results in erosion along this bank and a short distance downstream from the bend. On the inside of the bend, the stream velocity decreases, which results in the dropping out or deposition of sediment, usually sand and gravel, along this bank. Looking at the long-term history of a valley over hundreds or thousands of years, the stream moves back and forth across the valley bottom. This side-to-side or lateral migration of the channel, along with down-cutting that occurred in a stable, predictable way, actually formed the valleys we see today.

Figure 3. ***How Slope Affects a Stream's Ability to Meander***

The channel and behavior of a stream can vary considerably along its length. Mountain headwater streams flow swiftly down steep slopes. At lower elevations, the slope is generally gentler and the stream is more likely to meander (form curves) across its valley.



Courtesy of Amy Reges,
Upper Susquehanna Coalition

Stream Reach

A reach is a segment of a stream with similar physical characteristics throughout its length. These characteristics are related to the stream's structure and other physical processes such as valley slope and bed material. In Vermont, reaches vary greatly in length, from hundreds of yards to a few miles.

Example of stream curves or meanders; aerial flight over the Browns River

Riparian Area/Riparian Buffer/Riparian Zone

These terms can refer to a number of things depending on the context in which they are used. Generally, they refer to the land immediately adjacent to a stream that includes vegetation, wildlife, and other natural features. Derived from the Latin word *ripa* meaning streambank, this area is where the water is separated or buffered from adjacent land uses. Once established, the plant roots in the buffer help stabilize the bank and the tree canopy provides shading to cool water temperatures. The buffer allows vegetation to filter sediments and excess nutrients. The term "riparian" may also be applied legally to define the rights of landowners along a stream.

Courtesy of Vermont Rivers Program

Note the presence and absence of forested riparian buffers along different sections of the Browns River.

Floodplain

Floodplains are essential to the health of river systems. They are generally flat areas of land adjacent to the stream. These areas are constructed of material deposited by the stream, separated from the channel by a stream bank, and subject to flooding. Floodplains provide a place for water to go when it cannot be contained in the channel, such as during spring thaw or heavy precipitation.

A floodplain is formed by a stream that is eroding and depositing sediment. Over time, the stream channel moves or meanders across the floodplain. In turn, this causes erosion in some places and deposition of materials in other places. When water fans out across the floodplain, the speed of the water is decreased, thereby decreasing and dissipating the energy of the stream. This relieves pressure on stream banks and offers a place for the water to flow temporarily. The outcome is a reduction of the amount of flooding and erosion downstream. If no human development is located in the floodplain, then this area can perform its natural functions of storing and conveying floodwater and dissipating excess energy. Vegetation also slows the water's velocity, and the roots hold soil in its place, reducing erosion. A stream that is no longer able to overflow onto its floodplain is often a stream with erosion problems.

River Corridor

River corridors are comprised of the channel, floodplains, and adjacent lands. They provide an area within which the channel can meander or curve so that sediments and the energy of flowing water are distributed more evenly—the condition of dynamic equilibrium. These are complex ecosystems that provide an avenue for wildlife movement and other important natural processes.

C. How Streams Work

In the process of moving water and sediment downhill, a stream dissipates energy. This process results in the formation of a stream channel. The natural stability and balance in a river system depend on its ability to build and access a floodplain and create meanders and bed forms. These structures help evenly distribute a stream's energy and sediment load. The next few sections describe the physics of the energy flow of streams and how stream channels are constantly adjusting to keep their energy in a state of balance.

Streams start in headwater areas where there is tremendous potential energy because of generally steep slopes. The energy that develops in these headwater areas is used by the stream in the following ways:

- **Kinetic Energy**
  As the water begins flowing downhill, potential energy is converted to the energy of movement or motion—kinetic energy. This energy is what powers mills and hydroelectricity, or simply moves a boat downstream.

- **Friction**
  Up to 95 percent of a stream's energy is dissipated through friction with its bed, banks, and floodplain. Woody debris and vegetation in the channel and on the floodplain also break the water flow and increase roughness or friction. In addition, streams expend energy flowing around their curves (meandering).

Stream Flow

The amount of water carried by a stream can vary from none, in the case of streams that are dry during part of the year (ephemeral streams) to extreme flood conditions. Precipitation reaches the stream by two different pathways that affect the quantity, quality, and timing of stream flow: infiltration into the ground where it contributes to groundwater flow or "base flow;" and water that flows across the surface of the land, referred to as surface runoff or "storm flow." Stream flow at any one time consists of water from one or both sources.

- **Base Flow**
  Rainwater and snowmelt that soak into the ground recharge the groundwater. This water moves slowly through the soil and bedrock before eventually reaching the surface water. This regular, continuous discharge of groundwater that provides a steady supply of water to many streams and rivers is called base flow. Enormous amounts of water move slowly through the soil, creating the base flow in streams from rainwater that fell days, weeks, months, or even years before.

  Base flow enables many streams to flow year-round, even when there has been no recent rainfall. The amount of base flow varies with groundwater levels, so some streams have continuous flow during part of the year but dry up during dry periods and droughts.

- **Storm Flow**
  Some of the rainfall and snowmelt within a watershed flows quickly into the stream by moving over the land surface or through near-surface soil. This water is the main component of high stream flows during rainy weather and spring snow melt. This is called storm flow.

Each stream has developed in response to the amount of water it carries and the way that water moves through the channel. The volume and timing of runoff into a stream is called its hydrology. This is dependent on precipitation patterns and watershed characteristics.

The flow processes within a stream channel are called hydraulics and are influenced by the characteristics of the channel. These characteristics include the stream's slope, the shape of the cross section of the channel, and roughness. Roughness is caused by the water coming in contact with sediments and vegetation, which causes friction, slowing the flow of water.

Sediment Flow or Transport

Stream energy not used by kinetic motion and friction is available for transporting sediment. The sediment in the channel comes from the surrounding landscape and erosion of the bed and banks.

A stream develops over time to handle a certain sediment load, which it transports and deposits in a fairly predictable pattern. Streams are constantly balancing the energy they have by meandering (curving), transporting, and depositing their load of sediments. This means that some erosion is natural and a normal function of how streams work.

When the energy or sediment inputs are changed, the energy balance is altered and the system must adjust. If a stream is slowed down, backed up, or spread out, it may lose the energy needed to transport its sediment load and sediments will deposit or drop out of the stream flow (deposition). Conversely, if the stream becomes steeper or is deepened and has more energy than is needed to transport the available sediment, it will obtain additional sediment by eroding its bed or banks.

If the amount of sediment entering a stream increases, but there is no corresponding increase in water flow and energy to move the sediment, the sediment will deposit. This occurs at the tail end of a large flood, as it did in Tropical Storm Irene. Flows begin receding, along with the energy to move all the sediment that has entered the channels from numerous hillslope failures. Conversely, if the sediment flow decreases significantly (e.g., when it becomes trapped behind a dam), but the flow and energy are not also decreased, this excess energy works on the bed and banks, increasing erosion.

Courtesy of Winooski Natural Resources Conservation District

Because water and energy levels in streams vary with time, so does their ability to carry sediment. When the stream does not have enough energy to transport its sediment load, material is temporarily stored (deposited, referred to as deposition) within the stream system. When high flows return, this sediment is re-mobilized and transported farther downstream. Point bars on the inside edge of meanders (curves) are formed by sediments held in temporary storage between high flow events.

Dynamic Equilibrium

Despite frequent change, streams exhibit a dynamic form of stability. Streams are changing but generally in a slow and predictable manner. As long as the conditions that influence the stream's energy are relatively constant, then the stream for the most part stays in equilibrium. This process of establishing and maintaining a balanced condition is called dynamic equilibrium. In other words, the stream is moving and changing, but generally maintains its dimensions, pattern, and profile without dramatic changes in the pattern of its erosion and deposition processes. When a natural stream achieves an equilibrium depth and slope, the shape of its channel is maintained by the following additional characteristic(s):

> ***Dynamic equilibrium means that the stream moves and adjusts toward the most efficient distribution of the energy of the system that is its least erosive form. Change is what makes the equilibrium dynamic.***

Channel slope and channel roughness and/or resistance, including:

- the coarseness of the sediments in its bed; and/or
- the soil cohesiveness and soil binding properties of vegetative root systems on its banks.

Farming along the Meandering Browns River

Gary and Tammy Davis own and operate a pasture-based family dairy farm in Jericho, Vermont. Many advantages as well as struggles for this farm relate to its very close proximity to the Browns River. The alluvial soils grow fertile hay and pasture crops, and livestock watering is made easy at their concentrated cattle stream crossings. But annual flooding, constant channel migration and streambank erosion are continuously destructive to the prime agricultural land they manage. For many years, the Davises moved portable fencing in response to new river bank erosion on the outside bend and recreated their stream crossings to allow cows access to lush pastures on the far side of the river.

Courtesy of Vermont Rivers Program

Courtesy of Winooski Natural Resources Conservation District

Left: Browns River meanders on the Davis property. At right, temporary pasture fencing at the Davis farm was no match for the erosive force of the Browns River.

As flooding and bank erosion continued, the effort and struggle with the river became exhausting and the ever-evolving seasonal deposition and erosion locations made farming along the Browns River too unpredictable. Huge sediment deposits would typically clog up the tight meander bends and cut new river channels. In June of 2010, the Davises signed a 23.7- acre corridor easement on the portion of their farm where the river dramatically meanders through extensive areas of the farm's pasture land. The corridor easement will allow the establishment of a riparian buffer of permanent vegetation, give the river space to continue its meandering, and relieve the farm of its ongoing struggles to prepare for and reorganize after degradation and aggradation events.

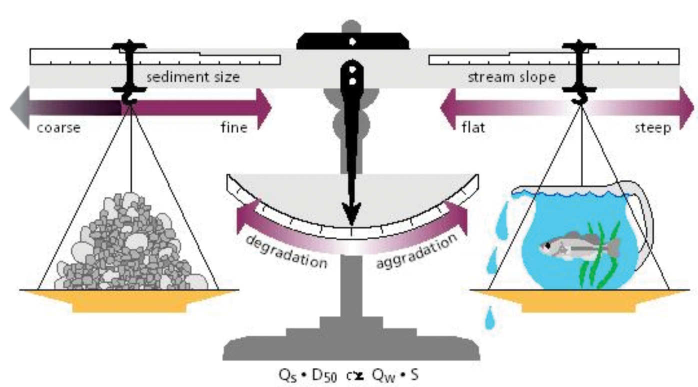
Tammy Davis is clear that "clean up will always be an issue" as the Browns River will continue to flood many of the farm's lower pastures. After the dreadfully wet spring of 2011, Tammy reported, "You'd be amazed to see how far the sediment went this year. There is a section of the pasture that is full of river silt. The river has a field day with the fences that were up!"

The following diagram illustrates the relationship between the water in a stream and the system's ability to transport sediment. The relationship is shown as a balancing scale (Figure 4), with sediment load on one weighing pan and stream flow on the other. The hook holding the sediment pan slides along the horizontal arm to reflect adjustments according to sediment size. The hook holding the stream flow side adjusts to reflect changes in stream slope. Adjustments and changes in a stream system occur when there is an imbalance in the system's energy. When any one or more of the variables change, the system is no longer in balance. When a stream is free to make adjustments, then one or more of the other variables in the system is likely to change until equilibrium is restored.

The diagram indicates how the variables will change. For example, if the slope increases (gets more steep), then the size of sediments being moved will get bigger. The process can take place suddenly during one storm event or it may occur gradually over hundreds or thousands of years.

The physical laws which govern the evolution of stream channels dictate that, in time and left in their natural state with no human development or interaction, rivers will self-adjust (erode and deposit) to a least erosive, equilibrium condition. When these conditions are achieved across an entire watershed, they are

Figure 4. ***Elements of Dynamic Equilibrium in Streams***



Courtesy of Winooski Natural Resources Conservation District

Lane's Balance of Sediment Supply & Sediment Size with Slope & Discharge (Lane, E.W. 1955. The Importance of Fluvial Morphology in Hydraulic Engineering. In Proceedings of the American Society of Civil Engineers 81(745): 1-17.) Reproduced by permission of the American Society of Civil Engineers.

Courtesy of Winooski Natural Resources Conservation District

Per the two photographs above, channels that are in equilibrium have a balanced sediment budget, meaning there is just enough sediment in the channel of the right sizes to absorb the erosive energy of the water. The sandy section of bank in the first photograph is called a point bar. It is sized about right for the stream and provides a source of sediment for the stream to work with when flows increase. Streams in equilibrium have minimal erosion hazards, the highest potential for ecological function, and the greatest societal and economic values.

associated with minimal erosion, storage of organic material and nutrients throughout the watershed, and aquatic and streamside (riparian) habitat diversity.

D. How Channels Change their Shape

Streams in dynamic equilibrium are considered to be stable. This is because they generally maintain consistency with respect to channel dimensions, pattern, and profile as presented earlier. Streams in (dynamic) equilibrium erode their banks, migrate over time across their floodplains, and experience small-scale adjustments in the formation of their channel. These conditions change over time (are dynamic) based on water and sediment inputs that are driven by natural flood events. This evolution of channel form often takes place over decades or even generations.

Substantial changes in channel form are reactions to large-scale events such as major floods and human activities that take place in the stream corridor and across the landscape. The following terminology is generally used to describe these adjustments to the formation of a stream channel.

The long time frames over which a channel evolves may result in "quiet" periods where little or no channel adjustment occurs. This period can last for decades or generations. During these periods, trees grow on the banks, aquatic life may be thriving, and a long-time resident may be heard saying, "My father put the stream along the hillside when I was a kid, and it's been stable over there ever since!" Physics dictates, however, that if the stream is not in an equilibrium condition, it will eventually go through the channel evolution process. Just the right flood can start a chain reaction that launches the quiet, but altered, stream into a period of major adjustments.

Degradation, Incising, Scouring Down, Head Cuts, Vertical Adjustments

When a stream has more energy than needed to move available sediment, it will acquire additional sediment by **eroding its bed or banks** in a process referred to as scouring down or "degrading" the stream's channel structure. This process is also referred to as channel incision, scouring, or degradation of the bed and occurs primarily via head cuts that migrate upstream through the system. A headcut is a small waterfall, often resulting from the deepening of a channel caused by dredging or excavation. These cause sediments to be washed into the stream as the waterfall moves upstream if the hole that created the problem isn't corrected.

Courtesy of the town of Williston

Active headcut on Sucker Brook, Williston

Aggradation, Lateral (Width) Adjustments

When a stream does not have enough energy to transport its sediment load, it will **deposit sediments in its channel** through a process called "aggrading." As the streambed rises, the water spreads out, eroding laterally (lateral width adjustments), and thus widening the channel.

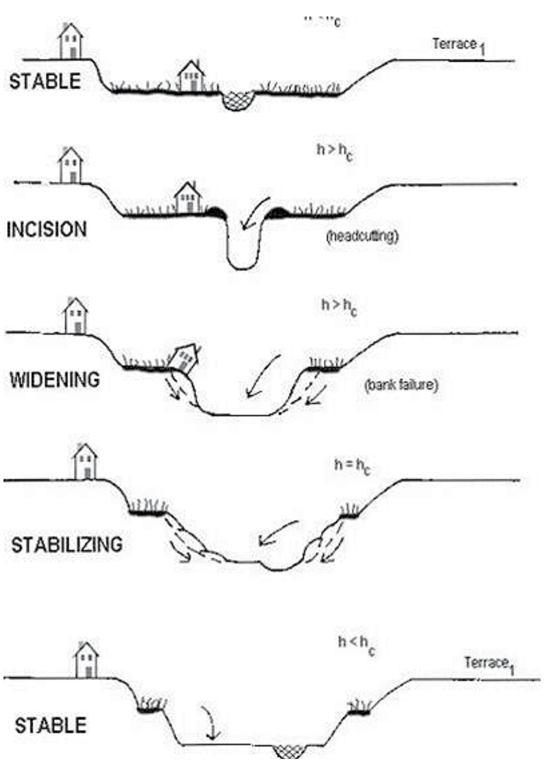
Disequilibrium and channel evolution occur when moderate to major vertical adjustments have been set in motion. Figure 5 below shows a cross-section of a stream channel as it adjusts from one stage of equilibrium (I) to another (V).

Courtesy of Winooski Natural Resources Conservation District

Signs of sediment deposits or aggradation in the Browns River

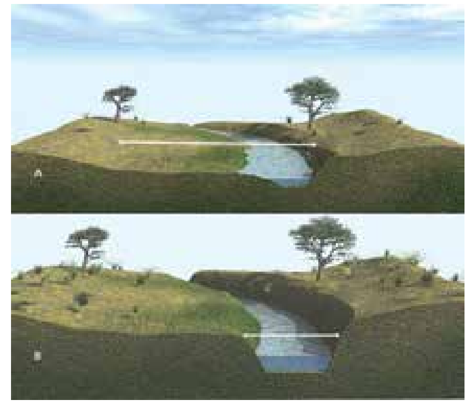
The rate of change in a stream channel, often referred to as the stream's "sensitivity," is a function of the erodibility of the bed and bank materials, the supply of sediments, and the frequency of flooding. A gravelly stream bed with non-cohesive banks in a flashy watershed may evolve in a much shorter time frame than a stream in clayey soils where flooding has not occurred very often.

Figure 5. ***Channel Evolution Process***



E. Describing Channel "Conditions"

A stream reach is a section of stream with similar physical characteristics. The condition of stream reaches can vary from one that is in dynamic equilibrium to one where its channel structure has begun to evolve, adjust, or be "in adjustment." The Vermont Rivers Program describes three benchmarks along the gradient of physical condition. The following terminology and photographs describe these different conditions.



Courtesy of Vermont Rivers Program

Loss of critical flood prone width when a river undergoes channel down-cutting

Reference Condition

Reference condition refers to a stream reach that is in or near dynamic equilibrium. That means it is maintaining its channel dimensions and watershed functions within the range of natural variability and is providing high quality aquatic and riparian habitats. Such conditions can typically be found in headwater sections of streams, where human influence is limited.

An understanding of the reference (natural) or stable condition provides a way of measuring if conditions are different from

Courtesy of Bear Creek Environmental

Example of a stream reach in natural or "reference" condition. This short section of the Kingsbury Branch of the Winooski River (M15-B) had high quality habitat including excellent in-stream cover, deep pools, stable banks, and a high quality riparian zone.

a stream's natural characteristics. A change or departure from the reference condition can be measured by various degrees of change as described below. This is often referred to as "degree of departure." (This is not so different from a physician judging one's health by reference to the characteristics of a healthy person.) In the case of about three-quarters of Vermont streams, their condition is no longer in equilibrium, to varying degrees, in response to stream stressors.

Knowledge of which stage of stream adjustment a particular stream reach may be in is critical for anticipating future conflicts with human infrastructure and in designing any restoration or protection strategies.

In Adjustment

The "in adjustment" condition refers to a stream reach where the channel structures and stream processes have deviated from the expected natural conditions. These unstable stream segments haven't evolved into a completely new stream type. However, the aquatic and riparian habitats of such a reach are in "fair" condition as they lack certain streambed features, cover types, and connections with related habitats (connectivity).

Reaches that are in adjustment are poised for additional adjustments. When floods occur, major adjustments will take the channel either toward or further away from equilibrium or reference conditions. Further departures may even change the stream channel to a different type—that is, develop different structures and exhibit different processes.

Courtesy of Bear Creek Environmental

Example of a stream reach in fair condition or "in adjustment." This segment of the Kingsbury Branch of the Winooski River (M-15A) lacked large woody debris, riparian vegetation and a diversity of pools where the channel had been historically straightened.

Poor Condition

A stream reach in poor condition is said to be in "disequilibrium" or exhibiting a departure from its stream type. Such a stream reach is experiencing adjustments to a much greater degree and rate beyond the expected natural conditions of a reach in fair condition.

This means the reach is exhibiting a new stream type. For example, a reach that may have alternated between deposition and erosion (riffle and pool) has become completely erosional or completely depositional. In poor condition streams, habitat features may be disturbed beyond the range of some species' adaptability. Such a reach is expected to continue to undergo major adjustments until it evolves back to the reference stream condition or a new equilibrium.

This chapter of the guide has provided an introduction to stream processes and energy dynamics under natural or relatively predictable conditions. The next chapter takes a closer look at unnatural stressors on streams due to human behaviors and influences.

Courtesy of Vermont Rivers Program?

Example of a stream reach in poor condition or active adjustment. This site was formerly a deposition zone. Upstream development caused the channel to incise and lose access to its former floodplain on Rugg Brook in St. Albans.

3. Human Activities and How They Affect Streams

The natural tendency of streams to adjust and move has often been altered by human activities. Certain land use practices, such as draining wetlands, logging, and gravel mining, described below, were not intended to affect rivers but, in fact, did so. Other actions were intended to control streams in an attempt, often misguided, to protect human infrastructure and land uses by keeping high flows in the channel. Mostly started in the 19th century and continued throughout the 20th century, these channel management practices included straightening (channelizing), steepening, dredging (cleaning out sediment deposits), berming, armoring (adding riprap), and damming.

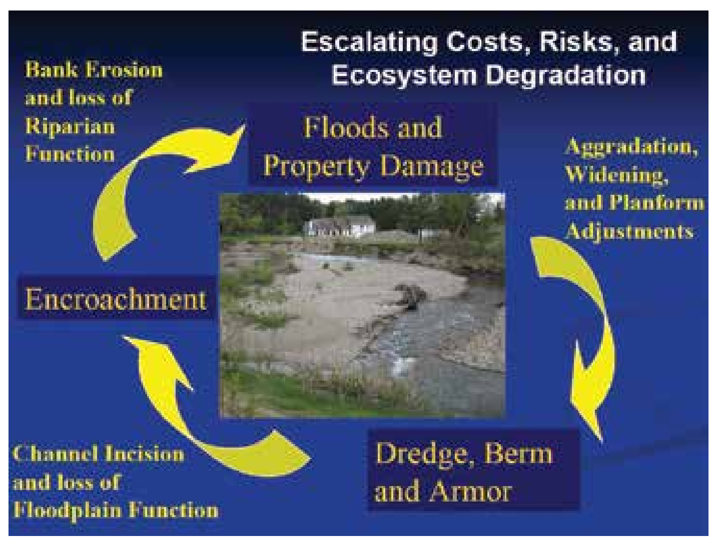
The history of channelizing Vermont rivers to protect land use investments, and the erosion and flood damage that follow, are among the most significant threats to water quality, aquatic habitat, and public safety.
— the *Vermont River Corridor Protection Guide*

When denied the ability to meander (curve) or access their floodplains, which would dissipate some of their energy, straightened and channelized streams retain enough energy to carry their loads through the stream systems until the sediments, soils, and nutrients are deposited in Vermont's lakes and reservoirs. This is one cause of the increasing nutrient enrichment and algal blooms in parts of Lake Champlain. The increased power of larger floods, especially where the water has been restricted within the channel, has led to greater amounts and increased rates of bed and bank erosion. This sets up a never-ending cycle in which, inevitably, an even larger flood occurs and then additional structural constraints are built in an attempt to contain the stream.

Courtesy of Vermont Rivers Program

This aerial photograph of a section of the Lamoille River illustrates development in the valley and how roads and the railroad have affected the natural flow and meander of the river.

Figure 6.
Diagram of the escalating cycle of cost and destruction which occurs when people try to contain (channelize) streams



Courtesy of Vermont Rivers Program

This section of the guide describes many human-caused stressors to streams and how they affect the equilibrium conditions of streams. It further explains and illustrates how stream channels in particular react to these stressors.

A. Stream Stressors

The natural ability of streams to adjust to changing conditions has been altered by human-imposed changes to their depth and slope. For most Vermont streams, a combination of watershed, floodplain, and channel modifications over the past 150 years has led to major vertical channel adjustments that are still unfolding today. These adjustments often consist of degrading or scouring down of the bed of the stream channel, referred to as incision, which often comes about through an erosional process called a head cut. A head cut is a sudden drop in the stream bed, sometimes a miniature waterfall, which "eats" its way upstream, scouring the channel as it proceeds. Nearly every Vermont watershed has streams that are stressed beyond their natural adjustment pattern. The term "in adjustment" is used to describe streams that are not in equilibrium but are reacting to stresses, many of which are caused by one of more of the activities described below.

Deforestation

A forested landscape intercepts and stores precipitation. When trees are removed, more rainwater is available to wash into streams at a faster pace. Increased storm flows following timber harvesting, especially where fewer trees remain to stabilize the banks, may lead to increased erosion in the stream. Primarily during the 19th century, many Vermont stream channels were overloaded with deposits of sediments (aggraded), and their floodplains were often buried by as much as a meter of sediment. High energy flash floods in denuded, sheep-grazed watersheds, with little vegetation to slow and store precipitation, eroded and carried away much soil and sediment. Stream channel adjustments that are happening today may still be linked to this deforestation.

Photo provided by Waterscapes LLC

This aerial photograph illustrates how little forest remains along this river valley. Vermont agriculture has taken advantage of the prime agricultural soils along many rivers and streams for cropland. The stream has also been extensively straightened, another stressor.

Snagging and Ditching

Snagging includes clearing boulders, beaver dams, and woody debris in a misguided attempt to increase channel efficiency and, in earlier times, to enable logs to float from headwaters to the valley mills. Many mountain streams that appear to be pristine contain only a fraction of their former channel roughness and resistance and therefore store less sediment and debris. Mill owners would hire crews to work eight months a year clearing streams. This enabled them to sluice logs to the valley mills.

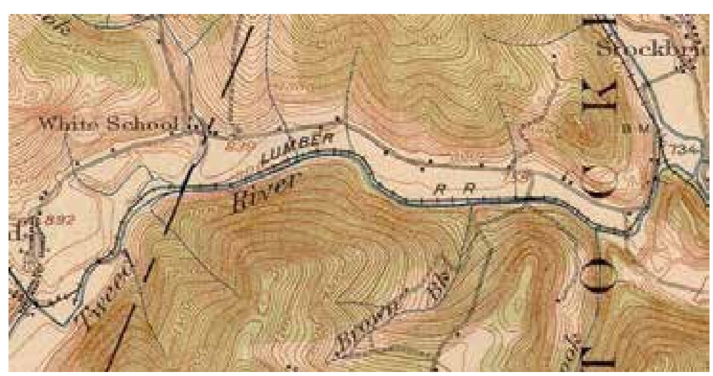
Courtesy of Vermont Rivers Program

A 2006 photographic example of a ditch that was dug to a Lake Carmi tributary in Franklin, VT to drain an agricultural field

Ditches were dug during the 19th century to drain wet soils for agriculture. Drain tile and ditch networks were enlarged and maintained through the 20th century. These practices increased the volumes of stream flow, thereby enlarging channels and reducing infiltration (movement of water from the surface into the soil).

Villages, Farms, Roads, and Railroads — Channeling the Stream and Maintaining It

Most of the level land — and most fertile soils — in Vermont lie next to our streams and rivers. As a result, our settlements,



Courtesy of Vermont Rivers Program

This is an example of how rivers were channelized. The topographic lines indicate the low elevation of the broadness of the Tweed River valley. Yet the river is pushed right up against the valley wall and hemmed in by a railroad bed. Before it was channelized, it's likely the river meandered back and forth across this valley.

farms, and transportation routes were established around streams. Early settlements led to stream channelization to keep floodwaters away from development. These works have been maintained with various practices including gravel removal, channel realignment, streambank armoring, and flood control projects, moving rivers to the sides of valleys like the illustration below of the Tweed River.

Courtesy of the Vermont River Program

A road is located in close proximity to the river. Along with negative impacts of failed riprap along the banks, it also becomes expensive to continue to maintain riprap to protect infrastructure that is placed in the river's meander path.

Mills, Dams, and Diversions

Hundreds of mills, dams, and diversions of water flow were built over time in all Vermont watersheds for many purposes including the textile and paper industries. Today, small mill ponds have been replaced by larger dams to generate electricity and control flooding. These structures have changed the amount and rate of water and sediment runoff.

Dams change both the hydrology and ecology of stream systems by creating artificial flow regimes and by changing water temperatures and timing of flows. Because they prevent larger sediments from moving down the channel, the released water carries less sediment than the stream can handle. This water has

Courtesy of Winooski Natural Resources Conservation District

This is a photograph of a small impoundment at Cilley Hill in the Browns River watershed, where the flow is slowed above it and the power of the release deepens the channel below it.

excess energy and is referred to as "sediment hungry." It will pick up and move more materials downstream of the dam, resulting in a deeper or wider channel below the dam to replace the lost sediment load.

Gravel Removal/Dredging that Produces a Headcut

Dredging is the process of scooping up or cleaning out sediments from the bottom of a body of water. This practice was intended to maintain or create straighter, deeper channels, to provide gravel for roads, and to control flooding. Unfortunately, excessive use of this practice actually increases flood damage.

Courtesy of the Vermont River Program

This is an illustration of how rivers are dredged and deepened.

When a section of a stream channel is deepened, it can cause a small, steep drop at the upstream end of the excavation. This increase in streambed slope causes the water to flow faster, erodes the streambed, and results in down-cutting or degradation of the channel. This erosion shifts the steep section more and more upstream as the stream adjusts to form a more stable slope. This moving drop in elevation is the headcut, and it can extend a significant distance upstream and contribute large amounts of gravel and sediment to lower sections of the stream system. A stream subject to a headcut or deep dredging has higher, steeper banks that are likely to erode, causing even more sediment to enter the channel.

Riprap and Grade Control Structures (Check Dams)

Riprap is rock used to armor streambanks against scouring by water and ice as an attempt to keep the stream stationary and stop the erosion of property. Check dams and riprap have been used to replace naturally occurring boulder steps, cobble riffles, and the deep, soil-binding roots of trees and shrubs. However, they may cause the channel to undergo other adjustments, either upstream or downstream, and must be periodically maintained. Check dams can create small waterfalls that disrupt natural processes and prevent upstream passage of fish and other aquatic organisms. Riprap can effectively deflect a stream's energy and flow away from an eroding streambank but unintentionally cause greater erosion on the opposing bank or downstream.

Courtesy of Bear Creek Environmental

Trees along the bank of the Ompompanoosuc River were cut and replaced with rock riprap—a move in the wrong direction toward establishing equilibrium.

Courtesy of Vermont Rivers Program

An example of a housing development encroaching on the West Branch of the Little River

Encroachments, Stormwater, and Urbanization

These activities have increased the amount of impervious surfaces (i.e. through which water cannot penetrate), leading to higher amounts of stormwater runoff. Sewers and drainage ditches compound the problem by increasing the rate of stormwater canveyance. Each storm drain, tile drain, or roadside ditch serves as a small channel, carrying water more quickly than the broad overland route it replaces. The efficiency with which storm drains and ditches collect and deliver water causes increased peak flows, downstream flooding, channel enlargement, and reduced infiltration and base flows.

Housing Development on the West Branch, Stowe

Earlier adoption of planning and zoning regulations might have helped prevent a development so close to a particularly unstable section of the West Branch corridor (upper right photo). Extensive armoring exists along the bank upstream of the houses to protect the bike path and other human investments. The positioning of the riprap effectively transfers river sediment to the gravel bars opposite the outside bend where the new homes are perched. As sediment accumulates, the river flows are further pushed against and erode the sandy gravelly banks adjacent to the homes.

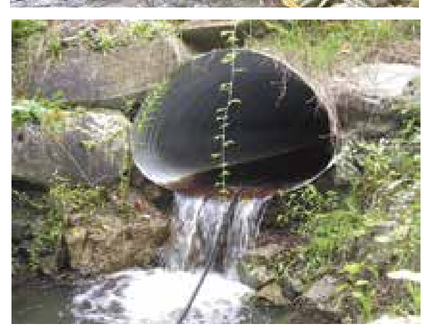
The result of putting these homes in this dynamic and hazardous location ensures that many dollars will be spent armoring this bend over and over indefinitely into the future. The riprap, which is already failing on the upstream end of the eroding bend, will need to be repaired to protect the homes. This will actually add to the impacts on this reach of river, leading to further destabilization and the need for further expensive channelization practices.

Bridges and Culverts

Both bridges and culverts can cause a channeling of stream flow that alters the stream's equilibrium. Some constrict stream flow, while others may accumulate debris which can block flow. Improperly sized structures may result in water running over or around them, or undermining them due to bed erosion, and may ultimately be washed out. Undersized structures also negatively impact fish and other aquatic organisms by destroying habitat and creating an impediment to their movement.

The inlet (top) and outlet (bottom) of this culvert are located on a tributary to the West Branch of the Ompompanoosuc River in Strafford, Vermont. The culvert is perched (freefall) and is impeding fish passage. The undersized structure is causing localized geomorphic instability. Undersized culverts, such as this, prevent aquatic organism passage upward in the watershed, disrupt natural sediment transport and often result in an accumulation of sediment upstream of the structure and a large scour pool below the structure.

Courtesy of Bear Creek Environmental



Removal of Streamside Vegetation for Cropping and Grazing

Well established woody vegetation on streambanks (riparian areas) and adjacent corridor lands slows down flood waters and provides important habitats for terrestrial and aquatic organisms. Extensive root systems hold soil (sediments and nutrients) in place, reduce erosion and bank scour, and prevent the loss of land along the stream. The removal of riparian vegetation is a major contributor to erosion.

Courtesy of Bear Creek Environmental

Note the lack of any woody vegetation for habitat, tree root system to support the banks, or shade to cool the water temperature along this section of Pekin Brook.

Gravel Berms or Dikes

A berm is created by building up the streambank with gravel or soil to keep rising water flows within the channel. Refer to the photo below for an example along a railroad. These structures are not engineered to withstand the hydraulic pressure from high water on one side of the berm and lack of water on the protected side. High velocity water may shoot through a breach, rapidly flooding and eroding the land behind the dike. The damage may be worse than that caused by the gradual rise of floodwater which

Courtesy of Vermont Rivers Program

Construction of the Lamoille Valley Railroad along this reach of Black Creek in Fairfield required about six miles of embankment (bringing in soil fill) that destroyed about 200 acres of functioning floodplain and wetlands.

could have naturally occurred if the berm were not there. While the berm holds, thehe increased bank height also channels the force of the water downstream increasing bed and bank erosion.

Removal of or Degrading Wetlands

Wetlands serve as water storage and treatment areas which can slow down the rate at which water reaches streams. Refer to the photo of Black Creek for an example. Nearly fifty percent of Vermont's historic wetlands have been lost or severely impaired since European settlement (Vermont Department of Fish and Wildlife, 2010). Loss of wetlands impacts the watershed in ways similar to those of increased stormwater runoff.

B. Sensitivity

Besides stresses from development and other human activities, streams have natural stressors, such as highly erodible soils and steep gradients. Sensitivity refers to the likelihood that a stream or reach will respond to disturbances caused by either a natural event or human activity.

Referring back to the model of river processes by Lane in the previous chapter, it becomes easier to understand how human land uses and management activities can cause an imbalance in the natural equilibrium of streams. Many human activities, especially those within or adjacent to stream corridors, may alter either the hydrology of a watershed or the hydraulics of the stream channel.

- **Changes in hydrology**—the amount and timing of runoff into a stream can result from drainage ditches, deforestation, development, and other land use changes.

- **Hydraulic changes**—alterations to a channel or floodplain are caused by such actions as channel straightening and maintenance, bridge, culvert, and dam construction, and filling of the floodplain.

All these factors collectively determine the degree of sensitivity that a reach, sequence of reaches, or a watershed has to flow events. Estimating sensitivity helps in predicting the rate at which stream adjustment and channel evolution will occur.

The process of continuous adjustment is more dramatic in some stream systems than in others. The ratings of streams for sensitivity are based on their setting and location in the watershed. This placement affects the likelihood of a stream or reach to undergo episodic, rapid, or slow adjustments. Vermont has created a method of measuring these changes by evaluating the physical (geomorphic) characteristics of streams. The following characteristics are used to rate stream sensitivity in Vermont:

- Erodibility of the soils along the channel and banks;

- Water volume and runoff characteristics;

- Narrowness or width (confinement) and slope of the valley; and

- How different the stream is from natural conditions. The terminology used is "degree of departure from reference (natural) conditions." Sections (reaches) of the stream, both upstream and downstream of a study area, are factored into the analysis.

C. Upstream-Downstream Relationships

The preceding discussion serves as an introduction to the complex relationships between streams and human structures and development. However, before turning to Vermont's new approach to river management, it is important to understand that watersheds consist of interrelated parts, not just collections of individual sites.

Take bank erosion, for example. Occurring first at one location, its consequences may be felt both upstream and downstream. Head cuts (pp 14,19) cause upstream erosion, while eroded soils carried downstream can alter stream depth and width. In short, activity in one stream reach may extend to other reaches until the entire watershed is affected. The fundamental concept is that a watershed is a dynamic system of interrelated forces.

Making sense of these inter-related processes is important for choosing the best management action to encourage or allow a stream to move toward its equilibrium as soon as possible. This analysis cannot be isolated to a particular site where a project is proposed. It must be conducted over larger reach and watershed scales. These concepts are important for understanding the next section of the guide.

4. How Vermont Protects River Corridors

Many traditional practices of managing streams lead to a cycle that begins with implementing costly site-specific projects that can add to existing problems, cause more damage, and/or move the problem downstream. River scientists have determined that there are ways of managing streams that will break the vicious cycle (see diagram in previous chapter). This section of the guide summarizes a new, more holistic approach based on the work of the Vermont Rivers Program (VRP) in the Vermont Agency of Natural Resources (ANR).

> ***Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land.***
> — Luna Leopold

A. A New Approach

Fundamental to the new approach is managing stream systems over the long term instead of on a reactive, project-by-project basis. Recognizing this, in 1988 the Vermont General Assembly via Act 137, directed the ANR to identify options for state flood control policy and a state flood control program. This prompted the ANR to develop two new processes: a planning process for river corridors; and a Fluvial Erosion Hazard (FEH) risk assessment and mapping process. This included the creation of the VRP in 1999.

The VRP is a comprehensive and science-based management program that breaks free of the habitual decisions of the past to provide a new perspective. This new holistic approach takes into account entire stream ecosystems with a special emphasis on corridor areas. It also focuses primarily on the most sensitive areas, those most subject to human and natural stressors. Acknowledging that streams will continue to be managed, the VRP encourages the anticipation of future problems. This will enable protection of both human infrastructure and habitat wherever possible.

The VRP took the lead in developing an expanded view of streams. More than low-flow channels that convey summer runoff, streams are valley landforms that convey floods and transport and deposit sediments. Streams do the least work when allowed to follow a naturally sinuous or meandering course. This allows them to evenly distribute their energy and sediment loads across their floodplains. When a stream cannot meander and has lost access to its floodplains, an unstable condition results. The stream no longer has a "release valve" or ability to dissipate energy out of the stream channel and onto the surrounding flat landscape. Streambank erosion, sedimentation, and infrastructure damage are likely to occur when meanders and floodplain connection are lost.

To remedy the situation, new procedures have been developed for evaluating streams based on their geomorphic characteristics (channel form) and physical habitat. The geomorphic data collected have been helpful in changing how streams are managed in Vermont. In the past, management mainly focused on stabilizing streambanks and re-vegetating streamside areas (creating buffers). The primary focus of new projects is to promote stable channel equilibrium more broadly. Streams in equilibrium are less likely to encroach on human structures and activities.

As a result of this change in focus, river corridors are being created with two overarching goals: maintain natural channel form and functions; and mitigate flood and erosion hazards. The change serves the following objectives of the state's work:

1. reducing flood damage;
2. making the hydrology and sediment regime more like natural conditions;
3. improving water quality by increasing the natural function of floodplains to store sediment and nutrients and thereby reduce loading; and
4. restoring the structure and function of aquatic and riparian habitats.

Stream Geomorphic Assessment (SGA)

A Stream Geomorphic Assessment (SGA) is the protocol now used in Vermont for conducting stream assessments. The SGA is a systematic examination of elements that may change the natural variations in the flow of a stream. These include eroding stream banks, lack of riparian vegetation, dams, culverts, bridges, mining of gravel, and development of impervious surfaces (non-porous materials that water cannot pass through) such as buildings and parking lots in the stream corridor.

SGAs are divided into three phases:

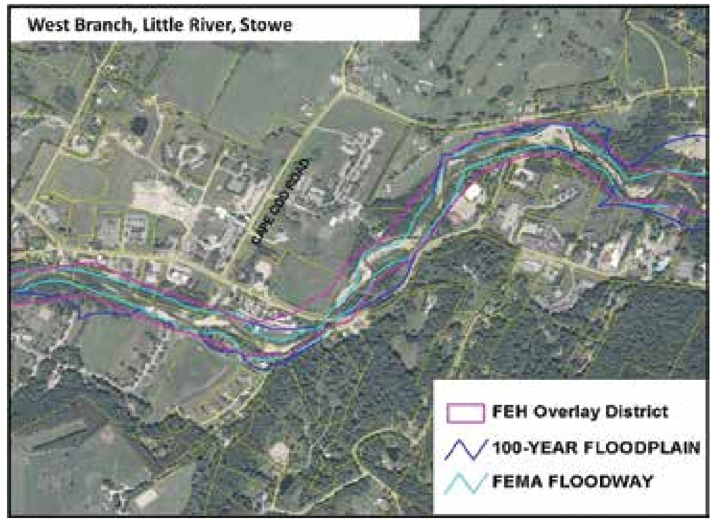
- Phase 1 involves collection of information from topographic maps, aerial photographs, existing studies, and from limited field observations known as "windshield surveys." Phase 1 is also called the **remote sensing phase** because the techniques used allow for many miles of stream corridors to be assessed within a few months' time at a relatively low cost. The Phase 1 assessment flags problem reaches of the stream, whereas more extensive field studies are undertaken in Phase 2.

- Phase 2 is referred to as the **field assessment phase** because more detailed data is collected at the reach or sub-reach scale. This requires intensive field work, collecting information about the stream system at the rate of about one mile per

Courtesy of Friends of the Winooski River

Taking measurements of streambanks is one action of the Phase 2 assessments.

Courtesy of Vermont Rivers Program



Defining and protecting the meander belt width corridor that will accommodate equilibrium conditions may be the most important objective in any river restoration project.

day. One of the primary outcomes of a Phase 2 stream geomorphic assessment is an evaluation of stream conditions. The terminology used is "the degree of departure from equilibrium." The Phase 2 assessment identifies potential restoration and protection projects that may be proposed in a River Corridor Plan. It also identifies specific reaches for protection and restoration projects to be further designed in the Phase 3 assessment.

- Phase 3 assessments, where needed, are the engineering survey-level assessments for more complicated sites. Phase 3 data may be used in computer modeling exercises that help measure transported sediments. These measurements reveal whether the stream is more depositional or more erosional. These assessments make possible the final designs for stream corridor restoration projects.

> ***The natural stability and balance in the river system depends on its opportunity to build and access a floodplain and create meanders that help evenly distribute its energy and sediment load.***
> — *Vermont River Corridor Protection Guide*

Additional information about SGA technical protocols can be found at the following section of the Vermont River Program's website: http://dec.vermont.gov/watershed/rivers/river-corridor-and-floodplain-protection/geomorphic-assessment

B. Why Streams Need Room to Meander

The study of river systems over the past few decades has led to a greater understanding of the importance of meanders within the entire river corridor. When rivers are in dynamic equilibrium, the curving or meandering of the channel helps to minimize erosion by decreasing stream gradient or slope and allows the energy of moving water and sediments to dissipate across the floodplain.

These studies, including studies in Vermont, have produced a geometric formula that expresses the relationship between a channel's width and the width of land along the channel that allows dynamic equilibrium conditions to occur. The distance of this land on both sides of the channel is called the meander belt. For low gradient streams in wider valleys the meander belt should be allowed to be the width of at least six bankfull channels.

Floodplains are flat geologic features next to streams. They are constructed of sediments deposited by streams, are separated from the channel by the streambank, and are subject to flooding. Floodplains and meander belt-based stream corridors may or may not be the same width. In wide valleys, floodplains are typically wider than the meander belt. About one-third of Vermont stream miles occur in low gradient valley settings. These streams flow through land with a fairly gentle slope and are naturally inclined to meander across the floodplain. In low gradient valleys, the highest priority should be given to allowing a meander belt-based corridor. Each corridor should have within it a perennially vegetated and wooded buffer.

C. Creating River Corridor Plans

A River Corridor Plan is a formal report based on the SGA Phases 1 and 2 and is most often prepared by technical consultants. The report presents information to communities and organizations and may recommend site-specific stream projects. Most often a steering committee reviews the information and helps set priorities for action. These stream restoration and protection efforts have a better chance of succeeding because the issues of stressors, sensitivity, and adjustment processes of the stream can be considered before a project is undertaken. The *Vermont River Corridor Planning Guide* is the primary document to follow when preparing a River Corridor Plan.

Many activities may be undertaken to restore and protect stream corridors. Recommendations that may be included in River Corridor Plans include the following:

1. Protect river corridors through easements (legal restrictions of activities that may prevent or minimize human development in stream corridors)
2. Designate river corridor and floodplain protection and zoning areas
3. Minimize stormwater runoff from new and existing development including the adoption of Low Impact Development (LID) practices
4. Plant stream buffers
5. Remove invasive species
6. Stabilize stream banks
7. Arrest head cuts
8. Remove berms
9. Remove or replace in-stream structures (dams, bridges, culverts)
10. Restore an aggraded stream through natural channel design
11. Restore an incised stream through floodplain restoration

Some of these strategies, 4-11, are direct actions on the land and/or in the stream and therefore are called active strategies. They will be discussed in the next chapter. Activities 1, 2, and 3 in this list are protection strategies that change the status of the lands in river corridors and do not necessarily involve on-the-ground actions.

A Note about Tactical Basin Planning

The River Corridor Plans described in this document are not to be confused with Vermont's tactical basin planning process. There are seventeen major watershed drainages in Vermont and each is required to have a tactical basin plan to address water quality by dealing with the complete range of physical, chemical, and biological stressors. These plans include goals and strategies developed by citizens and agencies in the watershed to restore impaired waters and identify opportunities for protection and restoration projects.

Each tactical basin plan includes summaries of water quality and natural resource assessments. Staff from the Vermont Department of Environmental Conservation (VT DEC) provide technical assistance and coordination of funds needed to implement these plans. A statewide Surface Water Management Strategy at http://dec.vermont.gov/watershed/map/strategy developed by the VT DEC Water Quality Division explains that the findings and recommendations in the River Corridor Plans will be incorporated in the tactical basin plans as they are developed.

D. River Corridor Protection Strategies

On-the-ground or active restoration efforts will always be important for stream management and are discussed in more detail in the next chapter. Perhaps even more important, however, are decisions by landowners and local communities that consider long term impacts and not just short term gain or resolution of immediate conflicts. River corridor protection strategies that support an "avoidance" approach are becoming a priority of the Vermont Rivers Program.

Conservation easements, protection of river corridors, and avoidance strategies to minimize encroachments and stormwater runoff are important activities that may help define new relationships between people and streams. A better understanding of the value of river corridors is resulting in more efforts to preserve and restore natural floodplain functions wherever possible. Landowners are conserving land in river corridors by placing conservation easements on their land. In planning new developments, local communities are more often avoiding areas with flooding and erosion hazards.

Easements

The centerpiece of Vermont's program is the river corridor easement, which allows an entity, such as a nonprofit organization or the state, to purchase the right from a landowner to manage a stream channel and its corridor. The landowner may continue to engage in certain land use activities in the corridor, such as agriculture and timber harvesting. However, activities such as placing, repairing, and modifying bank revetments (e.g. rip rap), levees, or earthen fills are restricted. These would interfere with the ability of the stream to re-establish a natural slope, meander pattern, and access to the floodplain. Additionally, the easements

Conserving the Winooski Main Stem Marshfield Inn

Tracey Hambleton and Diana Batzel, owners of the Marshfield Inn (map on page 26) along the main stem of the Winooski River in Marshfield, wanted to both protect the river on their property as well as provide access to their guests, fishermen, and local people who simply wanted to enjoy the river. Despite being relatively steep, the land had been used as pasture land. There were few trees or shrubs along the river and the banks were steep and eroding.

They worked with the Friends of the Winooski River (FWR), the Winooski Natural Resources Conservation District (WNRCD) and the Vermont River Conservancy (VRC) to restore riparian vegetation and protect their river corridor in perpetuity. VRC worked with them to place a permanent corridor easement on their property. The easement, for which they were compensated, restricts development in the river corridor. The easement, completed in 2009, encompasses 12.3 acres along 2,215 feet of the river. In addition, a 35-foot wide vegetated buffer was planted with 440 native trees and shrubs by volunteers organized by the WNRCD and FWR. The easement is held by the VRC and was accomplished with funding support from the Vermont Rivers Program.

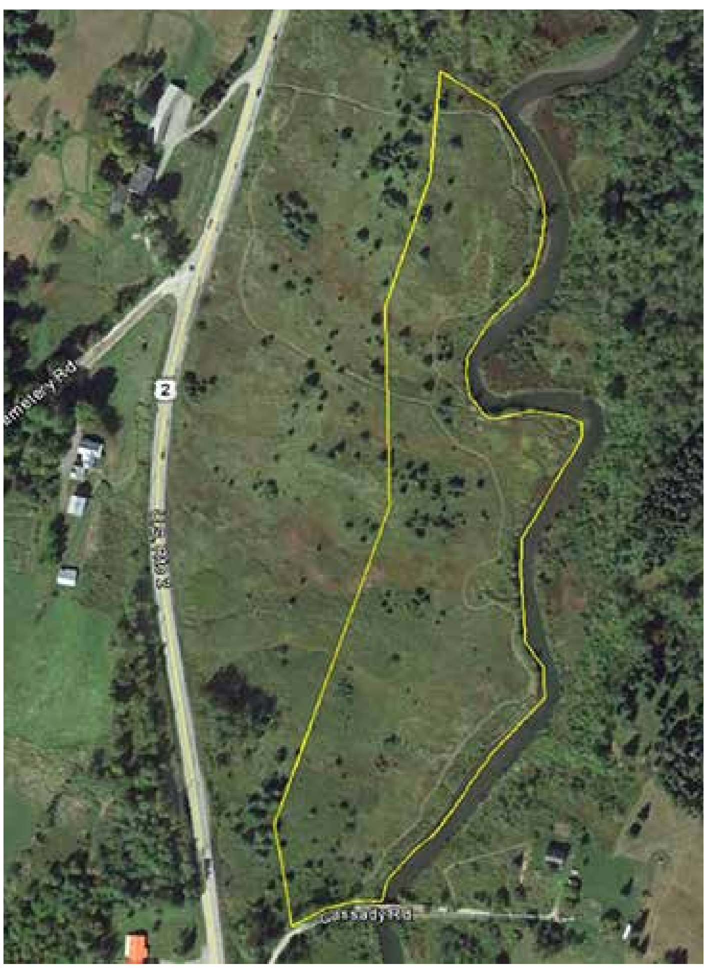
give the easement holder the ability to establish a naturally vegetated buffer, the width of which is measured from the river banks.

The River Corridor Protection Guide (Kline and Dolan, 2008) presents the corridor protection programs that have been developed in the state. These include the Conservation Reserve Enhancement Program (CREP) which is the state and federal farm service agency program through which farmers receive assistance in establishing a buffer within a river corridor easement. Other related programs have been set up in partnership with the following organizations:

- VTANR Clean Water Initiative
  http://dec.vermont.gov/watershed/cwi

- Vermont Natural Resources Conservation District,
  Trees for Streams Program
  http://vacd.org

Marshfield Inn Site



Courtesy of Vermont Rivers Conservancy

The easement on this property will allow the re-establishment of vegetation at least 35 to 50 feet along both sides of the river.

River Corridor and Floodplain Protection

Flooding has become the most widespread and destructive hazard in the United States. In Vermont, precipitation analyses indicate that more intense, localized storms are occurring with greater frequency. Also critical to note is that most flood damage in Vermont is caused by erosion and not inundation.

Floods rarely follow precise boundaries on a map, so damage to infrastructure often occurs outside official floodplain boundaries shown on Flood Insurance Rate Maps (FIRMs). The digital FIRMs of rural, sparsely populated areas like most of Vermont are less detailed than those for areas with high populations.

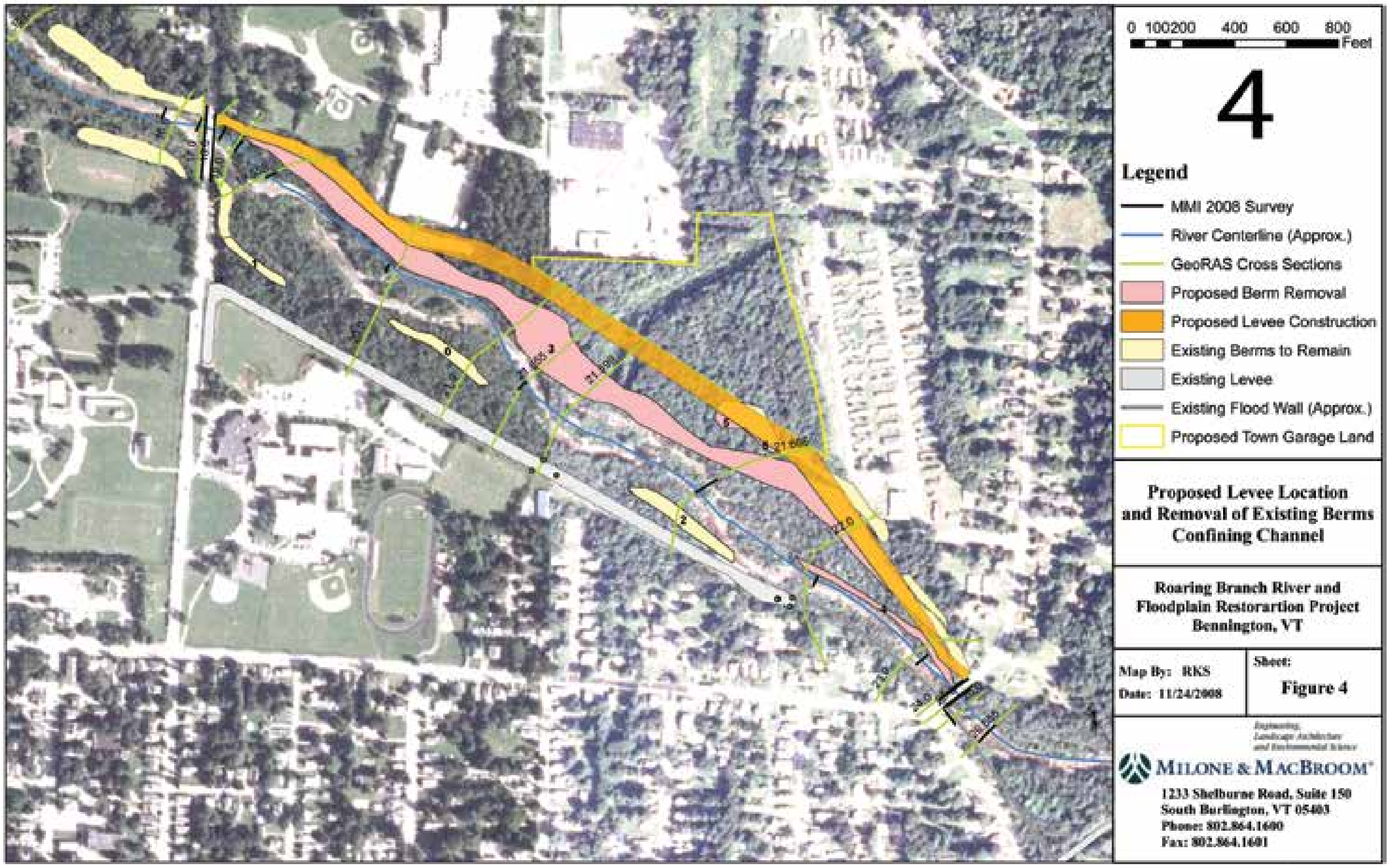
Roaring Branch in the Village of Bennington

The Village of Bennington (map on following page) is situated in a particularly hazardous location on an alluvial fan at the foot of the Green Mountains. The Roaring Branch is a tremendously dynamic and powerful force at times of flood, delivering astounding volumes of boulders, rock and woody debris into the urbanized area. For 150 years or more, this municipality and its residents have struggled with the river, attempting to confine and control it with a system of earthen berms and structural levees.

Unfortunately for village residents and town taxpayers, the river has won most of the contests. It has breached and then catastrophically avulsed (torn away) the berms, inundated residential and industrial areas, and devastated public infrastructure including roads and bridges. Each flood would trigger a reaction by the village to re-dredge the channel and reconstruct the temporary and inadequate confining structures along the channel margins. The result was to leave the "protected" property and infrastructure behind the berms extremely vulnerable to the next flood.

In 2008, the Town of Bennington formed a partnership with the Vermont Department of Environmental Conservation (DEC) to find ways of reducing flood and erosion hazards associated with the Roaring Branch. One major initiative was to a public process to adopt Fluvial Erosion Hazard (FEH) bylaws (now known as River Corridor bylaws). The FEH bylaws prohibit the encroachment of additional development into currently undeveloped areas of the river corridor. The ordinance model and FEH zone map were provided by the Vermont Rivers Program (VRP). Support for the town selectboard and planning commission throughout the process of adopting the bylaws was also provided by VRP staff.

In response to the town adoption of the FEH bylaws, the VRP found funding to design and construct a major flood plain restoration project. This involved removal of 3500 linear feet of earthen berms (excavation of over 35,000 cubic yards of earth and rock), construction of a new engineered, armored berm set well back from the river, and the restoration of approximately twelve acres of functioning floodplain in a critical area of the village.



Courtesy of Vermont Rivers Program

Allowing the Roaring Branch greater access to its floodplain has reduced the amount of damage to infrastructure in the Town of Bennington.

Meander belt-based delineations and small stream setbacks are used to define river corridors in Vermont. Like the FIRM maps, river corridor maps will not capture all areas susceptible to flood damage, but they show the area most susceptible. They also show where an equilibrium channel may be established and maintained, thereby reducing erosion hazards at the reach and watershed scales.

Limiting structures and other encroachments into river corridors and onto floodplains is an important method for reducing conflicts and the need to manage streams. There is guidance available for crafting and implementing local programs that can steer future development out of harm's way while preserving every landowner's right to be free from harm due to others' actions.

The following strategies can be used by every town to protect its streams and infrastructure:

- Create conservative top-of-bank setback recommendations for small streams via local ordinances that can accommodate equilibrium channel geometry;

- Learn about flood and fluvial erosion hazards and work with DEC watershed coordinators, river scientists, floodplain managers, and regional planners to institute river corridor and floodplain protection bylaws;

- Undertake local, more detailed mapping of floodplains and river corridors; and

- Adopt development standards that have been proven to prevent loss of life and property in floods.

Avoidance Strategies to Manage Stormwater and Promote Low Impact Development

Stormwater runoff is unfiltered water that reaches streams and other water bodies by flowing across surfaces that cannot absorb water (impervious). Highly developed areas in cities and towns with their roofs, roads, pavements, and driveways have large amounts of impervious surfaces and therefore, frequently create stormwater problems. Lawns also generate high levels of runoff. Rural residential developments and associated road networks, agricultural drainage networks, logging roads, landings, and skid trails are all potential sources of concentrated runoff that may change the timing, volume, and duration of flow in a receiving stream.

The best way to reduce runoff is to use avoidance strategies that start with education and outreach, but active strategies are also necessary (see next chapter).

The Vermont League of Cities and Towns (VLCT) provides model ordinances and technical assistance to towns for planning and promoting low impact development (LID) (http://vlct.org/

municipal-assistance-center/water-resources-assistance/). State natural resource, land use, and transportation agencies have programs to help individuals and communities use best management practices (BMPs) to control stormwater.

The Vermont Department of Environmental Conservation's (DEC) Stormwater Program at http://dec.vermont.gov/watershed/stormwater and the following state program links provide a wealth of information on the technical and financial assistance available:

- VT Better Roads Program: http://vtrans.vermont.gov/highway/better-roads
- Agency of Agricultural Water Quality Program: http://agriculture.vermont.gov/water-quality
- Department of Forest, Parks & Recreation Forests for Water Quality: http://fpr.vermont.gov/forest/ecosystem/water_quality

When geomorphic-based river corridor planning, stormwater management, and floodplain protection are implemented at the same time, towns are able to mitigate erosion hazards in their entire town at the reach scale rather than concentrate efforts on a project-by-project basis at individual sites. The next chapter offers guidelines for using these and other methods.

How People Are Getting Involved in Protecting Corridors

The previous sections introduced three avoidance strategies for protecting stream corridors and floodplains. Protective approaches generally use legal and public policy methods to minimize new infrastructure in a stream corridor, allowing it to re-establish its meanders, floodplains, and equilibrium. People can participate in these strategies by:

(1) helping with stream geomorphic assessments which provide the science for both protection and restoration strategies;

(2) educating others in their communities about these corridor protection opportunities;

(3) helping to craft local stream-focused ordinances;

Courtesy of Friends of the Winooski River

U-32 High School students learning about stream geomorphology and stream protection strategies.

(4) encouraging the refinement of the state River Corridor maps and adoption of smart development practices;

(5) participating in River Corridor and the Tactical Basin Planning processes;

(6) building local consensus for implementing protection strategies across watersheds and subwatersheds to promote equilibrium conditions;

(7) involving key partners and stakeholders;

(8) placing a corridor easement on their property if they are streamside landowners; and

(9) implementing stormwater reduction or retention practices.

Protection approaches are designed to avoid conflict with rivers and allow space for rivers to function and adjust more naturally. When protection approaches are not timely for resolving conflicts between rivers and people, a more active restoration approach may need to be considered. Often a combination of protection and active restoration approaches is most effective.

5. Undertaking Stream Restoration Projects

The history of stream management is marked by efforts to reduce flood losses by controlling floods using dams, levees, and channel modification. However, scientists are learning that controlling natural processes in this way is not cost effective and, in many cases, is a futile effort. Although there is a role for structures in certain locations, there is an increased realization that we should be changing the behavior of people instead of streams.

> ***Man's error has not been the neglect of flood-control measures, but his refusal to recognize the right of rivers to their floodplain…***
> — *Engineering News-Record, 1937*

This chapter presents information about stream sensitivity and how a stream or reach could react to various active management strategies. Then a number of active strategies are presented followed by answers to questions that landowners frequently have about stream ownership, liability, and processes.

A. River Management and Restoration Strategies

Approaches to restoring and managing streams include construction of bank stabilizing features, re-establishing meanders and floodplains, and removal of human-placed physical infrastructure. Re-vegetating streambanks and corridor areas, referred to as riparian buffers, is often done fairly easily and without engineering expertise (unless re-shaping of the streambank is involved). Other restoration strategies, such as grading banks to restore floodplain access, rebuilding meanders, restoring aggraded stream reaches through natural channel design, removing berms, arresting head cuts, and removing invasive species, frequently require more involved design, engineering, and construction methods.

It is not the intention of this guide to provide detailed information about specific designs of stream restoration projects. Many manuals and reference materials have been written for these projects. Brief descriptions are presented next, and additional references are found in Appendix C.

Courtesy of Winooski Natural Resources Conservation District

Community volunteers install willow wattles to stabilize the bank along the North Branch of the Winooski River.

Planting Vegetated Buffers

Establishing a buffer of native vegetation on all reaches of every stream is important for natural stream stability, water quality and fish and animal habitat. An ideal buffer contains a high density of woody vegetation including large trees and some shrubs. The width of the buffer depends on the sensitivity of the site. In more sensitive areas (where rapid change is still expected), the planting should start further back from the stream. General planting guidelines include using lower-cost native grasses, herbaceous species and shrubs in the near bank region and more expensive native tree stock farther from the bank. The trees may strengthen the banks when the stream has eroded to the outer extent of a delineated meander belt width.

Stabilizing Banks

It is most important to stabilize banks where infrastructure is at risk and where a lack of action increases the risk of erosion. Stabilization with trees and shrubs may also be considered for reaches that are near equilibrium but are still unstable laterally and are therefore eroding.

Arresting Head Cuts

If a stream is in the process of abandoning its floodplain, it may be then eroding its streambed and sending sediment downstream. Sometimes head cuts occur. Not all head cuts should be stopped. However, in some situations where no natural grade controls exist immediately upstream of the head cut, constructing one or more weirs (a low dam that can raise or divert flow) may arrest the incision process of the stream.

Removing Berms

A berm is a mound of earth, gravel, rock or other materials constructed along a stream, road or other area to protect land from flooding or erosion. These structures should be removed where feasible because they increase water velocity (speed) and the

Courtesy of Intervale Center Nursery, Burlington, VT

These two photographs show a bank restoration in Isle LaMotte on Lake Champlain in the fall of 2010 with about 500 live stakes. The live stakes were collected a day or two before planting to ensure the viability of the plant material and offer a natural way to combat erosion. Many sites need preparation involving excavation or earth removal to shape the bank before plantings are introduced.

likelihood of erosion during high flows. Berms can break during high flows, causing more downstream erosion. Streamside berms prevent the water from accessing the floodplain and may also prevent wildlife from accessing a stream.

Removing or Replacing Structures

Low dams, bridges, and undersized culverts may obstruct water and sediment flows and impede free passage of water, fish, and other species, to habitats upstream or downstream. Detailed studies are needed to determine sites where removal of structures is feasible and where the equilibrium and habitat benefits of removal outweigh the disturbances caused by their removal.

Restoring an Aggraded Reach

Aggraded reaches are sections of a stream where the streambed has been built up. If left to evolve naturally, an aggraded reach could lead to large scale changes in the channel form. In some cases, preventative dredging of a channel may be done in a restorative manner. In most cases, restoration efforts of aggraded reaches will require detailed engineering and complex strategies.

Courtesy of White River Natural Resources Conservation District

The Newton School students plant native trees and shrubs along the Ompompanoosuc River on land that was previously horse pasture.

Courtesy of the Vermont Rivers Program

Removal of a berm or embankment along a river.

Restoring an Incised Reach

Incised reaches are sections of a stream where erosion of the streambed has caused deepening of the channel to a point where the stream is no longer connected to its floodplain. Efforts to restore an incised reach may involve a number of complex actions. Engineering studies should be undertaken to determine the potential success of such actions as re-establishing a channel on a previous floodplain or excavating a new floodplain at a lower elevation.

Before and after channel restoration on an aggraded reach of the White River in Granville, Vermont.

Courtesy of the Vermont Rivers Program

Courtesy of the Friends of the Winooski River

Planting a rain garden in Plainfield

Low Impact Development (LID) Techniques

When storm waters fall on surfaces such as roofs and pavement, the speed of the water increases because the water cannot be absorbed. These types of surfaces are referred to as "impervious." Towns spend many dollars managing stormwater with structures such as holding ponds, storm drains, and sewer systems. However, there are many techniques that can be used to reduce the amount of runoff that storm waters produce. These include rain gardens, rain barrels, and planting and caring for trees. Additional resources for LID techniques are found in Appendix C.

Indian River Berm Removal

The Vermont Rivers Program (VRP) removed approximately 2000 linear feet and 1800 cubic yards of berm material adjacent to the Indian River in West Pawlet. The berm was constructed to constrict the flow and maintain the channelized section of the Indian River. It was acting as an obstacle to the river restoring its natural pattern.

Now that the berm is removed, the stream will redevelop a stable meandering pattern and access the floodplain during seasonal high flows. This will allow the stream to deposit sediment and nutrients within the floodplain rather than flushing them downstream into the Mettowee River and ultimately Lake Champlain. The access to floodplain and meanders will also improve aquatic habitat and reduce flood and erosion hazards within the watershed. The adjacent area will be seeded and the stream will be allowed to migrate within a vegetated belt width corridor.

The project was a partnership between the Poultney Mettowee Natural Resources Conservation District, the United States Department of Agriculture, the Vermont Agency of Agriculture and the Vermont Agency of Natural Resources.

It is important that people understand the need to take a broad approach when selecting sites for restoration projects. Overall the most efficient and cost effective approach is to focus on improving stream stability (equilibrium conditions) and function as the core management goal. By relying on applied fluvial geomorphology studies, as described in this guide, it will be easier to predict how a stream system will respond to proposed land uses, riparian corridor encroachments, and channel modifications such as flood control projects.

An important part of this approach is setting priorities. Two things must be considered: the severity of the impaired or threatening condition and the likelihood of success, given the natural and human-made characteristics of the site and reach. The section of stream that calls for attention is part of a much larger system. Conditions far from the immediate problem may determine success or failure.

Courtesy of Town of Williston

This stream is undercutting its bank instead of being able to access its floodplain.

After the bank is reshaped, the water can flow into the floodplain during high flow conditions.

This shows restoration of a reshaped bank along Allen Brook in Williston. Bank reshaping serves two purposes: to connect the river to its floodplain and/or to increase tree survivability. This reshaping helped tree survivability since the inside bend provided the necessary floodplain access. If the bank hadn't been shaped at this location, the trees would have had to be planted at least 20 feet from the bank. That means all the sediment from the collapsing bank would have entered the brook. Allen Brook is considered impaired for sediment due to stormwater runoff.

B. Legal Concerns and Permits for Managing Streams

Projects altering a stream or floodplain may require permits. It is helpful to understand some basics about stream ownership, landowner liability, and regulatory agencies.

Ownership of and Responsibility for Streams

Who owns the water, streambed, and streambanks of a stream?

In Vermont, navigable water bodies and their beds and banks are considered to be in the domain of the public or in the public trust. A navigable water body is one large enough for the operation of a canoe or larger craft.

Who has the right to use water in a stream?

Each person whose property abuts a lake or stream has common law rights to use the water in a reasonable way. This means that no one landowner can use the water so as to deprive the others of their rights. If a water use interferes with the reasonable use of another riparian owner, the aggrieved party may go to court to protect his/her rights.

Assume that every stream is regulated unless determined otherwise.

Who is responsible for the stream?

Various individuals and agencies have responsibility for the protection and use of streams. Government agencies oversee navigation, public safety, and environmental matters. Bridges and culverts are the responsibility of local or state highway departments. Dams and power plants may fall under the purview of all levels of government from local to federal.

Conflicts regarding access and use are usually left to the aggrieved parties to negotiate or litigate. Landowners or municipalities are generally responsible for dealing with stream problems, but they may need permits before taking action.

Landowner Liability

Common Law is that body of law developed from judicial decisions based on custom and precedent. As such, it is constantly changing by extension or by interpretation. The central point of common law is damage. The owner of a bridge, hydraulic structure, or other stream project has a legal obligation to protect adjacent landowners from damages due to changes in natural drainage that result from that project. Anyone claiming such damage may file suit in court. The following questions are frequently asked by landowners, so their answers are useful to have in this guide.

If flooding occurs or gets worse after a stream has been modified (by diverting flow, modifying the channel, constructing a bridge, etc.), is the person who made the modification liable for damages?

Courts have, according to common law, followed the adage, "use your own property in such a manner as not to injure that of another." This means that no landowner, public or private, has a right to use his/her land in a way that substantially increases flood or erosion damages on adjacent lands. A municipality or property owner may thus be liable for construction, improvements, or modifications that they should reasonably have anticipated to cause property damage to adjacent property. The lack of proper planning, design, and execution thereof, may be considered a clear indication of the lack of good faith, and hence negligence, with regard to damages that subsequently occurred.

May someone be held liable for failing to remedy a natural hazard that damages adjacent property?

Courts have generally not held governmental units and private individuals responsible for naturally occurring hazards such as stream flooding or bank erosion that damage adjacent lands. In keeping with this principle, a municipality would not be liable for failure to restrain waters between the banks of a stream or failure to keep a channel free from obstruction that it did not cause. However, a small number of courts have held that government entities may need to remedy hazards on public lands that threaten adjacent lands. In addition, landowners and governments are liable if they take actions that increase the hazards.

Can liability arise from failure to reasonably operate and maintain a bridge, drainage structure, dam, or flood control structure?

The owner of a dam or other water-control structure is responsible for inspecting and maintaining it. Where there is a duty to act and the risk of not acting is reasonably perceived, then failure to take appropriate actions may be considered negligent conduct.

May a regulatory agency be liable for issuing a regulatory permit for an activity that damages other private property?

In fact, a careful analysis of hundreds of cases in which the lawsuit involved permitting, indicates that a municipality is vastly more likely to be sued for issuing a permit for development that causes harm than for denying a permit based on hazard prevention regulations. The likelihood of a successful lawsuit against a municipality for issuing a permit increases if the permitted activity results in substantial flood, erosion or physical damage to other private property owners.

How safe is safe enough?

Municipalities regularly issue permits for activities that are in compliance with existing laws but might still be at risk of damage. For example, floodplain development regulations generally apply only to areas mapped as the 100-year floodplain. Yet significant flooding and erosion damages can and do occur outside of these regulated flood-prone areas. Some municipalities address this additional risk by attaching conditions to their approvals for those projects with identified risks. These conditions can clearly state that the municipality is not obligated to fix personal property in the event of damage. One town granted approval for a driveway bridge that met all applicable standards but attached material clearly warning the applicant about the hazards of driving through floodwaters, the risk that emergency vehicles may be unable to reach the house during floods, the potentially high maintenance costs, and the potential liability for the owner if the project resulted in damage to other property.

Can governmental units be held liable for refusing to issue permits in floodways or high-risk erosion areas because the proposed activities could damage other lands?

In general, landowners have no right to make a "nuisance" of themselves by creating a hazard for others. Courts have broadly and consistently upheld regulations that prevent one landowner from causing a nuisance or threatening public safety.

What precautions can be taken to avoid liability?

The overall issue, in most instances, is the "reasonableness" of an action by the community or property owner. Due to advances in technology and products, there is an increasingly high standard of care for "reasonable conduct." The "act of God" defense is seldom successful because even rare flood events are now predictable. As a precaution, technical assistance from stream professionals should be obtained prior to implementing any stream project. Because a well-designed project is less likely to damage other lands, this reduces the potential basis for legal action. If you are sued, the best defense is a well-documented record showing "due diligence." That is, that you have done sufficient analysis and design to demonstrate the adequacy of the project with "a reasonable degree of certainty."

Permits and the Agencies that Issue Them

Any project that disturbs a streambank, streambed, or floodplain is likely to require permits from various government agencies. Permits allow agency staff to review projects for potentially adverse impacts on the stream, the aquatic life that it supports, development in the floodplain, and the property of adjacent landowners. Government regulations are designed to minimize the potential for damaging results that may occur upstream and downstream of a project.

For information about stream maintenance and restoration assistance, contact the website and agencies listed below. Details, and in some cases, applications for the following list of permits and others are available at: http://dec.vermont.gov/watershed/stormwater/permit-information-applications-fees

- Act 250
- Aquatic Nuisance Control
- Army Corps of Engineers
- Shoreland Encroachment
- Stormwater
- Stream Alteration
- Stream Crossing Structures
- Stream Obstruction
- Water Quality Certification (401)
- Water Withdrawals
- Wetland Regulation

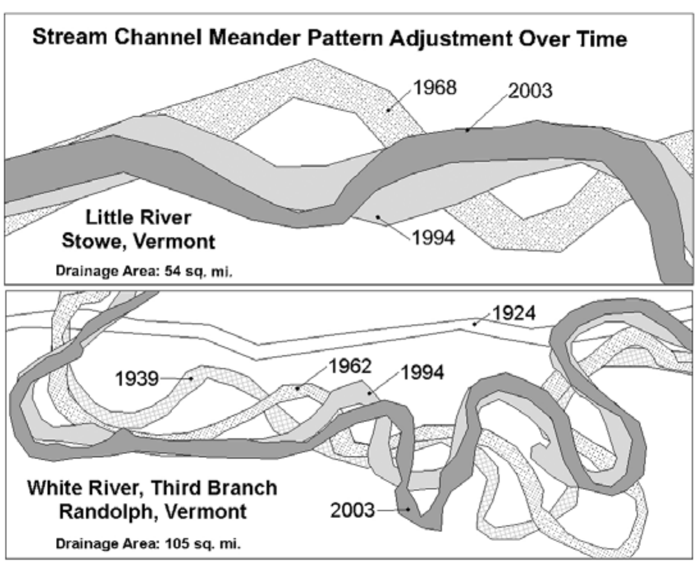
Frequently Asked Questions

The following questions are frequently asked by many landowners who may be unaware of the complexity and interrelationships of stream systems. Many well-meaning attempts to address stream problems, as illustrated by the questions posed, have resulted in the creation of even more problems. The answers are based on information contained in this handbook.

How many meanders does a stretch of stream need?

The natural stability and balance in a stream depend on its ability to access a floodplain and create meanders that help evenly distribute its energy and sediment load. The degree of valley slope; type of soil and vegetation along the banks and adjacent to the stream; the size and quantity of sediment moving on the stream bed; and the hydrology — water flowing over and in the ground (groundwater) — in the general area of a particular stretch of a stream all contribute to determining the meander pattern. This includes the number of meanders. So there is no set number of meanders. Additionally, the shape and number of meanders in a particular section of stream can also change over time under natural conditions as well as due to human activities along the stream and throughout that section of a watershed.

Courtesy of Vermont Rivers Program



Changing patterns of meanders over many decades

Who is responsible for removing trees that fall into streams?

Resolving conflicts with streams is generally the responsibility of the private landowner. However, trees falling into streams in many cases can be beneficial due to the coarse woody debris (CWD) that a tree provides to organisms in the water. Although various government agencies have regulatory jurisdiction over how a stream is managed, it is not necessarily their job to fix these problems. Having the responsibility of resolving personal conflicts with stream behavior does not give the landowner the right to fix a problem without a permit. It is also important to note that Vermont's Acceptable Management Practices (AMPs) for logging do not allow felling of trees into streams. This would be considered a discharge.

That gravel bar takes up most of the stream channel — that's why the stream floods. Wouldn't the stream stay in its banks if we removed the gravel bar?

Although gravel bar removal may provide temporary relief in some situations, the gravel bar is likely to return during the next high flow event. In many streams, gravel bars are an integral part of the stream and floodplain system. They are comprised of sediment that will be carried farther downstream during the next high flow event and replaced by a fresh supply of gravel. The State River Management Engineers are available for consultation about removal of gravel.

If this stream could be dredged, it would be deeper. Wouldn't that reduce all of these problems with flooding and erosion?

Past disturbance of stream channels has resulted in some of the stream problems we see today. Dredging can result in increased erosion and/or increased sediment deposition. Because dredging alters the shape and slope of the channel and disconnects the stream from its floodplain, it destroys those features that naturally dissipate the stream's energy. This frequently results in severe erosion problems. In addition, the shape of the dredged channel is generally not conducive to sediment transport, resulting in a buildup of eroded sediment within the channel.

Shouldn't we straighten the stream to keep it from washing out that bank? And if the water flows through here faster, it won't flood my neighbor's house.

Stream straightening or "channelization" can have adverse impacts and is no longer permitted by the Rivers Program. Because the curves in a stream channel dissipate energy, a straightened stream has more energy available to erode its channel. In addition, channelization may increase the downstream flood risks. Remember rivers naturally meander to slow down water and limit streambank erosive forces.

Would using a bulldozer to build up that streambank increase flood protection?

Floodplain soils are usually poorly suited for levee construction. By cutting off the stream's access to its floodplain, an elevated streambank *will increase the stream's energy and thus the potential for erosion. A berm made of local materials pushed up on a streambank is not true flood protection. Although it may withstand the forces of small flood events, these structures are prone to failure during major floods.*

I've owned this land for ten years and it's never been flooded. Why can't I build on it even if they say it's floodplain?

Floodplain development may be allowed if rules are followed to minimize the flood risk. However, in Vermont rising waters are of less concern generally than erosion problems from flooding, referred to as "Fluvial Erosion Hazards" or FEH. Courts at all levels have upheld the validity of floodplain regulations that prevent damage from hazardous development in locations where flooding is anticipated. Most municipalities have enacted standards that allow some development in the floodplain if it meets flood protection criteria and will not cause damage to adjacent properties. However, it is wiser to locate new development outside of the floodplain.

I remember when you could step across this creek. Nobody has done anything to it, but now trees are falling in and the banks are over my head. What happened?

It is likely that development or other changes in the watershed have increased stream flow, which triggered erosion of a larger channel. Although it is possible that the creek is adjusting to a channel disturbance, the reason for increased flooding or erosion is often found in the watershed that drains into a stream. The hydrologic alterations associated with forest clearing, agriculture, and urbanization increase peak flows and decrease base flows, resulting in more frequent flooding, increased bank erosion, sediment buildup, and other effects. Sometimes it only takes a few new houses or a new access road to cause problems in a stream.

My driveway bridge washed out. Who is going to pay for it?

All maintenance and repair costs for private stream crossings are the responsibility of the landowner. Federal disaster assistance is not available unless the flood is declared a federal disaster. This assistance doesn't cover all damages and may be limited to a low interest loan. The National Flood Insurance Program only offers policies for buildings and building contents. Damage to bridges, culverts, driveways, lawns, etc. is not covered by flood insurance. While local governments may be helpful, your private property is not their responsibility.

C. Watershed Stewardship: More Things to Do

Besides getting educated about stream processes, using best practices on your land, and engaging in the strategies as discussed above, there are even more possibilities for people to help restore streams to a more natural state.

The key to success in stream management is the assessment of stream characteristics and development of plans that encourage management actions to restore dynamic equilibrium in as many reaches of the stream as possible. Local watershed groups and town planning and conservation commissions can play key roles in creating plans and implementing their recommendations. Consider joining one of these groups and lending them a hand.

Volunteer for some days in the stream assisting the river scientists' collecting cross-section data during the follow-up Phase 2 assessment process. Seeing an entire river section, spending time walking the river, and observing its relationship to adjacent lands, in-stream features, and human impacts will help you to better understand the complicated and delicate nature of river systems in concert with successful action-management projects.

Whatever you choose to do, be certain of the fact that this is important work. The future health of our streams, wildlife species that depend on the habitats of stream corridors, and the water quality of receiving waters all hang in the balance. Our children will appreciate the time and energy we spend on these efforts, and besides, streams are beautiful and inspiring places. We can all enjoy the many dimensions of our experiences and benefits of our actions.

Courtesy of Charles Fish

Looking west along the Winooski River toward Camels Hump.

Three Lessons from Irene And How Vermont Responded

In August of 2011, flooding from Tropical Storm Irene devastated dozens of communities across Vermont. Flood responders, both public and private, made changes to rivers in an attempt to help affected communities, but many were working without training or guidance on river science and without appropriate regulatory constraints. Since that time, Vermonters have come together and started several new initiatives that have greatly expanded the training, technical support, and capacity for river protection and restoration. The rapid launch of these policies and programs was made possible by our Legislature, the involvement of our river community, and Vermont's prior commitment to sound, science-based river management.

Outreach and Training are Needed:

During the Irene recovery, many bridges were built to reconnect communities. In addition to physical bridges, many agencies and organizations needed to learn to bridge the gaps in communication between different disciplines and community interests. From this work, new outreach and training programs have been created:

- **Rivers and Roads Training** – online and in field training for municipal, contractual, and state transportation workers http://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_riversroads_fieldguide_plain_2014.pdf
- **Flood Ready Vermont** – data and resources for community leaders to wisely address flood vulnerabilities http://floodready.vermont.gov
- **River Flume Curriculum** – stream table to demonstrate stream, sediment, and encroachment dynamics. http://onrcd.org/documents/2015lessonpacket.pdf
- **River Smart Communities** – policies and programs that can help New England towns thrive despite river floods (UMassAmherst) https://extension.umass.edu/riversmart/policy-report

Oversight of Instream Emergency Measures is Needed:

The River Management Program lacked clear and enforceable authority over instream activities during flood emergencies. The legislature responded with Act 138. Vermont now has technical guidance and design requirements within adopted stream alteration rules. These provide a needed structure to the extent and types of instream work that towns may conduct when addressing imminent threats to public safety:

- River Management Principles and Practices
- Stream Alteration Rules
- Stream Alteration General Permit
- Reporting Emergency Protective Measures

River Corridor and Floodplain Protection are Needed:

Our ability to manage rivers toward their least erosive, equilibrium condition is interdependent with changing land use expectations and protecting river corridors and floodplains. Avoidance is by far cheaper than removing, relocating, replacing, retrofitting, or restoring. Act 138 also directed the ANR to provide communities with river corridor maps, guidance, and incentives:

- Flood Hazard Area and River Corridor Protection
- Statewide River Corridor Maps
- Flood Resilient Community Incentives (ERAF)

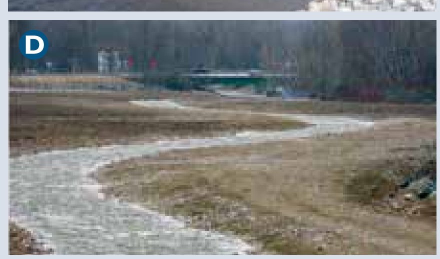
Each of these post-Irene initiatives would benefit greatly from community and citizen participation!

Irene filled many river channels, and some needed to be re-opened to protect public safety (A). Most were dredged more than was necessary or prudent from a stream stability and river health standpoint (B and C). Some were restored to equilibrium dimensions and will be less prone to erosion in the future (D).

Emergency measures needed to re-create channel flow capacity and address threats to public safety.

Out of equilibrium: Over-widened and prone to deposition.

Out of equilibrium: Straightened, bermed, and prone to high scour.



Restored with equilibrium: Slope, meander form, and floodplain connection.

References

Bisson, P.A., D.R. Montgomery and J.M. Buffington. 2006. Valley Segments, Stream Reaches, and Channel Units. In Hauer, F.R. and G.A. Lamberti, eds. *Methods in Stream Ecology.* Second Edition. San Diego, CA: Academic Press, 23-49.

Catskill Streams. 2011. Website at http://www.catskillstreams.org/pdfs/instreamtablepdfs/Berming.pdf

Kline, M., C. Alexander, S. Pytlik, S. Jaquith and S. Pomeroy. 2007. Vermont Stream Geomorphic Assessment Protocol Handbooks and Appendices. Published at: www.vtwaterquality.org/rivers/htm. Vermont Agency of Natural Resources, Waterbury, VT

Kline, M. 2010. *Vermont ANR River Corridor Planning Guide.* Vermont Agency of Natural Resources, Waterbury, VT.

Kline, M. and K. Dolan. 2008. *Vermont River Corridor Protection Guide.* http://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_rivercorridorguide.pdf . Vermont Agency of Natural Resources, Waterbury, VT.

Medlock, S.R. 2009. *Preparing for the Next Flood: Vermont Floodplain Management.* Vermont Law School Land Use Institute, South Royalton, VT.

Minnesota Department of Natural Resources. 2011. Accessed the Stream Habitat Program website: http://mndnr.gov/eco/streamhab and DNR Waters website: http://mndnr.gov/waters St. Paul, MN. http://files.dnr.state.mn.us/publications/waters/understanding_our_streams_and_rivers_resource_sheet_1.pdf

Naimen, R.J., H. Decamps, and M.E. McCain. 2005. *Riparia: Ecology, Conservation, and Management of Streamside Communities.* Elsevier Academic Press, Burlington, Massachusetts.

Rosgen, David L. 1997. A Geomorphological Approach to Restoration of Incised Rivers in Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision. Ed. By S.S.Y. Wang, E.J. Langendoen and F.D. Shields, Jr.

Schiff, R., M. Kline, J. Clark. 2008. The Vermont Reach Habitat Assessment Protocol. Prepared by Milone and MacBroom, Inc. for the Vermont Agency of Natural Resources, Waterbury, VT. Published at: www.vtwaterquality.org/rivers/htm

Thigpen, J. 2006. *Stream Processes: A Guide to Living in Harmony with Streams.* Chemung County Soil and Water Conservation District, Horseheads, NY.

Vermont Department of Fish and Wildlife. 2010. Website at http://www.vtfishandwildlife.com/get_involved/partner_in_conservation/community_wildlife_program

Vermont River Management Program. Stream Geomorphic Assessment Technical Protocols. www.vtwaterquality.org/rivers/htm/rv_geoassess.htm

Vermont Stream Geomorphic Assessment Projects, Phase 2. http://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_SGA_Phase2_Protocol.pdf

Washington State Department of Natural Resources. 2008. Family Forest Fish Passage Program Guidelines. Small Forest Landowner Office. Olympia, WA. http://www.dnr.wa.gov/Publications/fp_sflo_fffppguidelines.pdf

Appendix A.

Glossary

Taken from *Stream Processes: A Guide to Living in Harmony with Streams,* Chemung County Soil and Water Conservation District (Thigpen, 2006)

100-year flood – A large, but infrequent, flood event that has a 1% chance of occurring in any given year (occurs, on average, once every 100 years).

100-year floodplain – Areas adjacent to a stream or river that are subject to flooding during a storm event that has a 1% likelihood of occurrence in any given year (occurs, on average, once every 100 years). Most municipalities require a floodplain development permit for new development within areas mapped as the 100-year floodplain.

aggradation (aggrading) – The general and progressive buildup of a streambed due to sediment deposition. Aggradation occurs when the channel is supplied with more sediment load than it is capable of transporting.

alluvial fan – A fan-shaped deposit of material at the place where a stream issues from a steep valley onto a plain or broad valley with a low slope.

bankfull – The full capacity of the stream channel to the top of the bank on either side. The bankfull discharge is the flow at which water first overtops the banks onto the floodplain, which occurs, on average, every 1.2 to 2.0 years. Bankfull flow is largely responsible for the shape of the stream channel and is sometimes called the channel-forming flow.

base flow – The portion of stream flow that comes from groundwater seepage into the channel; constitutes the natural dry weather flow in the stream.

bedload – Sediment that is transported in a stream by rolling, or sliding on or near the streambed.

berm – A mound of earth or other materials, usually linear, constructed along a stream, road or other area. Berms are often constructed to protect land from flooding or eroding, or to control water drainage. Some berms are constructed as a byproduct of a stream management practice whereby streambed sediment is pushed out of the channel and mounded on (and along the length of) the streambank. These berms are frequently breached by the stream and should not be relied on for flood control. Streamside berms often interfere with other stream processes such as floodplain function, and can exacerbate flood-related erosion or stream instability.

braided channel (braided stream) – A stream that has flow in several channels, which successively meet and divide. Braiding occurs when sediment is deposited within the channel area.

buffer – See riparian buffer.

channel – A natural or artificial watercourse with a definite bed and banks that conveys continuously or periodically flowing water.

channelization – Straightening or deepening of a natural stream channel.

check dam – A low dam constructed across a channel to decrease the stream flow velocity (by reducing the channel gradient), minimize channel scour, and promote sediment deposition.

cluster development – The use of a site design that incorporates open space into a development site. The open space can be used for recreation or preserved as naturally vegetated land.

culvert – A pipe or closed conduit for the free passage of surface drainage water. Culverts are typically used by highway departments to control water running along and under the road, and to provide a crossing point for water from roadside drainage ditches to the stream, as well as for routing tributary streams under the roads. Landowners also use culverts to route roadside drainage ditch water under their driveways.

debris – Floating or submerged material, such as logs, vegetation, or trash, transported by a stream.

degradation (degrading or down cutting) – The general and progressive lowering of a channel due to downward erosion of the streambed over a relatively long channel length. A degrading stream may have high, unstable banks and be disconnected from its floodplain.

dike (levee) – An embankment to confine or control water, often built along the banks of a river or stream to contain over-bank flow and prevent inundation of floodplain development.

discharge (stream flow) – The rate of flow passing a fixed point in a stream, expressed as a volume of water per unit of time, usually cubic feet per second (cfs).

dynamic equilibrium – A stream system that has achieved a balance in transporting its water and sediment loads over time without aggrading (building up), degrading (cutting down), or migrating laterally (eroding its banks and changing course). A stream in dynamic equilibrium resists flood damage, resists erosion, and provides beneficial aquatic habitat.

erosion – The detachment and movement of soil or rock fragments by water, wind, ice, or other geological agents. In streams, erosion is a natural process that can be accelerated by poor stream management practices.

floodplain *(see also 100-year floodplain)* – Any flat or nearly flat lowland bordering a stream that is periodically inundated by water during floods. The floodplain acts to reduce the velocity of floodwaters, increase infiltration, reduce streambank erosion, and encourage deposition of sediment. Vegetation on floodplains greatly improves these functions.

floodway – That portion of the floodplain required to store and discharge floodwaters without causing potentially damaging increases in flood heights and velocities.

grade (gradient) – The slope of a stream, measured along the length of the stream channel.

grade stabilization (grade control) – The use of hard structures in a channel to prevent headcutting or degradation (lowering of the channel grade).

gravel bar *(see also point bar)* – An elevated deposit of gravel located within a stream channel and lacking permanent vegetation.

groundwater – Water beneath the earth's surface, found at varying depths, where every space between soil or rock particles is filled with water.

headcut – A marked change in the slope of a streambed, as in a "step" or waterfall, that is unprotected or of greater height than the stream can maintain. Increased potential for erosion at this location causes the headcut to move upstream, eventually reaching an equilibrium slope.

hydraulics – The applied science that deals with the behavior and flow of liquids. When used in reference to a stream, hydraulics refers to the processes by which water flows within the channel.

hydrologic cycle – The global circulation of water in the air, on land, and in the sea.

hydrology – The science that deals with the occurrence and movement of water in the atmosphere, upon the surface, and beneath the land areas of the earth. In reference to a particular stream, the hydrology is the amount and timing of water flow into the stream.

impervious – Those surfaces that cannot effectively infiltrate rainfall and snow melt (e.g. rooftops, pavement, sidewalks, driveways, etc.). Impervious cover causes an increase in the volume of surface runoff.

incised stream – A stream in which degradation (erosion of the streambed) has caused deepening of the channel to a point where the stream is no longer connected to its floodplain.

infiltration – The process of water percolating into the soil.

instability (unstable) – An imbalance in a stream's capacity to transport sediment and maintain its channel shape, pattern, and profile.

intermittent stream – A stream or portion of a stream that flows in a well-defined channel during the wet seasons of the year, but not the entire year.

invasive plant – A species of plant that is not native to a region and has the ability to compete with and replace native species in natural habitats. Invasive plants present a threat when they alter the ecology of a native plant community.

kinetic energy – Energy of motion. The kinetic energy of a stream is equal to one-half the mass of water, times the square of the velocity at which the water is moving.

levee – *See dike.*

meander – Refers to both the winding pattern of a stream ("meander bends") and to the process by which a stream curves as it passes through the landscape (a "meandering stream"). A meandering stream channel generally exhibits a characteristic process of bank erosion and point bar deposition associated with systematically shifting meanders.

National Flood Insurance Program – Federal program that makes available subsidized flood insurance in those jurisdictions within which the local government regulates development in identified flood hazard areas. Local regulations must be at least as stringent as federal standards.

natural stream design – A stream restoration method that uses data collection, modeling techniques, and stable or reference channels in the design of ideal channel configurations.

nutrients – Essential chemicals, including nitrogen and phosphorous, that are needed by plants and animals for growth. Excessive amounts of nutrients can lead to degradation of water quality and algal blooms.

pattern (of a stream channel) – The shape of a stream as seen from above or on a map.

peak flow – The maximum stream flow from a given storm condition at a specific location.

planform – The shape of the stream as seen from above.

point bar – A stream deposition feature usually found on the inside of a bend; consists of sand, gravel, or other sediment and lacks permanent vegetation.

pool – A stream feature in which water is deeper and slower than in adjacent areas. Pools typically alternate with riffles along the length of a stream channel.

potential energy – Energy that results from gravitational pull on an object. The potential energy in a stream is equal to the weight of water times the elevation of a specified point relative to the mouth of the stream.

profile – The shape of a stream drawn along the length of its channel to show both the streambed and the water surface.

riffle – A stream feature in which water flow is shallow and rapid compared to adjacent areas. Riffles typically alternate with pools along the length of a stream channel.

riparian – The area of land along a stream channel and within the valley walls where vegetation and other land uses directly influence stream processes.

riparian buffer (or stream buffer) – Zone of variable width along the banks a stream that provides a protective natural area along the stream corridor.

riparian rights – The rights of an owner whose land abuts water.

riprap – Broken rock placed on a streambank or other surface to protect against scouring and erosion.

rock vanes – Rock structures built below the water level to control the direction of flow within a stream.

root wad – Streambank stabilization technique in which one or more tree trunks are embedded in the streambank with the root mass facing the flow to dissipate energy.

roughness (hydraulic roughness) – In a stream, roughness refers to the frictional resistance to flow.

runoff – *See surface runoff.*

scour – The process by which the erosive action of flowing water removes material from the bed or banks of a stream.

sediment – Solid material, both mineral and organic, that is being transported or has been moved by air, water, gravity, or ice from its site of origin (streambank or hillside) to the place of deposition (in the stream channel or on the floodplain).

skidding – Short-distance dragging of logs or felled trees from the stump to a point of loading or processing.

skid trail – Rough travel ways for logging machinery. Logs are often dragged over the skid trail surface.

stable *(see also dynamic equilibrium)* – Although no stream is truly stable in the sense that it doesn't change over time, a stream may be described as stable if it is in dynamic equilibrium, with no appreciable change from year to year.

storm flow – The portion of stream flow that comes from surface runoff and constitutes the main component of high stream flows during rainy weather.

storm hydrograph – A graph of stream discharge against time for a single storm event.

stormwater – Surface runoff; generally referred to as stormwater when the surface runoff is from developed areas.

stormwater management – The use of structural or non-structural practices that are designed to reduce stormwater runoff and mitigate its adverse impacts on property, natural resources, and the environment. Structural practices involve construction of systems that provide short-term storage and treatment of stormwater runoff. Non-structural techniques use natural measures to reduce pollution levels, do not require extensive construction efforts, and/or promote pollutant reduction by eliminating the pollutant source.

stream – A natural watercourse with a definite bed and banks that conducts continuously or periodically flowing water.

streambed (bed) – The bottom of a stream channel bounded by banks.

streambank (bank) – The sides of a stream channel between which the flow is normally confined.

stream restoration – The process of converting an unstable, altered, or degraded stream corridor, including the adjacent riparian zone and flood-prone areas to its natural stable condition considering recent and future watershed conditions.

stream stabilization – The in-place stabilization of a severely eroding streambank and/or streambed. Although stabilization techniques address the immediate problem, they may not restore the system's dynamic equilibrium.

surface runoff *(see also stormwater)* – The portion of precipitation or snow melt that reaches the stream channel by flowing over the land surface.

transpiration – The process by which water taken up by plants is returned to the atmosphere by evaporation from leaves.

tributary – A stream that feeds into another stream; usually the tributary is smaller in size than the main stream.

velocity – In streams, the speed at which water is flowing, usually measured in feet per second.

water bar – A shallow trench or diversion ditch that diverts surface runoff from roads, fire breaks, or skid trails into a dispersion area. Water bars are used to disperse flow, minimize erosion, and enhance conditions for re-vegetation.

watershed – A unit of land on which all the water that falls (or emanates from springs) collects by gravity and runs off via a common outlet (stream).

wetland – An area that is permanently or periodically saturated by water with vegetation adapted for life under those soil conditions, such as swamps, bogs, fens, and marshes.

Appendix B

Acronyms

EPA	U.S. Environmental Protection Agency
FEH	Fluvial Erosion Hazard
FWR	Friends of the Winooski River, or the Friends
FEMA	U.S. Federal Emergency Management Agency
LCBP	Lake Champlain Basin Program
LID	Low Impact Development
NPS	Nonpoint Source (Pollution)
NRCS	USDA Natural Resource Conservation Service
TMDL	Total Maximum Daily Load (of phosphorus into Lake Champlain)
TNC	The Nature Conservancy
VRC	Vermont River Conservancy
VRP	Vermont River Program
USDA	U.S. Department of Agriculture
USDI	U.S. Department of Interior
USGS	USDI United States Geological Survey
UVA	Use Value Appraisal Program
UVM	University of Vermont
VANR	Vermont Agency of Natural Resources

Appendix C

Guidance for Projects and Other Materials

Overview of Programs to Help Landowners

Winooski Watershed Landowner Assistance Guide, 2011, Montpelier, VT. Available at http://www.winooskiriver.org/land-owner-assistance-guide.php

Offers an index of resource sources, along with an index of resources by type. Many resources cited are useful to watersheds throughout the state.

Understanding Stream Structures and Processes

Many fact sheets are available at Vermont Rivers Program and Flood Ready web pages.

Stream Geomorphic Assessments (SGA)

Stream Geomorphic Assessment Protocol Handbook, 2009

SGA technical protocols can be found at the Vermont Rivers Program website http://dec.vermont.gov/watershed/rivers/river-corridor-and-floodplain-protection/geomorphic-assessment

SGA Reports for Various Watersheds

https://anrweb.vt.gov/DEC/SGA/finalReports.aspx

River Corridor Planning

Vermont River Corridor Planning Guide

This is the primary document to follow when preparing a River Corridor Plan. It presents the corridor protection and restoration programs that have been developed in the state. http://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_rivercorridorguide.pdf

Vermont League of Cities and Towns (VLCT) provides model ordinances and technical assistance to towns for planning http://vlct.org/municipal-assistance-center/water-resources-assistance/

Tactical Basin Planning:
Tactical basin plans focus on the projects or actions needed to protect or restore specific waters and identify appropriate funding sources to complete the work, based on monitoring and assessment data. http://dec.vermont.gov/watershed/map/basin-planning

Flood Ready Vermont:
Tips for communities to become more flood resilient. http://floodready.vermont.gov/

Easements and Corridor Land Conservation

A Guide to River Corridor Easements, 2010

http://dec.vermont.gov/sites/dec/files/wsm/rivers/docs/rv_RiverCorridorEasementGuide.pdf

Conservation Reserve Enhancement Program (CREP)

This is the state and federal farm service agency program through which farmers receive assistance in establishing a stream corridor easement.

VTANR Clean Water Initiative
http://dec.vermont.gov/watershed/cwi

Land Trusts and Conservation Organizations:
Vermont River Conservancy
Vermont Land Trust
The Nature Conservancy
Middlebury Land Trust
Stowe Land Trust
Upper Valley Land Trust
Vermont Housing and Conservation Board

Low Impact Development (LID) Techniques, Including Stormwater Control

State natural resource, land use, and transportation agencies have programs to help individuals and communities use best management practices (BMPs) to control stormwater.

Vermont Low Impact Development Guide for Residential and Small Sites
dec.vermont.gov/sites/dec/files/wsm/mapp/docs/pl_LID_Guide.pdf

Vermont Rain Garden Manual, *Gardening to Absorb the Storm*

Winooski Natural Resources Conservation District
http://winooskinrcd.org/wp-content/uploads/VTRainGardenManual.pdf

Chittenden County's "Smart WaterWays" website
http://www.smartwaterways.org/

The Vermont Department of Environmental Conservation's (DEC) Stormwater Program
http://dec.vermont.gov/watershed/stormwater

VTrans Local Roads Program
http://localroads.vermont.gov/

VT Better Roads Program
http://vtrans.vermont.gov/highway/better-roads

Agency of Agricultural, Food and Markets Water Quality Program
http://agriculture.vermont.gov/water-quality

Vermont Department of Forests, Parks & Recreation Forests for Water Quality
http://fpr.vermont.gov/forest/ecosystem/water_quality

Stream Restoration Assistance and Getting Permits

Resource people who can help plan and direct a project including staff at the Vermont Rivers Program in the Agency of Natural Resources, staff and volunteers of organized river groups, and consultants.

Vermont Natural Resources Conservation District, Trees for Streams Guide
http://winooskinrcd.org/watershed-stewardship/

Applications for the following permits and others are available at:
http://anr.vermont.gov/planning/permitting

Act 250
Aquatic Nuisance Control
Army Corps of Engineers
Flood Hazard Area and River Corridor Shoreland Encroachment
Stormwater
Stream Alteration
Stream Crossing Structures
Stream Obstruction
Water Quality Certification (401)
Water Withdrawals
Wetland Regulation

Video: *River Dynamics, River Restoration* by Mike Kline of the Vermont Rivers Program
From: memefilms | Nov 2, 2010

A video overview of river dynamics directed, filmed and edited by James Valastro, South Burlington, Vermont.
https://www.youtube.com/watch?v=0Va7E7KOz94

Video: *Vermont River Meanders and Floodplains, River Restoration* by Shayne Jaquith of the Vermont Rivers Program
From: memefilms | Nov 17, 2010

A video overview of river meanders and floodplains, how channel equilibrium has been altered by humans, and how rivers adjust to restore and preserve channel equilibrium over time. Directed, produced, and edited by James Valastro, South Burlington, Vermont.
https://www.youtube.com/watch?v=RQ6oyf9C8Lc


Courtesy of Charles Fish

Winooski hydro station


Courtesy of Jeff Dickinson

The mouth of the Winooski River at Lake Champlain.

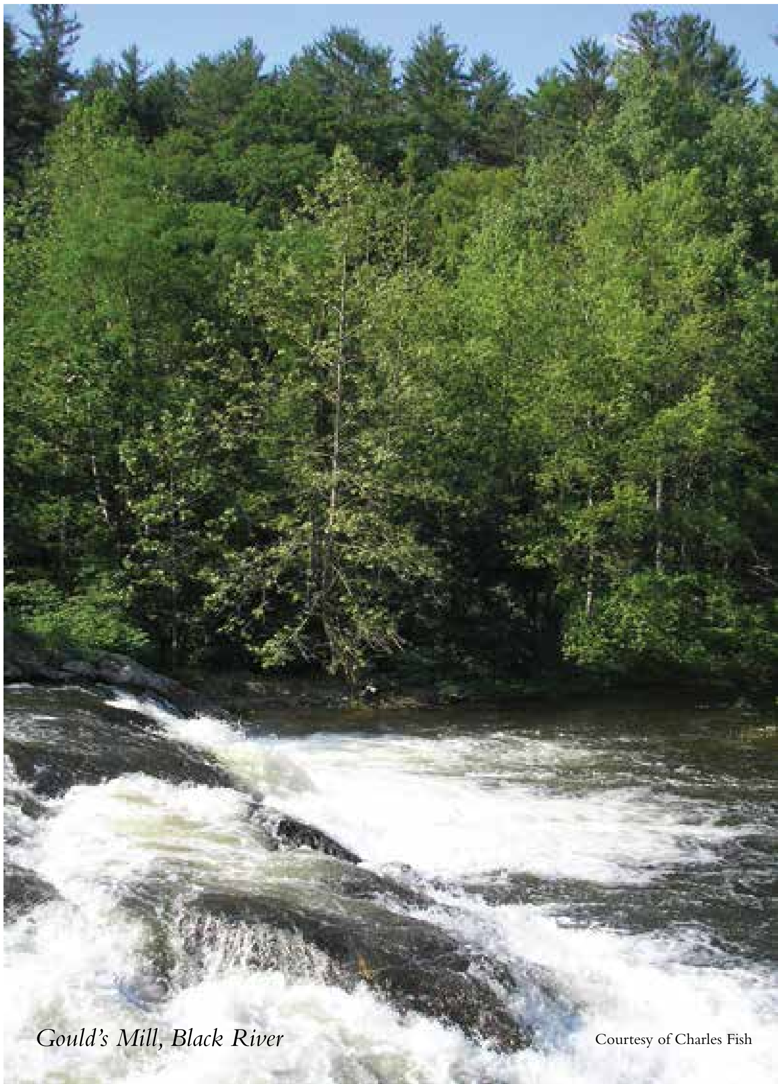

Courtesy of Charles Fish

Plainfield

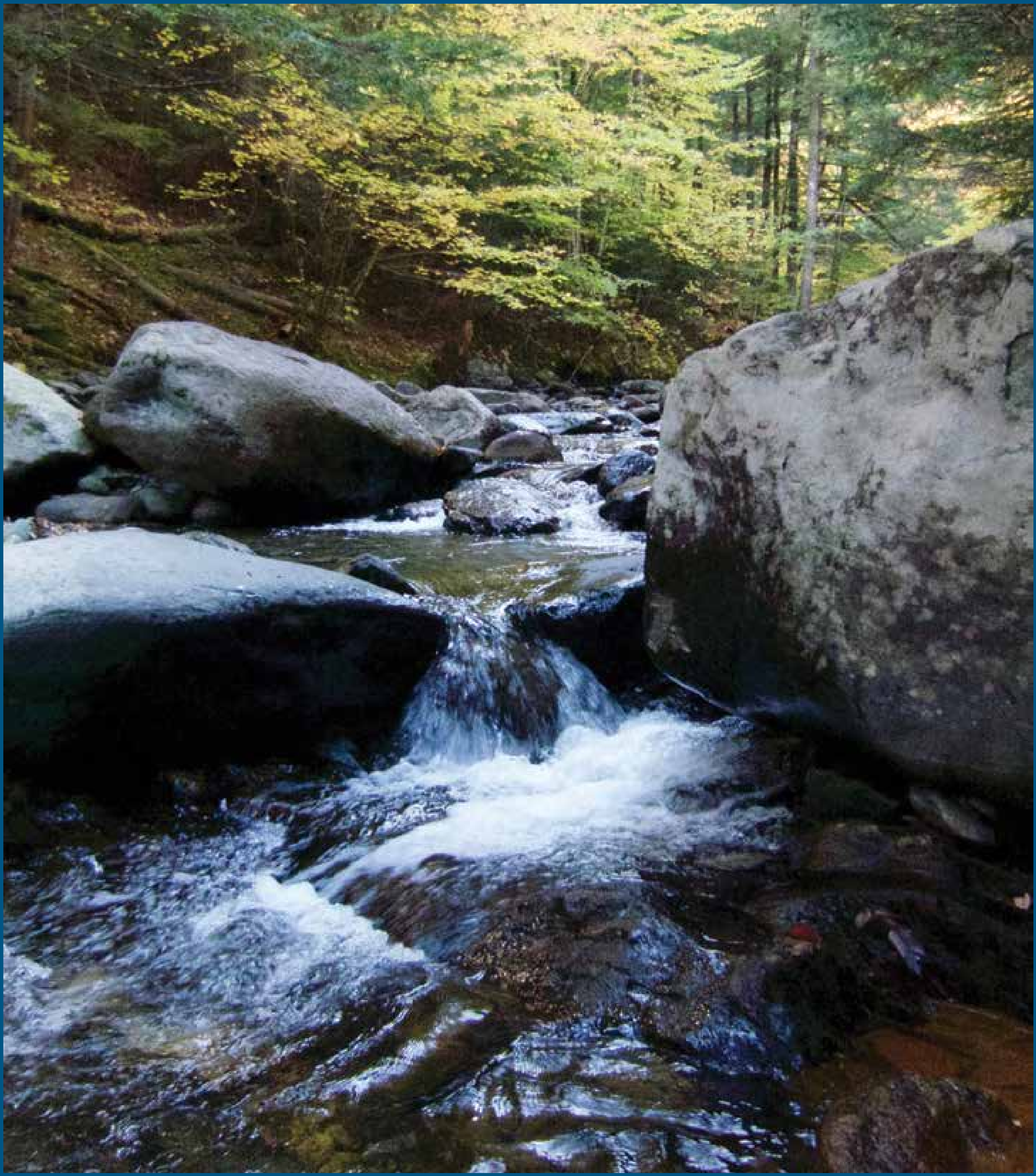
Courtesy of Tim Seaver

Hancock Brook, Worcester Courtesy of Emily Marie Ahtúnan

White River Courtesy of Mary Russ



Gould's Mill, Black River Courtesy of Charles Fish



Courtesy of Emily Marie Ahtúnan

For questions regarding the content of this handbook, contact:

Friends of the Winooski River

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To order additional copies of this handbook, contact:

Watersheds United Vermont

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