Stream Table Lesson Packet

Second Edition

A Companion Curriculum Guide for Vermont Schools

Using the Emriver Em2 Geomodel ("The Flume")

For Grades 3 to 6

In Schools and Communities

of the

Ottauquechee Natural Resources Conservation District (ONRCD)

Developed by

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April 2015

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Ottauquechee Natural Resources Conservation District
28 Farmvu Drive • White River Jct., VT • 05001

A letter from the Ottauquechee Natural Resources Conservation District

This lesson packet is part of the school portion of the "River Roadshow," an educational program run by the Ottauquechee Natural Resources Conservation District (ONRCD) to bring to the community an appreciation of rivers and how they work. ONRCD is a member of the Vermont Association of Conservation Districts.

In 2012, ONRCD was fortunate to receive a grant from the Vermont Community Foundation to purchase an Emriver Em2 Geomodel from Little River Research and Design (http://www.emriver.com/). The Em2 is commonly called a stream table or flume. Included in the school program of the River Roadshow is this lesson packet, written by Jennifer Guarino of Ecotone Education, a division of Verdana Ventures LLC. During September 2013, ONRCD received a grant from the Wellborn Ecology Fund of the New Hampshire Charitable Foundation to expand the River Roadshow and bring it to more schools.

The lesson packet covers many aspects of river dynamics in a way that encourages observation, discussion, and experimentation. For example, students do simple activities with marbles to see the effects of meanders on speed and the relationship of speed and volume to force. They carry these activities to the stream table and easily note the relationship of river speed and volume to erosion and degradation. In short, rather than being told how streams work, they discover, on their own, the concept of Lane's Balance, one of the primary principles of river dynamics. So while the topic of this lesson packet concerns rivers, the process is for students to learn to observe, question, form theories, test their theories, and formulate and apply their findings.

There is a wealth of material on the Internet regarding stream tables/flumes, including how to build them and how to use them. One article by the Missouri Dept. of Conservation explains how to build a stream table and expresses well its value:

An understanding of how sediment, vegetation and flowing water interact to form stream channels is essential in knowing how to restore and manage them. Because it is impractical or impossible to directly observe these processes in real streams, a portable model stream has been developed by the Missouri Department of Conservation.

This model stream is particularly useful because most observers, regardless of their age or background, can understand fairly complex concepts demonstrated by the model that are otherwise difficult to comprehend, e.g. illustrating a destructive practice like channelization. The model also effectively convinces audiences that protecting or restoring stream corridor vegetation is the best way to protect both property and fish and wildlife values. Within the model, fluvial processes like bank erosion and point bar *formation take place rapidly, so these processes can be observed in a short period of time. Regardless of their interest in stream conservation, most people are fascinated by the model.*

Why a Second Edition?

ONRCD has now been operating The River Roadshow for approximately three years. During this time, we have had many dozens of public educational events for thousands of people and trainings for those who work with heavy machines on roads and in rivers. And the *Stream Table Lesson Packet* has been used by dozens of teachers to teach well over a thousand students about how rivers work.

We have gotten wonderful feedback from teachers, telling us what has worked well with their students, what has not worked so well, and where they as teachers could use more information. This second edition of the *Stream Table Lesson Packet* reflects that feedback. We think this new edition is much improved, but we know more can be done, so we encourage you to continue giving us feedback. Please complete and return the **Teacher Evaluation Form** included in this packet so we may improve our work with schools.

Acknowledgements

ONRCD is grateful for the advice and assistance of Staci Pomeroy and Marie Lavesque Caduto of the Vermont Department of Environmental Conservation and Chris E. Smith of the U.S. Fish & Wildlife Service for serving as scientific advisors. We are also grateful to Kathy Renfrew, Vermont Agency of Education, Jenny Hewitt, a teacher at the Pomfret School, Audrey Halpert, a teacher at the Albert Bridge School, and Jill Kurash and Karen White of Woodstock School whose years of experience ensured that this packet would be valuable to classroom teachers. And finally, we thank Jennifer who has the talent to bring it all together.

We hope you find this lesson packet useful.

Larry Kasden, ONRCD Supervisor Chair; Sue Greenall, District Manager; Supervisors Judy Howland, and Bill Manner; Associate Supervisors Lynn Bohi, Roy Burton, Todd Menees, and Cynthia Rankin.

April 2015

STREAM TABLE LESSON PACKET

TEACHER EVALUATION FORM

Grade of students: _______ Number of days that you used the stream table: ___________

Subject(s) taught with stream table: ____

Stream Table Unit lessons that you taught to your students (please check):			
1. Corridors & Channels	❒ 1.1. Why Meanders Form	❒ 1.2. Changing Channel	❒ 1.3. Stream Anatomy
2. Marble Races	❒ 2.1 Meanders &Velocity	❒ 2.2 Thalweg & Riffles	❒ 2.3 Length & Slope
3. Water & Sediments	❒ 3.1. Gravel Mining	❒ 3.2. High Banks & Low Banks	❒ 2.3. Lane's Balance Scenarios
4. Streambanks	❒ 4.1 Bank Protection	❒ 4.2 Streambanks & Habitat	
5. Stream Crossings	❒ 5.1 Stream Crossing Experiment	❒ 5.2. Community Crossings	
6. Watershed Neighbors	❒ 6.1. Upstream, Downstream	❒ 6.2. Designing a Solution	

Which lessons (above) were particularly effective? Explain.

Can you recommend other lessons or sources of lessons that would complement this unit?

Please rank the following items.	1 (not useful)	2	3 (somewhat useful)	4	5 (very useful)
Usefulness of stream table as a teaching tool					
Usefulness of STREAM TABLE LESSON PACKET					

Suggestions for improvement:

Please check all that apply:

❒ I received training to teach with the stream table. *Please tell us about your experience:*

❒ I received a visit from a stream table educator (planning and/or teaching). *Please tell us about your experience:*

❒ I would like to receive training to teach with the stream table and Stream Table Unit.

❒ I would like to receive a visit from a stream table educator to help me teach with the stream table.

Thanks for your feedback! Please return this form to Sue Greenall, ONRCD, 28 Farmvu Drive, White River Junction, VT 05001.

GOAL & LEARNING OBJECTIVES

The Goal of the Stream Table Lesson Packet is:

To educate as many people as possible about how streams behave and how people can live in harmony with streams.

The Learning Objectives of the Stream Table Lesson Packet are:

To understand how streams…

- move over time within a predictable corridor
- form meanders as they flow through valleys
- follow a pattern
- seek to balance energy by moving water and sediments

To demonstrate human impacts on a stream and the ways in which a stream responds. Human impacts include:

- straightening, berming, and armoring
- removing gravel
- installing different sizes and types of culverts
- opening and closing access to floodplains

HOW TO USE THE STREAM TABLE LESSON PACKET

The STREAM TABLE LESSON PACKET was created for use with the Emriver Em2 Geomodel (stream table or "flume"), which can be borrowed from the Ottauquechee Natural Resources Conservation District (ONRCD), based in White River Junction, Vermont. Please see HOW SCHOOLS CAN RESERVE THE STREAM TABLE below for more information, or to request the use of the stream table.

- ♦ These lessons are geared for students in grades 3, 4, 5, and 6 and aligned with selected components of the *Next Generation Science Standards*. A brief section below introduces the Next Generation Science Standards and describes connections between the new standards and this lesson packet.

- ♦ Each lesson has the following parts:

  - A **Background** section that provides context for the lesson. ***More Info*** boxes are included that direct you to resources that pertain to that lesson. Two such resources are used extensively in this lesson packet: Living in Harmony with Streams: A Citizen's Handbook to How Streams Work (http://www.winooskiriver.org/images/userfiles/files/Stream%20Guide%201-25-2012%20FINAL.pdf), prepared by the Friends of the Winooski River and partners; and *After the Flood: Vermont's Rivers,* a series of 4 videos made by River Bank Media (http://www.youtube.com/watch?v=Wx7EQAY8CuA&list=PLX5V6zW7pAiYEC3bIrK3ymOegGrPwg0xT)

  - A **Materials** box that lists items that come with the stream table and items that you supply for that lesson.

  - A **Set-Up** box with information on how to prepare for the lesson.

  - A **Timeframe** box with a rough estimation of the time needed to teach the lesson.

  - **Instructions** for teaching the lesson.

- ♦ Some lessons have ***Student Activity Sheets****,* which can be used to assess student learning.

- ♦ A **Glossary** of terms used in this packet is included after the lessons.

- ♦ An annotated list of **Teaching Resources** is provided for more information.

- ♦ **Appendices** contain a watershed map of the Ottauquechee River and Black River (the region served by ONRCD) and two Extension Activities.

- ♦ A **Teacher Evaluation Form** is included to gather feedback on the lesson packet for future improvement. *Please complete this form and send it to Sue Greenall at ONRCD (see above).*

Curriculum Planning

Teachers borrow ONRCD's stream table for 1 to 2 weeks at a time. We strongly recommend that you hold a Parent / Community Night toward the end of your time with the stream table. During this event, students can teach what they've learned to adults and other children, extending the learning into the community and providing a powerful opportunity for student self-assessment.

Below are sample units based on the use of the table for 5 days and 10 days. We would love to hear from you as you adapt this unit to your own teaching goals and environment. Please send us your ideas!

Figure 1. Sample 5-Day and 10-Day Units

Most teachers borrow the stream table for 5 or 10 school days. Here are suggested unit formats for these two timeframes.

Before the stream table arrives:

- Consider your goals and student learning outcomes for the unit; decide which lessons to teach
- Do the *River Systems & Watersheds Lesson*
- Discuss guidelines and expectations with your students for using the stream table and associated materials

Once the stream table is in your classroom:

- Teach students how to run it and maintain it properly and safely.
- Discuss a system for organizing all the pieces (toys, marble race boards, etc.).
- Decide how you will pack up the stream table, and whether you will involve students in this process.

A Sample 5-Day Unit

Lessons are in italics; those with student assessment sheets are <u>underlined</u>

Mon	Tues	Wed	Thurs	Fri
Lesson 1: Corridors and Channels	<u>*Lesson 2: Marble Races*</u>	<u>*Lesson 3: Water & Sediments*</u>	<u>*Lesson 5: Stream Crossing Experiment*</u> Parent / Community Night	<u>*Lesson 6: Watershed Neighbors*</u>

A Sample 10-Day Unit

Lessons are in italics; those with student assessment sheets are <u>underlined</u>

Mon	Tues	Wed	Thurs	Fri
Allow students to visit the stream table in pairs or small groups. Ask them to record Observations, Thoughts, and Questions as they explore in an unstructured way.	*Lesson 1: Corridors and Channels*	<u>*Lesson 2: Marble Races*</u>	Introduce students to the scientific method, and explain that each experiment begins with a question that can be tested using this method. Discuss the Questions that students generated on Tuesday during unstructured explorations. Choose one Class Question that is testable, and ask pairs of students to develop a plan for testing it on the stream table.	<u>*Lesson 3: Moving Water and Sediments*</u>
Allow each student pair to take turns implementing their experiment on the stream table and gathering data. Have each pair present its work to the class.	*Lesson 4: Streambanks*	<u>*Lesson 5: Stream Crossings*</u>	<u>*Lesson 6: Watershed Neighbors*</u> Parent / Community Night	Culminating activity (such as <u>*Lesson 6.2: Designing Solutions*</u>)

<u>STREAM TABLE LOGISTICS</u>

The STREAM TABLE LESSON PACKET was designed to accompany the Emriver Em2 Geomodel (often called the stream table or "flume"), an educational tool that models stream dynamics and human impacts on streams through demonstrations and hands-on activities. Schools can borrow the stream table from the Ottauquechee Natural Resources Conservation District (ONCRD) for 1 to 2 weeks. See below for contact information.

Location, Set-Up, and Management

The stream table's dimensions are roughly 3 feet by 6 feet and its footprint is about 7 feet by 10 feet (this allows students to surround the table comfortably). It comes with all needed equipment for operation, complementary "toys" for educational programming, and a floor tarp that is laid down before the table is set up.

Experienced stream table assemblers can set it up in about 45 to 60 minutes (including time to bring all equipment into the building). A person new to its set-up should allow up to 2 hours. For more information on set-up, please consult the following:

- *Use and Care of the Emriver Em2 Geomodel,* a manual on the website of Little River Research and Design, the company that manufactures it: http://www.emriver.com/wp-content/uploads/2011/09/Emriver_Em2x_manual_2012_05-02_AQ.pdf
- ONRCD Set-Up Video, Part 1: https://www.youtube.com/watch?v=_0NEyUui7Ss&app=desktop
- ONRCD Set-Up Video, Part 2: https://www.youtube.com/watch?v=6J8nt2B5bwk&app=desktop

Recommendations for choosing a location and managing the stream table:

- Many schools put the stream table in a classroom, but some put it in a common space in the school like an extra classroom or a lobby. *Please note: If the stream table is in a common space, student access to it should be controlled. See below.*
- The stream table combines "sediments" (small plastic particles), running water, electrical equipment, and an electrical cord. Students should always be supervised around the stream table.
- The stream table requires 25 gallons of water. You need easy access to a sink to fill up its reservoir and to empty the reservoir during take-down of the table.
- Because it contains sediments and water, the stream table tends to be messy. Please consider this when deciding on its location.
- When the stream table is not being used, please cover it with a tarp or tablecloth. Some teachers also place a sign on it that reads "Stream Table Closed". This prevents students from playing with it when they are not supervised.

To reserve the stream table in Vermont, please contact:

Larry Kasden, Stream Table Coordinator
Ottauquechee Natural Resources Conservation District
larrykasden@gmail.com or 802-457-9221

The Next Generation Science Standards

In the spring of 2013, Vermont and 25 other states adopted the *Next Generation Science Standards* (NGSS), which are built on the *Framework for K-12 Science Education* developed by the National Research Academy in 2011.

NGSS introduces a new approach to teaching standards. Three dimensions – *Science and Engineering Practices*, *Disciplinary Core Ideas*, and *Cross-Cutting Concepts* – are intertwined to help students learn science content and gain important process skills. For more information about the Next Generation Science Standards, please visit http://www.nextgenscience.org/.

Starting in the fall of 2013, the Vermont Agency of Education launched a plan that will lead to the implementation of NGSS in 2016-2017. The first phase, during the 2013-2014 school year, focused on raising teachers' awareness of NGSS with an emphasis on Science and Engineering Practices. The Vermont Agency of Education has created a website called *Vermont Education Exchange* that includes a section on NGSS (http://ve2.vermont.gov/vt_science/n_g_s_s).

The Stream Table Lesson Packet represents a powerful way to address many parts of NGSS and offers a taste of NGSS before teachers are asked to align their curricula to these new standards. This lesson packet strongly emphasizes certain components of the three NGSS dimensions (Figure 2). Please note that many other NGSS components can also be addressed by this lesson packet, but we chose a subset that we believe fits especially well.

Figure 2. NGSS Dimensions & Stream Table Education

Science and Engineering Practices	Disciplinary Core Ideas (DCI)	Cross-Cutting Concepts
• Asking questions and defining problems • Developing and using models • Planning and carrying out investigations • Analyzing and interpreting data • Constructing explanations and designing solutions	• ESS2.A. Earth Materials and Systems • ESS2.C. The Roles of Water in Earth's Surface Processes • ESS3.C. Human Impacts on Earth Systems • ETS1.B. Developing Possible Solutions	• Patterns • Cause and Effect • Stability and Change • Systems and System Models • Influence of Engineering, Technology, and Science on Society and the Natural World

Figure 3 below includes two Disciplinary Core Ideas (ESS2.A and ESS3.C.) and examples of Performance Expectations for grades 4, 5, and grades 6-8 (middle school) connected to each of these DCIs. The Student Activity Sheets included in this lesson packet can be used to assess student learning and gauge achievement of the NGSS standards identified here.

For more information about the *Next Generation Science Standards*, the *Framework for K-12 Science Education*, and the work of the Vermont Agency of Education, please contact:

Kathy Renfrew
Grade K-5 science and math assessment coordinator
Vermont Agency of Education
kathy.renfrew@state.vt.us; (802) 828-6561

Gail Hall
Grade 6-12 science and math assessment coordinator
Vermont Agency of Education
gail.hall@state.vt.us; (802) 828-0156

Figure 3. Performance Expectations Addressed by Stream Table Education		
Grade-Level Performance Expectations (examples)	Disciplinary Core Ideas	
	ESS2.A. Earth Materials and Systems	ESS3.C. Human Impacts on Earth Systems
4th Grade	4-ESS2-1. **Make observations and/or measurements to provide evidence of the effects of weathering or the rate of erosion by water, ice, wind, or vegetation.** [Clarification Statement: Examples of variables to test could include angle of slope in the downhill movement of water, amount of vegetation, speed of wind, relative rate of deposition, cycles of freezing and thawing of water, cycles of heating and cooling, and volume of water flow.] [*Assessment Boundary: Assessment is limited to a single form of weathering or erosion.*]	4-ESS3-2. **Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans*** [Clarification Statement: Examples of solutions could include designing an earthquake resistant building and improving monitoring of volcanic activity.] [*Assessment Boundary: Assessment is limited to earthquakes, floods, tsunamis, and volcanic eruptions.*]
5th Grade	5-ESS2-1 **Develop a model using an example to describe ways the geosphere, biosphere, hydrosphere, and/or atmosphere interact.** [Clarification Statement: Examples could include the influence of the ocean on ecosystems, landform shape, and climate; the influence of the atmosphere on landforms and ecosystems through weather and climate; and the influence of mountain ranges on winds and clouds in the atmosphere. The geosphere, hydrosphere, atmosphere, and biosphere are each a system.] [*Assessment Boundary: Assessment is limited to the interactions of two systems at a time.*]	5-ESS3-1. **Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.**
Middle School (6th – 8th Grades)	MS-ESS2-2. **Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.** [Clarification Statement: Emphasis is on how processes change Earth's surface at time and spatial scales that can be large (such as slow plate motions or the uplift of large mountain ranges) or small (such as rapid landslides or microscopic geochemical reactions), and how many geoscience processes (such as earthquakes, volcanoes, and meteor impacts) usually behave gradually but are punctuated by catastrophic events. Examples of geoscience processes include surface weathering and deposition by the movements of water, ice, and wind. Emphasis is on geoscience processes that shape local geographic features, where appropriate.]	MS-ESS3-2. **Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.** [Clarification Statement: Emphasis is on how some natural hazards, such as volcanic eruptions and severe weather, are preceded by phenomena that allow for reliable predictions, but others, such as earthquakes, occur suddenly and with no notice, and thus are not yet predictable. Examples of natural hazards can be taken from interior processes (such as earthquakes and volcanic eruptions), surface processes (such as mass wasting and tsunamis), or severe weather events (such as hurricanes, tornadoes, and floods). Examples of data can include the locations, magnitudes, and frequencies of the natural hazards. Examples of technologies can be global (such as satellite systems to monitor hurricanes or forest fires) or local (such as building basements in tornado-prone regions or reservoirs to mitigate droughts).]

Before the Stream Table Arrives: Streams & Watersheds Lesson

Background

Every stream is the product of water flowing downhill and collecting in channels on the landscape. Raindrops that fall on high points of land course down the slope and join other drops of water, forming small brooks that continue to flow downward. One brook eventually joins other brooks, creating a stream. Streams join other streams to form a river, and so on down the slope until the gathering waters collect in the lowest valley. Eventually, this river system flows out of its "mouth" into the ocean. At every step in this process, water evaporates back into rain clouds, powering a continuous water cycle.

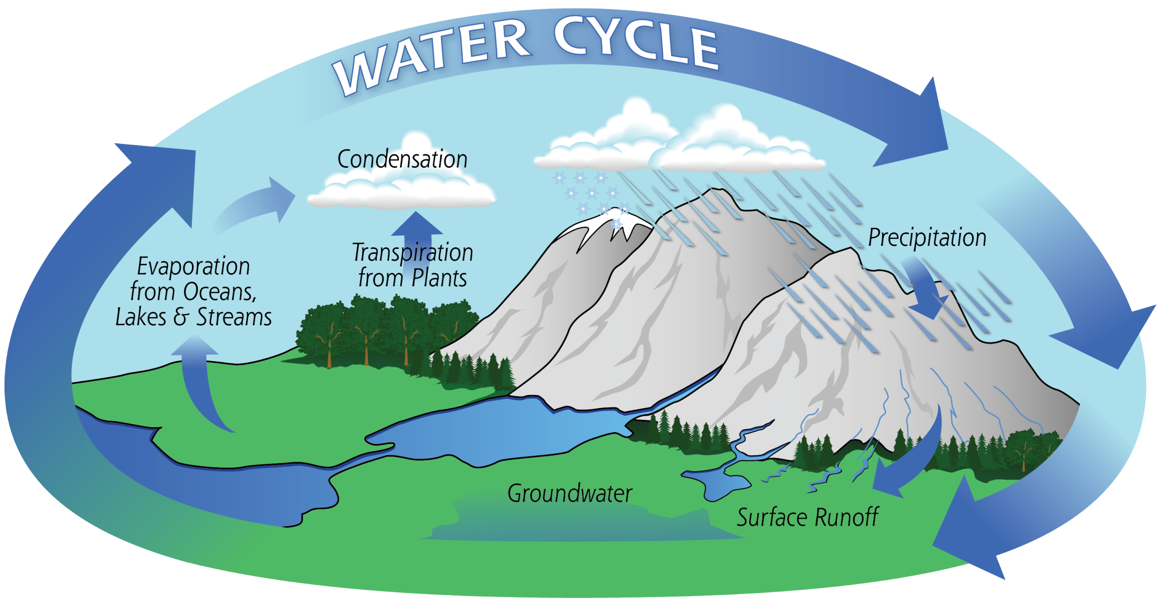


Figure 4. The Water (Hydrologic) Cycle.
(From the National Aeronautics and Space Administration's (NOAA) Precipitation Education Program: http://pmm.nasa.gov/education/water-cycle)

A basin of land that drains into a river system is called a *watershed.* The brooks and streams that form at high elevations comprise the *headwaters* of the watershed. They come together to create *tributaries*, which flow into the *mainstem* (the largest river at the lowest elevation in the watershed).

As these waters flow from top to bottom, they interact with landscape features, soils, and plant communities. The natural physical, chemical, and biological conditions along the river system go through a series of predictable changes that, collectively, are called the *river continuum concept*. Figure 5 below gives a summary of certain physical conditions of a typical river system and how they tend to change from the headwaters to the tributaries to the mainstem. Of course, human activities in the watershed often alter natural conditions.

Figure 5. Changing Physical Conditions Along the River Continuum (Please note: These are general conditions only; each stream is unique)			
Conditions	**headwaters**	**tributaries**	**mainstem**
Gradient (slope)	Steep	Moderate	Low / flat
Water velocity (speed)	Fast to moderate	Moderate to slow	Slow
streambed	Rocks	Rocks, gravel, and/or sand	Sand and/or silt
Channel width	Narrow	Moderate	Wide
Sinuosity (degree of meandering) *This assumes that the channel has not been straightened by humans*	None (straight channel) to narrow meanders	Narrow, moderate, or wide meanders	Moderate to wide meanders
Water temperature	Cold	Cool	Cool to relatively warm

Please note: The stream table represents one slice of a watershed and one section of a mainstem; it does not include the whole imaginary watershed in which this model stream flows, or any tributaries flowing into the mainstem on the table.

More Info:
Living in Harmony with Streams booklet, page 8.

♦ ♦ ♦ ♦ ♦ ♦ ♦ ♦ ♦ ♦

ACTIVITY INSTRUCTIONS

MATERIALS

- Basin 10 Map of the Ottauquechee River and Black River (in APPENDICES)
- An atlas or road map that includes the students' town and school
- an illustration of the hydrologic (water) cycle – see Figure 4 above or find another one

SET-UP

- none

Introduce students to the definition of a watershed (see GLOSSARY). Show them the Ottauquechee River and Black River watersheds on the Basin 10 map (in APPENDICES). If you are in a different watershed, find a map of your watershed or river system.

Explain that every *river system* drains a basin of land, from the highest elevations (the "rim" of the basin) to the lowest valley. A river system flows out its "mouth" into another river, a pond, a lake, a wetland, or the ocean.

Have students find the location of their town on the watershed map, as well as their school, and their homes (if, in fact, their school and homes are within this watershed). When water leaves their river system, where does it go? (into the Connecticut River). Where does the water go after that? (into the Atlantic Ocean). Explain that water in any watershed is part of the hydrologic cycle, which continuously circulates water through our atmosphere and our earth's crust.

Lesson 1. Corridors and Channels

Background

Flowing water carries energy as it courses across a landscape. This energy, and the water's natural "corkscrew" motion, erode a *channel* through the landscape and often create bends called *meanders*. (You can see the same meandering motion as you watch a water drop move down your car's windshield: it twists from side to side rather than running straight down.) The stream continually carves into the bends, making them more pronounced over time. This process adds length to the stream, thus making the stream's slope more gradual. This slows down the water. As flowing water hits the bends, it loses some of its energy and is further slowed. In this way, meanders help to absorb the force of the stream moving through the landscape.

A skier making turns down a snowy slope models a stream's meander pattern. As the skier turns to the left, her outer (right) ski travels a bit further and moves faster, pushing forcefully against the snow and carving into the outside of the curve. The inner (left) ski moves slower and carries less force. As the skier moves from one turn to the next, her skis move at equal speeds, producing less overall pressure on the snow. As she turns from side to side, she slows down, transfers some of her energy into the slope, and lengthens her route down the mountain.

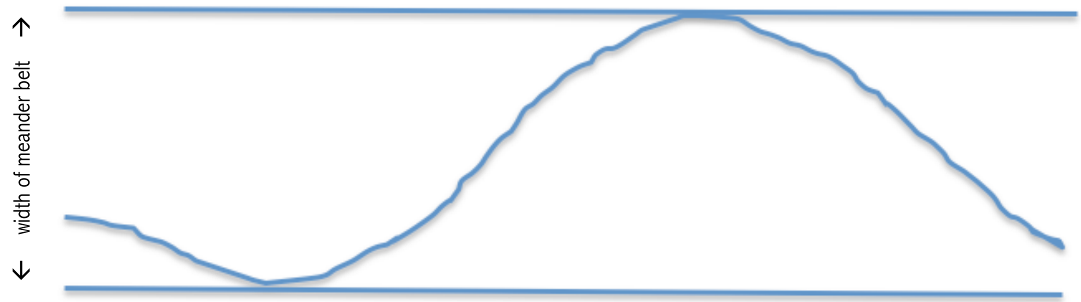
A stream's meanders can change over time, depending on many factors. A big storm can cause significant movement, as seen in the aftermath of Tropical Storm Irene in August 2011. A stream channel meanders within a broader *corridor*, which is defined as follows by the Vermont Agency of Natural Resources:

> River corridors consist of lands adjacent to and including the present channel of a river. River corridor delineations are based primarily on the lateral [side to side] extent of stable meanders . . . and a wooded *riparian buffer* to provide streambank stability. (From The Vermont River Corridor Protection Guide).

Many natural forces alter the river and cause it to move, so we say that it is *dynamic*. It tries to maintain a balance of water and sediment to equalize its energy; we call this balance equilibrium. A river in its natural state is said to be in *dynamic equilibrium* (see GLOSSARY). If a river has been disturbed by natural events or degraded by human activities, it will erode its banks and/or streambed and deposit suspended sediments when the water slows down in order to regain dynamic equilibrium. Often, this results in a changed meander pattern.

Figure 6. Meander Belt

The side-to-side (lateral) extent of stable meanders in a stream.



Each meander in a stream has a similar profile in cross-section. The inner bend has slower water and a gradual slope, while the outer bend has faster water and a steeper slope. Sometimes a *point bar* of deposits forms within the inner bend. The erosive force of the water gouging the outer bend often forms a steep or concave *cut bank.* The table in Figure 7 summarizes the physical conditions found in each location.

The stream table models an *alluvial* stream, which erodes and deposits sediments, forming meanders in the process. Please note that not all streams form meanders. For example, mountain (non-alluvial) streams tend to drop straight down steep gradients. They dissipate their energy as they flow across rough, rocky beds and over cascades and falls.

Figure 7. Comparing an Inner Bend and an Outer Bend

(in cross-section)

Inner Bend (depositing)

- slow velocity – drops sediments from upstream; often forms a *point bar*
- gradual slope
- shallow water
- smaller particles of sediment on bottom

Outer Bend (eroding/scouring)

- fast velocity – carries sediments from upstream and erodes more sediments from the bend
- steep, sometimes concave (undercut) slope
- deep water
- coarser particles of sediment on bottom

More Info:
Living in Harmony with Streams booklet, page 10 - 11
Little River Research and Design Educational Videos: http://www.emriver.com/?page_id=1521

- Emriver straight channel simulation
- Grand River remeandering, 1939-1996
- Grand River remeandering comparison

After the Flood videos:
http://www.youtube.com/watch?v=Wx7EQAY8CuA&list=PLX5V6zW7pAiYEC3bIrK3ymOegGrPwg0xT

- Video 1: Staci Pomeroy using stream table; starting at 4:08 minutes
- Video 1: straightening a stream; starting at 8:13 minutes
- Video 2: river corridor; starting at 5:50 minutes
- Video 2: urban areas, mitigating flood damage, and berms; starting at 9:09 minutes
- Video 3: straightening a river; starting at 6:38 minutes

ACTIVITY INSTRUCTIONS

MATERIALS

Items with stream table

- stream table
- toy houses

Items you supply

- student science notebooks, or sheets of paper on clipboards
- pencils
- camera
- clock
- small sticks or popsicle sticks
- STREAM ANATOMY PARTS STUDENT ACTIVITY SHEET (below)

SET-UP

- Get the stream table ready to run.
- Make Stream Anatomy Part signs (Student Activity Sheet)

TIMEFRAME

60 minutes

Lesson 1.1. -- Why Meanders Form

Give each student a science notebook or a sheet of paper on a clipboard, and a pencil. Create a straight channel from top to bottom on the stream table. Ask students to observe what happens as you turn on the water and let it flow for a few minutes. Ask them to write down 3 of their observations. They will see bends (meanders) form along the channel. Why does this happen?

(Flowing water moves in a corkscrew pattern, which eats into the channel and begins to form bends. As the flowing water scours the outer bend, it further erodes it, causing the bend to become more pronounced.)

Discuss student observations and explain that most (but not all) streams and rivers naturally form meanders as they flow over the landscape.

Lesson 1.2. – The Changing Channel

Turn off the water on the stream table. Create a straight channel down the stream table, and have students place sticks along the channel on both sides to define the width and path of the channel. Have students take a photo of the channel. Ask them to predict where it is safe to build houses along the stream, and have them place some toy houses on those spots.

Run the water and have students take a photo every 5 minutes for about 30 minutes. Occasionally, turn up the volume of water to model a heavy rainstorm.

After 30 minutes, discuss what happened. Did the stream behave as they predicted it would? Did any houses get dangerously close to the stream, or even fall into the stream? Ask them to explain what happened and why.

Lesson 1.3. – Stream Anatomy

After the stream table has run for a little while and nice meanders have formed, tell students that they will learn about the "anatomy" of a stream. Hand out a STREAM ANATOMY PART sign to each student. Taking turns, have each student read his/her sign and place the sign in an appropriate spot on the stream table. Clarify any confusion over terms and definitions.

Ask students to write some new observations in their science notebooks using the vocabulary they just learned. This gives them a chance to practice the new vocabulary and sharpens their observation skills.

LESSON 1.3. STREAM ANATOMY PARTS

Student Activity Sheet
Emriver Em2 Geomodel (stream table)

Directions: Laminate this sheet (so it can get wet on the stream table). Cut out the cards and tape each one to a stick. Discuss each term with the students and have them post each "sign" in an appropriate place in the stream table.

Bank The land along a stream, between the water and the upland areas.	**Point Bar** A low, curved bank of sediment along the *inner bend* of a meander. (It points to the *outer bend*.)
Cut bank An eroded, concave bank formed on the *outer bend* of a stream by the flow of water around the bend.	**Riparian Area** The vegetated areas along a stream.
Stream Channel An area between streambanks that contains or used to contain flowing water, and the floodplain along the stream.	**Streambed** The bottom of a stream channel that is covered by water.
Headwaters The high-elevation places from which the water in a stream originates.	**Mouth** The place where a stream empties into another body of water.
Groundwater Water that collects underground and sometimes flows beneath the surface.	**Surface Water** Water that is visible on the Earth's surface (lakes, streams, oceans, etc.)
Meander A winding curve or bend of a stream.	**Flood Plain** A strip of flat land along a stream that receives the overflow of floodwaters.

Lesson 2. Marble Races

Background

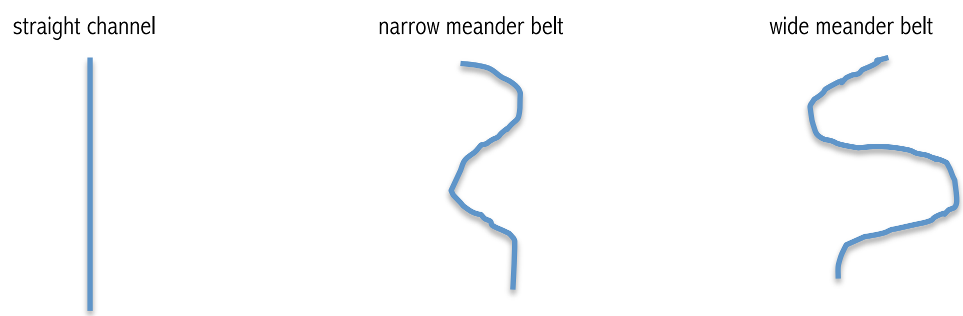
See also the *Background on meanders in Lesson 1. Corridors and Channels.*

A stream carves meanders to help establish an energy balance and maintain it over time. The width of the stream's winding path, from outside bend on one side to outside bend on the other, is called the *meander belt* of the stream. Often, the meanders become more pronounced as the stream carves more deeply into its bends. When this happens, the meander belt gets wider. A stream's meanders tend to migrate downstream over time. This is because the flowing water in the stream hits the downstream end of a meander with more force than the upstream end of the meander. This force carves into the downstream end, causing the meander to "move" downstream.

A meandering route down a slope covers more distance than a straight line, just as a skier covers more distance when she makes turns rather than skiing straight down. To control her speed, the skier makes use of the greater degree of friction that occurs when she turns side to side. Water snaking around meanders in a stream is also subject to more friction, which slows down the water. The meanders also reduce the steepness of the slope, further slowing the water.

Figure 8. Meander Belts & Channel Length

These stream channels start and end at the same place on the landscape. The straight channel is 100 feet long, the narrow meandering channel is 125 feet long, and the wide meandering channel is 200 feet long.



When meanders lengthen a stream and make the channel less steep, we say that the slope decreases. *Slope* (see Glossary) is determined by "rise over run," or how much the elevation drops over a given distance. A four-foot drop over 100 feet creates a 4% slope.

If we assume that the elevation at the "start" of each stream in Figure 8 is 4 feet higher than the "end" of each stream, then the *rise* is 4 feet for each stream. The *run* for each channel (straight, narrow meander, wide meander) is 100 feet, 125 feet, and 200 feet respectively. Given this information, we can calculate the *slope* for each channel as follows:

- straight channel = 4 feet / 100 feet = 4%
- narrow meander channel = 4 feet / 125 feet = 3.2%
- wide meander channel = 4 feet / 200 feet = 2%

Over time, or as a result of a severe storm, the channel often moves sideways within the stream *corridor* (see GLOSSARY). Because of this dynamic, the stream is likely to be someplace else within the corridor sometime in the future.

When the stream is swollen with floodwaters, it eventually rises over its banks and spills onto its floodplain. If the water cannot reach the floodplain due to retaining walls, berms, or some other obstacle, it will cut deeply into its banks and/or into the streambed, causing severe erosion and sedimentation downstream. Straightening a stream removes its meanders, making the water flow faster and stronger, disrupting the stream's natural equilibrium, and causing more erosion.

ACTIVITY INSTRUCTIONS

MATERIALS	SET-UP
Items with stream table • stream table • Channel Board-A, with Straight Channel-1, (48" long) and Meandering Channel-2 (60" long) • Channel Board-B, with Straight Channel-3 (60" long) • Riser Board • Run-Out Channel Board • jar of assorted glass marbles	• Sketch the inner bend-outer bend diagram (see above) on the board.
Items you supply • student science notebooks, or sheet of paper on clipboards • pencils • timers - 2 • long piece of string • flexible tape measure • MEANDERS & VELOCITY STUDENT ACTIVITY SHEET (in Lesson Packet)	**TIMEFRAME** 60 – 75 minutes

Lesson 2.1. – Meanders and Velocity

Show students Channel Board-A, with one straight channel and one meandering channel. Explain that the class will hold marble races to see which channel delivers its marble faster. Choose students to perform these 6 roles:

a. starter (one student)

b. marble releasers (two students, one for each marble)

c. marble catchers (two students, one for each marble)

d. timers (two students, one for each marble)

Give each student a copy of LESSON 2.1. MEANDERS & VELOCITY STUDENT ACTIVITY SHEET and review the sheet together. It follows the scientific method to explore the dynamics of slope, mass, and velocity in streams using 3 Questions. After students have investigated these 3 Questions, you may want to challenge them to generate new questions and design experiments to test them. The LESSON 2.2. CREATE-YOUR-OWN-MEANDERS & VELOCITY EXPERIMENT STUDENT ACTIVITY SHEET is provided for this follow-up activity.

Have the **starter**, **releasers**, **catchers**, and **timers** get into position. The releasers hold their marbles at the top of their channels. The catchers and timers get ready at the bottom of the channels. When the starter says “Go!,” both releasers release at the same time. Timers stop their clocks when the marble exits the channel, and catchers catch their marbles.

While the races are going on, have students without specific roles complete the activity sheet. You may want to rotate the roles to share the fun across the class.

Have students complete the MEANDERS & VELOCITY STUDENT ACTIVITY SHEET (below).

Extension Activity:

To complete the MEANDERS & VELOCITY sheet, students must draw conclusions to explain their results. They may be left with questions that they could not answer through this experiment.

Ask students to choose a question that they could “test” through further experimentation. Then ask them to brainstorm some hypotheses (proposed explanations) that could answer their question.

As a class, choose one hypothesis, have students design an experiment to test it, run the experiment, gather results, and analyze the results. Then ask students to review their hypothesis and draw conclusions. Was their hypothesis supported? If not, do they have a new hypothesis that might explain it? What can they conclude about what happened during their experiment, and how this “model” can help them to understand the real world?

This process – which starts with a question that is investigated and leads to more questions that are investigated in turn – reflects the process of scientific inquiry. As researchers spiral through the process, they gain more understanding and build more knowledge about the world. This is how scientific information is generated and refined over time.

LESSON 2.1.A. MEANDERS & VELOCITY EXPERIMENTS

Student Activity Sheet
Emriver Em2 Geomodel (stream table)

Name: ____ Date: _______

Questions, Hypotheses, Experiments, Results

1st Question: What would happen if you raced…

- a small marble down the 48” straight channel, and
- a small marble down the 60” meandering channel?

Hypothesis: I predict: ____

I think this because: ____

Experiment: Run the race

Data Collection	small marble 48” straight channel	small marble 60” meandering channel
Trial 1 - Time (in seconds)		
Trial 2 – Time (in seconds)		
Average Time (in seconds)		

Results: ____

____

2nd Question: What would happen if you raced …

- a large marble down the 48” straight channel, and
- a large marble down the 60” meandering channel?

Hypothesis: I predict: ____

I think this because: ____

Experiment: Run the race

Data Collection	large marble 48” straight channel	large marble 60” meandering channel
Trial 1 - Time (in seconds)		
Trial 2 – Time (in seconds)		
Average Time (in seconds)		

Results: ____

____

3rd Question: What would happen if you raced …

- a small marble down the 48” straight channel, and
- a small marble down the 60” straight channel?

Note: For this experiment, you'll need both Channel Boards, A and B

Hypothesis: I predict: ____

I think this because: ____

Experiment: Run the race

Data Collection	small marble 48” straight channel	small marble 60” straight channel
Trial 1 - Time (in seconds)		
Trial 2 – Time (in seconds)		
Average Time (in seconds)		

Results: ____

____

Conclusions

Review your predictions, data, and results for each race. What do you know now that you didn't know before these experiments?

What can you conclude about different sizes of marbles in straight and meandering channels? Think about *velocity* (speed) of the marbles and the *mass* (size and weight) of the marbles.

____

____

____

____

New question? ____

____

LESSON 2.1.B. CREATE-YOUR-OWN MEANDERS & VELOCITY EXPERIMENT

Student Activity Sheet
Emriver Em2 Geomodel (stream table)

Name: ____ Date: ________

Question, Hypothesis, Investigation, Results

Question: What would happen if you raced…

- ____ and
- ____?

Hypothesis: I predict: ____

I think this because: ____

Experiment: Run the race

Data Collection	________________ ________________	________________ ________________
Trial 1 - Time (in seconds)		
Trial 2 – Time (in seconds)		
Average Time (in seconds)		

Results: ____

____

Conclusions

Review your prediction, data, and results for your race. What do you know now that you didn't know before these experiments?

What can you conclude?

____

____

____

____

Lesson 2.2. – Thalweg & Riffles

When a marble travels down the meandering channel, where within the channel does it travel? Does it move down the middle of the channel, or does its course vary?

Choose the smallest marble and ask students to carefully watch its course as it travels down the meandering channel. Have them write their observations in their notebooks. Then discuss. Students should notice two things:

1. ***The marble hits the outer bend of each meander.*** (The same thing happens with real water in a channel. The force of the water hitting the bank digs into the bank, making the outer bend sharper and deeper.) The marble traces the *thalweg,* which is the deepest part of the channel. (Every meandering stream has a thalweg.)
2. ***The marble travels across the channel as it moves from meander to meander.*** (Remember our skier carving turns down the hill. Her skis hit "outer bends" during each turn and, in between turns, she crosses over her "channel." In a stream, shallow *riffles* tend to form between meanders, where the erosive force of the water is reduced and therefore less erosion of the streambed occurs.)

Students may notice that the marble hits the downstream part of the outer bend. The stream acts similarly, eroding the downstream end of the outer bank, causing the whole meander pattern to move downstream over time.

Lesson 2.3. – Length & Slope

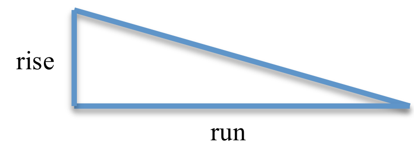
1. Ask students: If you straightened out **Meandering Channel-2**, how long would it be? Have students lay a piece of string along Meandering Channel-2, then measure the length of this string (60"). Have them also measure the length of Straight Channel-1 (48"). Even though both channels occupy the same landscape, the meandering channel is actually longer.
2. Show students **Straight Channel-3 on Channel Board-B**, which represents Meandering Channel-2 straightened out (60"). Lay Channel Board-B next to Channel Board-A and prop both of them on the Riser Board so that they are at the same elevation.
3. Have students compare the slope (the amount of drop in elevation) of the two straight channels from the highest ends to the lowest ends. Which one is steeper? How might slope affect water velocity and its erosive force?

    (Straight Channel-1 is steeper than Straight Channel-3. Meanders lengthen a stream, which makes it flatter. This slows down the water, reducing its erosive force. The water's force is further reduced when it hits each bend in the meandering channel. The same thing happens when you turn while skiing: each turn you take slows you down and reduces the force that you carry downhill by lengthening your route and making your descent less steep.)

4. Determine the slope of each of the channels using this formula:

slope = rise / run

(divide the rise by the run)



Remember, the *run* of Straight Channel 1 is 48” and the *run* of Straight Channel 3 is 60”. The Riser Board (*rise*) for each channel is 2.4”.

So, the % of angle (<u>not</u> degree) for Straight Channel 1 is:

2.4” / 48” = 5%

And the % of angle (<u>not</u> degree) for Straight Channel 2 is:

2.4” / 60” = 4%

5. Have students discussed their results.

- Which channel board has the steeper slope? (1; at 5%, it’s steeper than 3, at 4%).
- Which channel would have greater velocity? (1)
- Which channel carries more force and causes more erosion? (1; greater velocity means more force and more erosive power)

Extension Activities for Marble Races: see APPENDICES

LESSON 3. WATER & SEDIMENTS

BACKGROUND

A stream always moves more than water. Its flow carries suspended particles of soil as well as dissolved substances. Erosion of the stream banks and streambed cause more soil particles to become mobilized in the flow. They are carried along and drop to the streambed when water velocity slows down enough to lose its ability to keep them suspended. Some particles are neither carried nor dropped, but get pushed or bounced along the streambed through a process called saltation. Deposited particles are called *sediments,* which can be minuscule (silt particles) to very large (boulders).

When water velocity increases again, either because of increased volume or because the slope becomes steeper, the water can pick up sediments, suspend them in the water column, and transport them downstream within the stream corridor. During very high floods, these sediments can get carried up onto the floodplain and deposited in locations that are separate from the typical stream channel.

People also move stream sediments. This is done to straighten a channel, to collect gravel for construction, or to deepen a channel to "make room" for floodwaters. Ironically, removing sediments from a stream can create unstable conditions and increase flood damage, which can lead to further change in the stream channel as the stream seeks to reestablish balance. Here are two hypothetical examples of gravel removal (cause) and the stream's response (effect):

Example 1: Deepening the Channel to Make More Room

1. A community dredges a stream channel, lowering the streambed, so it can hold more water during a flood.
2. A huge rainstorm occurs, during which a slug of water enters the channel.
3. The water in the stream rises rapidly, but is contained within the banks because the streambed is now lower. The stream cannot overflow its banks and spill out over its floodplain, which would have absorbed both the larger volume of water and the increased energy created by rapidly moving water.
4. The energy of the high, fast water eats away at the banks, making them unstable and susceptible to collapse.
5. The swollen stream (which includes both water and eroded soil particles) barrels downstream at high velocity, hits a bend in the stream, bites into the bank, and takes out the road at that bend.

Example 2: Mining Gravel for Construction Material *(see Figure 9 below)*

1. A landowner removes gravel from the streambed and sells it to a construction company. This creates a hole in the streambed. The slopes around the hole are steeper than the slope of the adjacent streambed.
2. When flowing water tips into the hole at the upstream end, it falls down the steep slope, picks up speed (becoming "hungry" for sediment), and erodes the streambed along that steep slope.
3. Sediments continue to erode off the upstream slope, causing a *headcut* to work its way

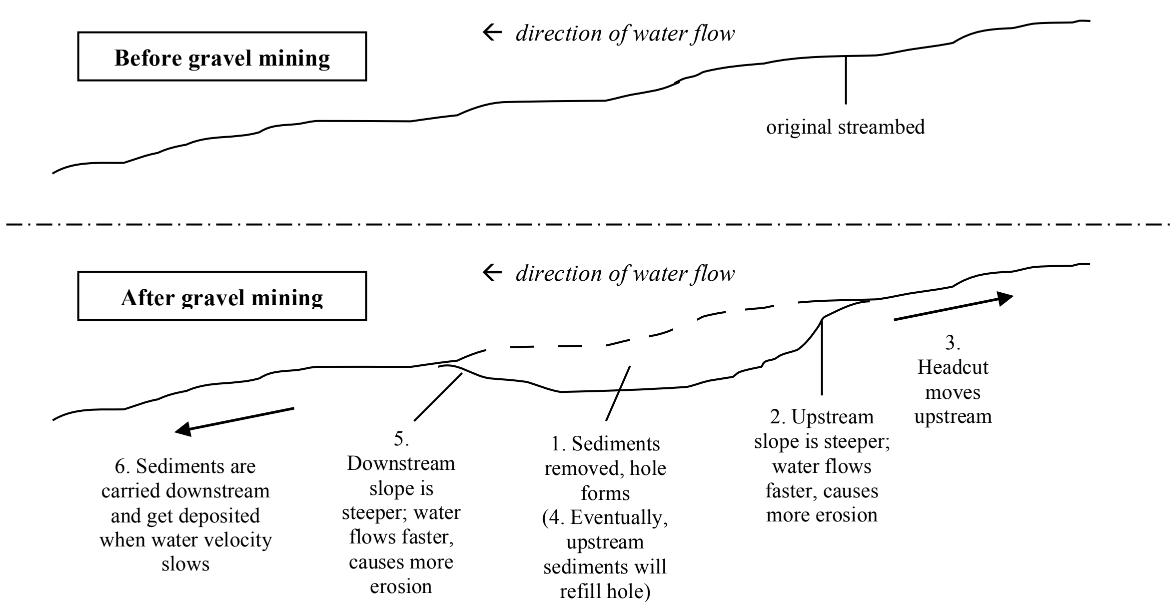
upstream (see ***More Info:*** Little River video on in-channel gravel mining). This causes high, steep, unstable banks to form below the headcut.

4. The sediments that are scoured off the upstream slope of the hole flow over the hole, where the water slows down and drops its load. (Eventually, these sediments will fill the hole.)
5. The flowing water is then forced up the slope at the downstream end of the hole, where it picks up speed again (becoming "hungry") and erodes the sediment on that downstream slope.
6. Once beyond the hole, the water tends to slow down again and drop its load of sediments, causing deposition downstream of the hole.
7. Another flood occurs, which bites into the unstable banks, causing them to collapse.

Recognizing the negative impacts that often result when stream sediments are removed, the state of Vermont banned commercial gravel mining and in-stream gravel dredging in 1987. Gravel removal is sometimes allowed where excess sediments pose a problem for human activities. For instance, the state of Vermont temporarily lifted the ban on gravel removal after Tropical Storm Irene occurred to allow people to deal with erosion and sediment damage. But sediment removal after Irene caused serious damage to some streams, so the state passed new rules to minimize future impacts.

Figure 9. Cross-section of a streambed before and after gravel mining

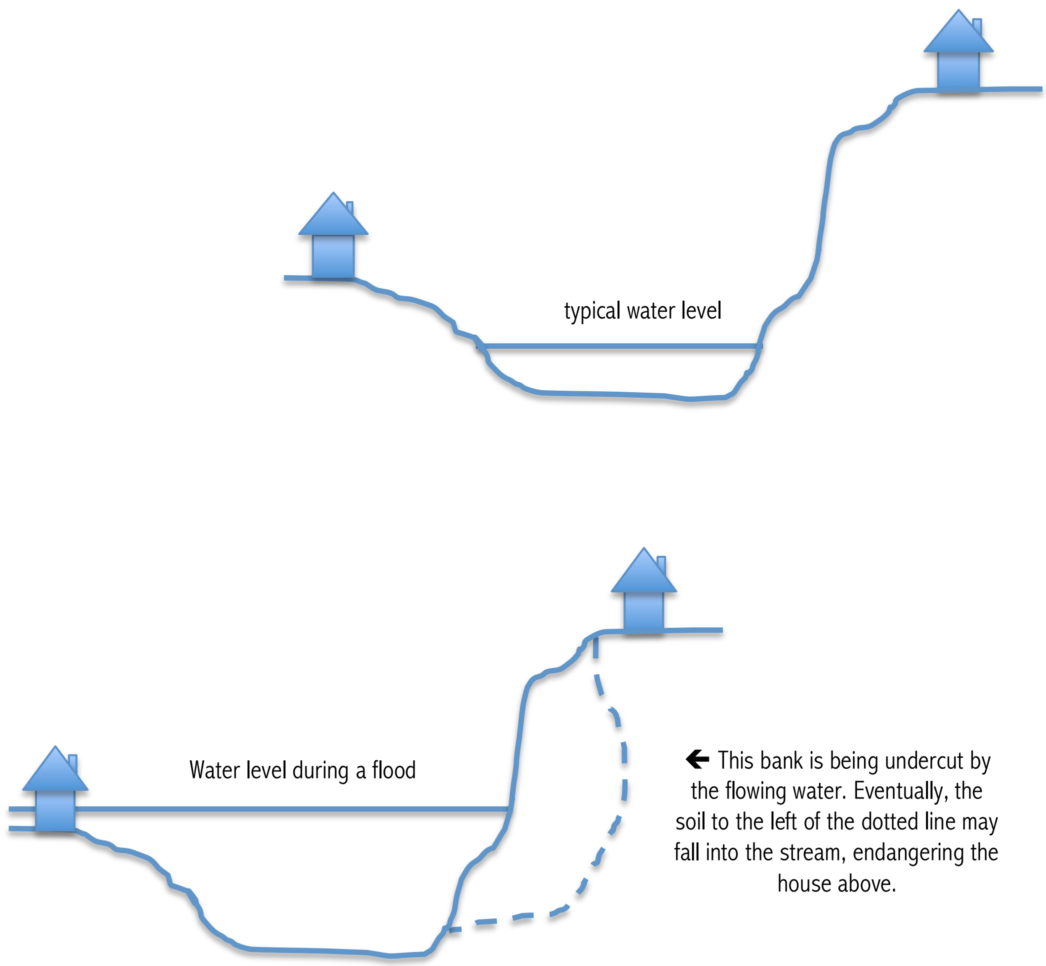
(Note: Numbers in the "After gravel mining" section refer to the steps in Example 2 above.)



Human-built structures that occur within a stream's *corridor* (see GLOSSARY) are often damaged during floods. We anticipate that structures located on floodplains will periodically experience flooding, but even structures that are high above the floodwaters can suffer flood damage. This occurs when a high bank gets undercut by fast-flowing, swollen waters. During Tropical Storm Irene in 2011, bank failure caused many houses on high banks to get ripped apart, and some even fell into the valley below (see Figure 10 below).

Figure 10. Houses on a Low Bank versus a High Bank

a. The house on the low bank below is within the floodplain while the house on the high bank is far above floodwaters.



b. During a flood, there is plenty of room for the stream's swollen flow to move to the left and flood the low bank, but almost no room for it to move to the right. The house on the left bank is surrounded by water while the house on the right bank remains dry. But the force of repeated floodwaters can eat away at the high bank, eroding it and eventually causing *bank failure.* Thus the house on the high bank is in danger of toppling into the stream.

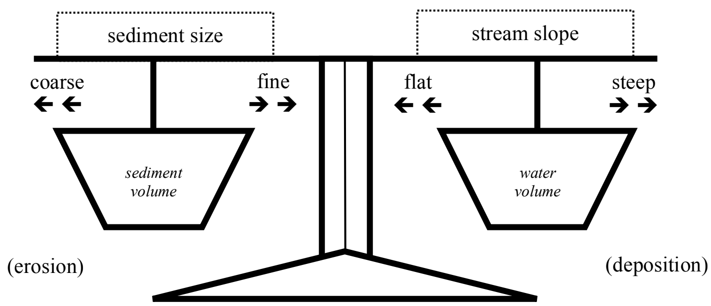
Lane's Balance (see Figure 11 below) is a model that shows how a stream balances the relationship between water flow and sediment transport to maintain or regain equilibrium. It can help us to understand cause and effect in a stream. This model incorporates 4 variables in a typical old-fashioned scale:

- amount of moving water
- slope (gradient) of the streambed
- amount of sediment
- size of sediment particles

If one of these variables changes, one or more of the other variables must change to regain balance in the river system.

We suggest that you play with the Lane's Balance included with the stream table before introducing it to your students to understand the relationships between these 4 variables.

Figure 11. Lane's Balance



More info:
Living in Harmony with Streams booklet, page 14 and page 19
After the Flood Videos
http://www.youtube.com/watch?v=Wx7EQAY8CuA&list=PLX5V6zW7pAiYEC3bIrK3ymOegGrPwg0xT

- Video 1: floodplain, headcut; starting at 5:53
- Video 1: high banks; starting at 8:53
- Video 3: recovering from flood damage; starting at 6:38
- Video 3: traditional river management and dredging; starting at 10:15

Little River Research and Design, Educational Videos, Inchannel gravel mining
http://www.emriver.com/?page_id=1521

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Activity Instructions

MATERIALS	SET-UP
Items with stream table • Lane's Balance model **Items you supply** • none	• View this video: *Inchannel gravel mining and bar pit capture* (http://www.emriver.com/?page_id=1521, bottom of page); shows *headcut* and other erosion conditions. • Practice using your hand as a backhoe and scoop out some sediment in the stream table's channel, watching the result. Look for a *headcut* to form. This is the effect that you want for this activity. • Watch this video: Steve Nelle explaining Lane's Balance (http://www.youtube.com/watch?v=Js7wDZE4I7o) • Refer to Figure 11 above for an illustration of a simple Lane's Balance. • Put together the Lane's Balance from stream table supplies; place the buckets in the same position along each arm and make sure that the arms are balanced.
	TIMEFRAME 60 minutes

Lesson 3.1. - Gravel Mining

Run the water in the stream table and allow meanders to form. Discuss gravel mining with students and ask them to imagine that your hand is a backhoe. When you scoop out some sediment, what will happen to:

- the water velocity?
- the streambed?
- the banks of the stream?
- the area downstream of the dredged area?

Ask them to write their predictions in their science notebooks.

- Now use your "backhoe" (hand) to scoop out sediments and have students observe the effects. Discuss the reasons why the stream adjusts as it does. (see BACKGROUND above).

Lesson 3.2. - High Banks & Low Banks *(see Figure 10 above)*

On the stream table, build a channel section with very high vertical banks and another channel section with low banks. Place a house on each, the same distance from the channel. Run a "storm event" (high water volume) and see what happens to each bank, and the house on each bank.

Here are some probable scenarios:

- The steep bank erodes and becomes unstable. It eventually collapses, taking the house with it.
- Water along the low bank surges up the bank and spreads out over the floodplain around the house, where it loses its velocity and force.
- The low house floods, but the land around it doesn't erode as much as the land under the high bank house.

Lesson 3.3 – Lane's Balance Scenarios *(most appropriate with older students)*

Introduce students to Lane's Balance (Figure 10 above), which is a model that shows the relationships between water, slope, and sediments in a stream.

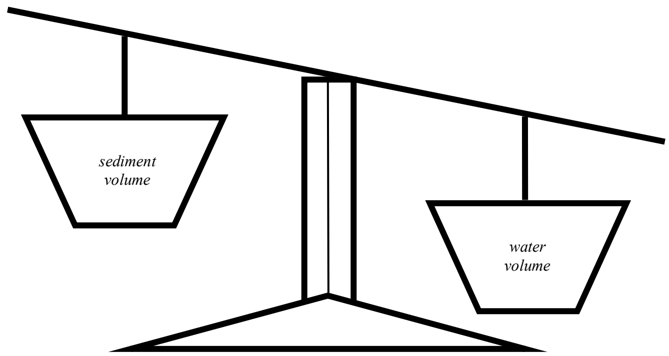
Hand out the LANE'S BALANCE SCENARIOS STUDENT ACTIVITY SHEET and discuss each scenario with the class. Once students understand how the stream "rebalances" itself in each scenario, ask them to describe it in writing. Then ask for volunteers to read their answers to the class, and clarify any confusing concepts.

LESSON 3.3. LANE'S BALANCE SCENARIOS

Student Activity Sheet
Emriver Em2 Geomodel (stream table)

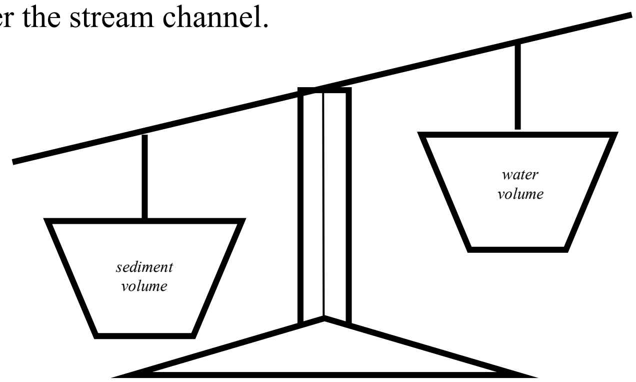
Name ____ **Date** ____________

1. It rains heavily all day and <u>*more water*</u> enters the stream channel.



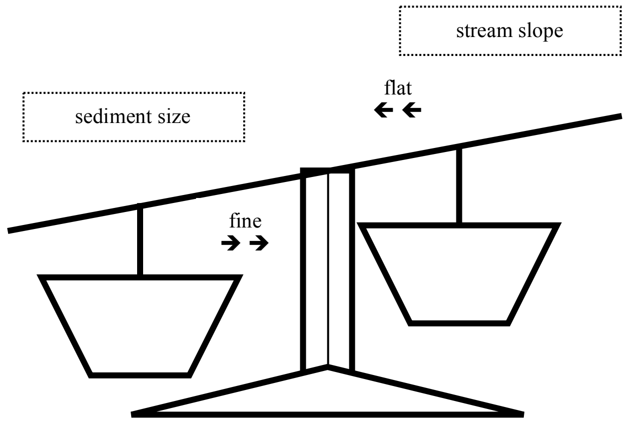
How does the stream regain balance?

2. A person upstream drives his car across the stream, creating erosion that causes <u>*more sediment*</u> to enter the stream channel.



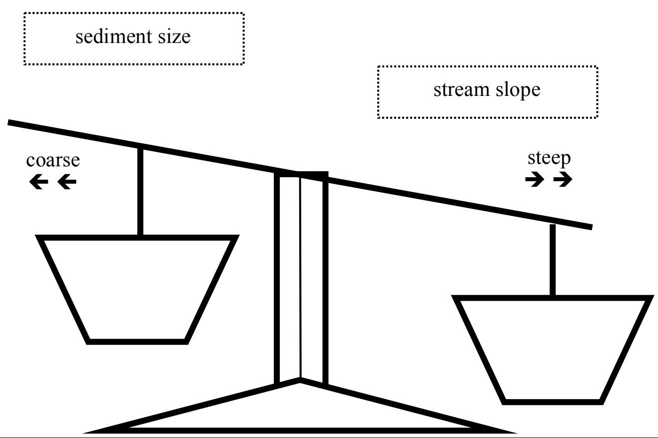
How does the stream regain balance?

3. A stream slows down and carves wider meanders, making the stream slope *flatter*.



How does the stream regain balance?

4. A town cuts through a series of meanders to straighten the stream, making the stream slope steeper.



How does the stream regain balance?

LESSON 4. STREAMBANKS

BACKGROUND

Vegetation growing along streams – the *riparian buffer* - helps to hold streambanks, filters pollutants from water that runs off the land, and absorbs the energy of floodwaters. Riparian plants directly benefit the stream ecosystem in several ways. They shade the water, keeping it cool and providing cover for aquatic organisms. Leaves, branches, and logs that fall into the water contribute resources to the stream's food web. On land, the riparian buffer provides cover for terrestrial animals that come to the stream for water and food, and offers them a safe travel corridor.

In general, trees are more effective at holding banks than herbaceous plants like grasses, but a good riparian buffer contains a variety of plant types. Tree roots grow deep, but the roots are widely separated. Grasses have dense roots, but they are shallow. And shrub roots are in between trees and grasses. Therefore, a diverse community of plants keeps the bank intact. It also offers varied habitats to support a range of wildlife species.

Humans often remove riparian vegetation to establish buildings, roads, industrial developments, and agricultural areas along streams. In so doing, we tend to destabilize their banks and increase the risk of erosion. To protect the banks, we implement streambank stabilization programs that call for building various structures along streams, including "riprap" (rocks that line the bank) andt walls. While these artificial materials armor the banks and may prevent erosion at that site, they can transfer the force of flowing water downstream, where it can cause significant erosion.

More Info:
Living in Harmony with Streams booklet, page 11
After the Flood videos
http://www.youtube.com/watch?v=Wx7EQAY8CuA&list=PLX5V6zW7pAiYEC3bIrK3ymOegGrPwg0xT

- Video 3: armoring banks; starting at 7:54 minutes
- Video 4: VT's fisheries; starting at 4:24 minutes
- Video 4: aquatic habitat; starting at 10:04 minutes

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ACTIVITY INSTRUCTIONS

MATERIALS

Items with stream table

- rocks
- washcloths
- cheesecloth, cut into long strips

Items you supply

- scissors

SET-UP

- Get the stream table ready to run. Allow water to flow and meanders to form.

TIMEFRAME

45 minutes

Lesson 4.1. – Bank Protection

Define the term *riparian buffer* (see BACKGROUND and GLOSSARY). Explain that people often remove the plants along a streambank and then armor it with artificial materials. Ask students to think about the kinds of artificial materials they see along streams. (The list should include rocks and cement walls).

Allow the water to run and meanders to form on the stream table. Give students various materials – rocks, solid surfaces that model cement walls, and washcloths and cheesecloth strips to represent vegetation. Have students use each material in turn to line the streambanks and make observations to answer the following questions:

1. Which material holds the bank the best?
2. Which one absorbs more water? (Talk about the holding capacity of roots, which can absorb and hold large amounts of water during flooding. *Please note: washcloths and cheesecloth are used here to model vegetation, but they lack the root structure that serves to hold stream banks so effectively in nature. Discuss this limitation as you model riparian vegetation with these materials.)*
3. Does erosion occur upstream and/or downstream with each kind of material?

Lesson 4.2. -- Streambanks & Habitat

Explain that streams and their riparian vegetation provide resources for wildlife and fish. Have students brainstorm some important habitat benefits provided by vegetation, riprap, and cement walls. Figure 12 below shows a table with possible answers.

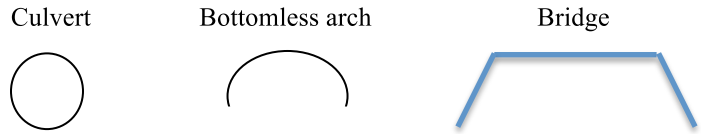
Figure 12. Streambank Materials & Habitat

Bank Materials	Habitat Benefits	
	For terrestrial organisms on land	For aquatic organisms in the water
riparian vegetation	• plant foods (seeds, berries, leaves, etc.) for terrestrial animals • cover from predators • easy access to water • aquatic prey species (e.g., crayfish) for terrestrial predators (e.g., raccoon) • homes like holes in trees and nests that are close to food and water resources • enriched soil from nutrient cycling of plants and animals	• plant parts drop into the water to provide food and habitat structures for aquatic animals • shade cools the water (which increases dissolved oxygen in water) which benefits fish and other aquatic animals • shade and overhanging vegetation provides cover for fish and other aquatic animals • plant roots hold soil along the banks, preventing excess erosion of soil into the stream.
riprap (rocks that line the bank)	• cover for small animals (if they can hide among or under the rocks) • others?	• rocks hold soil along the banks, preventing excess erosion of soil into the stream (but may divert the water's force downstream and lead to erosion there) • others?
cement walls	• attachment location for some plants (especially in the cracks, where roots can become established), which may serve as food and shelter	• any plants that attach and grow drop plant parts into the water, which provides some food. • any plants that attach and grow provide some shade (see above) • walls hold soil along the banks, preventing excess erosion of soil into the stream (but diverts the water's force downstream and can lead to flooding and erosion there)

LESSON 5. STREAM CROSSINGS

BACKGROUND

Since many of our human activities occur in valleys, we often need to cross flowing waters. *Stream crossings* are **culverts (pipes), bottom-less arches**, and **bridges** that are installed to convey water under a “travelway” such as a road or a path. The size, shape, material, and placement of the stream crossing should be carefully considered to accommodate high flows and to allow for the migration of aquatic organisms.



An undersized crossing, such as a pipe culvert that is not big enough to handle large volumes of water, can create lots of problems. During a big storm, streams collect more water than usual and can rise dramatically. A small culvert pinches the flow, causing a backup of water upstream of the culvert, where its swirl can erode the banks and streambed. When a large volume of water is squeezed through the small pipe, the water speeds up and carries more force, creating a “fire hose” effect downstream, often causing severe erosion. If the culvert becomes clogged with debris, it passes even less water or completely dams the stream. In this situation, water flows around and/or over the culvert, often gouging the land and destroying roads. Eventually, the culvert can get washed out, causing the backed up water to surge downstream where it can do significant damage.

Small pipe culverts can also become “perched” when the outflow from the culvert erodes the streambed downward. (This is often the result of the fire-hose effect described above.) If a culvert becomes perched, the downstream end of the culvert is higher than the streambed. A small waterfall forms, causing additional erosion and creating a barrier to fish movements. This can interfere with spawning and prevent fish from escaping predators, moving away from pollution events, and/or finding food.

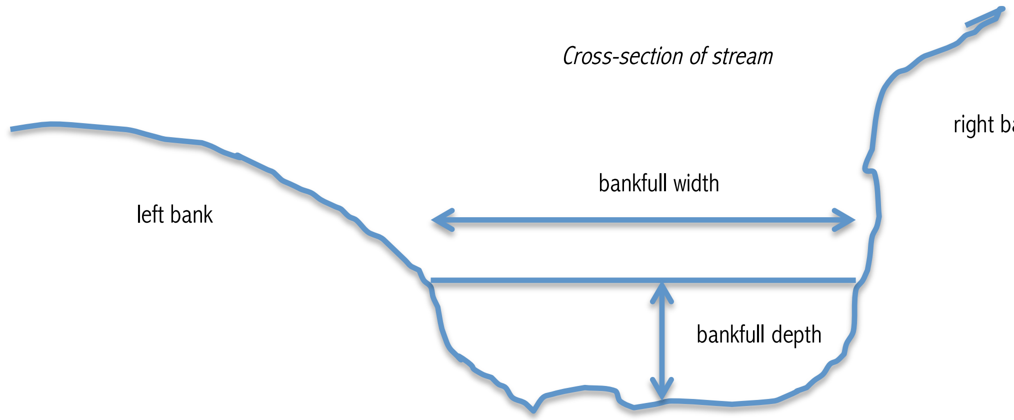
A large crossing (pipe, arch, or bridge) that is designed to fit a specific site can usually accommodate increased water volumes and more effectively manage floodwaters than a small one; it is more *flood resilient.*

“Bottomless” (open bottom) culverts or arches are now being installed in some areas in Vermont. Arches that are at or beyond *bankfull width* (see GLOSSARY and Figure 12 below) allow water to flow more smoothly, cause less erosion than pipe culverts, maintain natural streambed sediments under the arch, and do not become perched. All of these qualities may save taxpayers money. They also promote *habitat connectivity* by allowing wild species to move easily upstream and downstream to access important habitat resources. Such wild species include aquatic invertebrates, fish, salamanders, wood turtles, muskrats, and mink.

Bridges create even wider spans over the stream and are often anchored in the bank away from the active stream channel. Because of this, bridges can be very effective at promoting flood resiliency and habitat connectivity. But bridges are expensive and do not fit some sites.

Figure 13. Bankfull & Floodplain

a. **Bankfull width** is the distance across the channel from bankfull on one side to bankfull on the other side. **Bankfull depth** is the maximum depth of a channel within a riffle when flowing at a bankfull discharge.



b. A stream's **floodplain** is any ground that would get flooded if the stream rose up to twice the bankful height. In the diagram below, water would overflow the left bank first and spill out onto the floodplain on that side. If it got high enough, water would eventually overflow the right bank as well.

The Vermont Fish and Wildlife Department has developed a manual for conservation commissions, highway departments, local conservation and watershed organizations, and private landowners. Called the *Vermont Stream Crossing Handbook* (see ***More Info*** below), this document is an excellent source of information for designing stream crossings that promote flood resilience and habitat connectivity. This handbook is clearly written and well organized, with lots of color photographs and clear illustrations.

Figure 14. Stream Crossing Guidelines

(From *Vermont Stream Crossing Handbook*, Vermont Fish and Wildlife Department: www.vtfishandwildlife.com)

A Good Crossing…

- spans the stream and banks
- does not change the velocity
- has a natural streambed
- creates no noticeable change in the river

Effective crossings include…

- bridges
- open bottom arches
- culverts that span and remain buried in the streambed

More Info:

Living in Harmony with Streams booklet, page 2

Vermont Stream Crossing Handbook:

http://www.vtfishandwildlife.com/library/Reports_and_Documents/Aquatic%20Organism%20Passage%20at%20Stream%20Crossings/__AOP_%20Handbook.pdf

After the Flood Videos

- Video 2: culverts; starting at 11:36 minutes
- Video 3: culverts; starting at 00:00 minute (beginning)

♦♦♦♦♦♦♦♦♦♦

ACTIVITY INSTRUCTIONS

MATERIALS

Items with stream table

- small culvert (small metal can, like a tomato paste can)
- large culvert (large metal can, like a large soup can)
- bottomless arch (half a wide PVC pipe)

Items you supply

- bridge (a long, straight piece of wood with supports)
- STREAM CROSSING EXPERIMENT STUDENT ACTIVITY SHEET (either Grades 3/4 or Grades 5/6; see below)
- Clipboards, one per student

SET-UP

- Get the stream table running
- Prepare a chart on the board or large sheet of paper for the class brainstorm in Lesson 5.2.

TIMEFRAME

60 minutes or more; ideally carried out over 2 such time periods

Lesson 5.1. – Stream Crossing Experiment

(See appropriate section below -– Grades 3/4 or Grades 5/6 -- for your students' grade or ability level)

Grades 3/4

Show students 2 sizes of stream crossings: the small pipe and the large pipe. Give each student the Grades 3/4 STREAM CROSSING EXPERIMENT STUDENT ACTIVITY SHEET. Read the *Question* to students, clarifying as needed. Ask them to *hypothesize* which crossing size will minimize erosion by checking one of the boxes next to their crossing of choice, then have them explain their reasoning on the line below (their "because" statement). (**Step 1** and **Step 2** on the sheet.)

Step 3 asks students to run an *Experiment* that compares the 2 stream crossing structures to test students' hypotheses. Follow the procedure below to set up a comparable scenario with each type of crossing.

Part 1 – Small Pipe Culvert

1. Create a straight channel in the stream table that is the same width as your small pipe.
2. Install the small pipe in the flowing water on the stream table. Pack sediment against it on either side. (If you have a "road" that you can put across it and some toy cars to drive the road, all the better.)
3. Run the water at low volume and watch it flow through the culvert for a few minutes. Have students write an observation in the first box of the **Observation** table on the student activity sheet. (You may choose to have students draw their observation instead of writing it.) Encourage students to observe water movements, sediment movements, and the changing stream channel.
4. Now turn the volume up a bit (heavy rain) and have students write (or draw) their second **Observation**.
5. Finally, turn the volume up high to simulate a storm surge and have students write (or draw) their third **Observation**.

Part 2 – Large Pipe Culvert

1. Turn off the water flow and rebuild the channel to its original width (small pipe width).
2. Install the large pipe. Note: *The large pipe will be wider than the channel of flowing water. Pack sediment on either side of it.*

Repeat Steps 3, 4, and 5 in Part 1 above (low flow and Observation, medium flow and Observation, high flow and Observation).

Grades 5/6

Show students 3 stream crossings: the small pipe, the bottomless arch, and the bridge. Give each student the Grades 5/6 STREAM CROSSING EXPERIMENT STUDENT ACTIVITY SHEET. Read the *Question* to students, clarifying as needed. Ask them to *hypothesize* which crossing structure will minimize erosion by checking one of the boxes next to their crossing of choice, then have them explain their reasoning on the line below (their "because" statement). (**Step 1** and **Step 2** on the sheet.)

Step 3 asks students to run an *Experiment* that compares the 3 stream crossing structures to test students' hypotheses. Follow the procedure below to set up a comparable scenario with each type of crossing.

A Note to teachers of older and/or more accomplished students: See the box below entitled "Designing a More Rigorous Experiment"

Part 1 – Small Pipe Culvert

1. Create a straight channel in the stream table that is the same width as your small pipe.
2. Install the pipe in flowing water on the stream table. Pack sediment against it on either side. (If you have a “road” that you can put across it and some toy cars to drive the road, all the better.)
3. Run the water at low volume and watch it flow through the culvert for a few minutes. Have students write an observation in the first box of the **Observation** table on the student activity sheet. Encourage students to observe water movements, sediment movements, and the changing stream channel.
4. Now turn the volume up a bit (heavy rain) and have students write their second **Observation**.
5. Finally, turn the volume up high to simulate a storm surge and have students write their third **Observation**.

Part 2 – Bottomless Arch

1. Turn off the water flow and rebuild the channel to its original width (small pipe width).
2. Install the bottomless arch. Note: *The arch will be wider than the channel of flowing water. Pack sediment on either side of it.*

Repeat Steps 3, 4, and 5 in Part 1 above (low flow and Observation, medium flow and Observation, high flow and Observation).

Part 3 - Bridge

1. Turn off the water flow and rebuild the channel to its original width (small pipe width).
2. Install the bridge (long span with bridge supports). *Note: The bridge span will be wider than the channel of flowing water. Pack sediment around the supports.*

Repeat Steps 3, 4, and 5 in Part 2 above (low flow and Observation, medium flow and Observation, high flow and Observation).

Discussion – Gear it for your students’ grade and ability level

1. Ask for volunteers to read their Observations to the class – what happened with each of the stream crossing structures? At each flow level (low, medium, high)?
2. Ask students if they see any patterns and/or relationships in their Observations. For instance, did the water behave in a particular way with any of the crossings? Did the water’s flow change in a predictable way from one flow level to the next?
3. Have students review the *Question* that started this experiment, then their *Hypothesis* and their “because” statement. Remind them that a scientist’s hypothesis

is often proven wrong because the world is a complex place and sometimes things happen that you can't predict. But even disproving a hypothesis leads to tremendous learning, and scientific knowledge is often advanced when we get unexpected results.

4. Have students record their *Results* by checking the box next to the structure that they believe created minimal erosion. *Please note that a viable choice is "Not enough data*" (see below).
5. Ask students for a show of hands as follows:
   a. Grades 3/4: Who chose the small pipe? Large pipe? Not enough data? Record the number of votes that each choice received on a flipchart sheet. Have them explain their choices and encourage student discussion.
   b. Grades 5/6: Who chose the small pipe? Bottomless arch? Bridge? Not enough data? Record the number of votes that each choice received on a flipchart sheet. Have them explain their choices and encourage student discussion.

   Explain that professional scientists often work with lots of colleagues, some of whom may disagree about experimental results. By discussing their observations, questions, and understandings, they help to inform each other and produce more accurate, useful results overall.
6. Now that students have reviewed and discussed their *Observations* and *Results*, they are ready to draw *Conclusions*. What do they know now, after doing their experiment, that they didn't know beforehand? As students provide ideas, list them on flipchart paper. As a class, summarize students' ideas into 3 concluding statements. Or have each student summarize his/her own conclusions as an independent exercise. Then have them write their Conclusions on their STUDENT ACTIVITY SHEET.
7. Explain that, in the event that a scientist determines he/she doesn't have enough data for analysis, he/she should review the experiment's design, improve it if needed, and run the experiment again.

   If students chose "Not enough data," ask them to follow this process (above) and describe how they might work to produce more clearcut data. Older students may want to review Figure 12 for some suggestions of ways to improve the rigor of this experiment.

Figure 15. Improving the Rigor of the Stream Crossing Experiment

- For each crossing structure, dig the exact same channel (location and width) before installing the structure.
- Mark the flow dial to standardize your flow settings. (Please do note leave permanent marks on the stream table.)
- For each Observation, run the water for a specific amount of time.
- Measure the amount of sediment that flows out of the mouth each time you run the water for each Observation. Record the volume for each Observation, then compare volumes.

Thanks to Kevin Gianini, teacher at Grantham Village School, Grantham, NH, for contributing ideas.

LESSON 5.1. STREAM CROSSING EXPERIMENT

Student Activity Sheet (Grades 3/4)
Emriver Em2 Geomodel (stream table)

Name: ____Date: ___________

Look at 2 sizes of pipe culverts: ○ ◯

1. **Question**: *Which size will cause the least erosion?*

2. **Hypothesis**: Check one box below:

   small culvert ☐ ○ large culvert ☐ ◯

   I chose this size culvert because

   ____

3. **Experiment (A and B)**.

   A. Install the small culvert. Watch the stream flow through it. Write or draw 3 observations.

Small Culvert Observations
1.
2.
3.

B. Install the large culvert. Watch the stream flow through it. Write or draw 3 observations.

Large Culvert Observations
1.
2.
3.

4. **Results**: Which size culvert caused the least erosion? Check one.

small culvert	large culvert	Not enough data
❒ ○	❒ ○	❒

5. **Conclusions**: Review your *Observations* and *Results*. What do you know now that you didn't know before the experiment? Write 3 conclusions.

____

____

____

LESSON 5.1. STREAM CROSSING EXPERIMENT

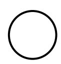
Student Activity Sheet (Grades 5/6)
Emriver Em2 Geomodel (stream table)

Name: ____ Date: ____________

Look at 3 kinds of stream crossing structures: small pipe culvert, bottomless arch, and bridge.

1. **Question**: *Which crossing structure will minimize erosion along the stream?*

2. **Hypothesis**: Check one box below

Small culvert	Bottomless arch	Bridge
❐ 	❐ 	❐ 

I chose this crossing structure because:

____

____

3. **Experiment**. Install each crossing structure, one at a time, and run the stream table. Write 3 observations for each structure below, one observation for each flow level.

Crossing Structure	Observations
small pipe culvert	1. low flow
	2. medium flow
	3. high flow

bottomless arch	1. low flow
	2. medium flow
	3. high flow
bridge	1. low flow
	2. medium flow
	3. high flow

4. **Results**: Which structure minimized erosion? Check one. *Please check "Not enough data" if your results are not clear.*

Small culvert	Bottomless arch	Bridge	Not enough data
☐ ○	☐ ⌒	☐	☐

5. **Conclusions**: Review your original *Question,* your *Hypothesis,* your *Observations,* and your *Results*. What do you know now (after your experiment) that you didn't know before? That is, what can you conclude? What new questions do you have about crossing structures?

Conclusions: ____

____

New questions: ____

____

Lesson 5.2. - Community Crossings

Different members of a community have different perspectives on installing stream crossings. Things to consider include:

- cost
- life-span (how long it will last, which affects the replacement cost)
- affects on fish and wildlife habitats
- affects on water quality
- affects on local roads, landowners, settlements, farms, etc.
- local, state, and federal requirements that need to be met to receive a permit for the crossing.

Imagine that a town has to replace a culvert on Trout Brook, a popular fishing location. A busy road runs over the culvert. Have students brainstorm the pros and cons of each type of crossing using a table format such as the one below. (Possible answers are provided for the teacher.)

Figure 16. Pros and Cons of Community Crossings

Types of Crossing	Pros (+)	Cons (-)
small culvert	• minimal cost • adequate for moving typical water volumes • minimal movement of earth required to install it • takes up a small "footprint"	• may not be able to handle storm waters, causing them to flood the land around it • may get blocked with debris or "blown out" during a storms, causing flooding around it • water often speeds up as it enters culvert, causing "firehose" effect downstream • often becomes "perched," interfering with migration of aquatic organisms
bottomless arch	• relatively inexpensive compared to bridge • adequate for moving typical and greater water volumes • does not change the velocity of water • has natural streambed, which provides aquatic habitat and allows migration • does not become "perched"	• higher cost than small culvert • requires more movement of earth to install than small culvert • larger "footprint" than small culvert
bridge	• lasts longer than culverts • much less likely to wash out than culverts. • does not change the velocity of water • has natural streambed, which provides aquatic habitat and allows migration • does not become "perched" • usually more sturdy than culverts and arches	• higher cost than either small culvert or bottomless arch • longer construction process

Ask students to play the roles of the following individuals. Which crossing structure would they choose and why?

- town manager, who’s in charge of balancing the town’s budget and dealing with flooding
- owner of Joe’s Fishing Store
- owner of the Riverview Motel, which is on the floodplain next to the stream
- school principal, whose athletic fields are on the floodplain next to the stream
- landowner, who drives the road over the culvert each day to get to work

LESSON 6. WATERSHED NEIGHBORS

BACKGROUND

Watershed neighbors are the people, settlements, and businesses that share the land and water resources within the landscape drained by a particular river system. Human activities in and along our streams often lead to changes in stream conditions, especially downstream, as the stream responds to our impacts. Some activities are felt more broadly throughout the watershed. Therefore, our activities can affect our watershed neighbors.

Often, a stream's response to human activities presents problems for watershed residents. For example, a straightened stream may develop meanders that cut into a farmfield, or an eroding channel may deliver its load of sediments onto a road. By responding in these ways, the stream is trying to stabilize its forces and adopt a pattern that it can generally maintain over time. *Dynamic equilibrium* describes the process by which streams constantly change in the process of creating or maintaining balance over time. Living in Harmony with Streams explains it this way:

> Dynamic equilibrium means that the stream moves and adjusts toward the most efficient distribution of the energy of the system. Change is what makes the equilibrium dynamic. (page 12)

These movements and adjustments cause the erosion of soil particles in some places and the deposition of soil particles in other places. In between, the soil particles become suspended and carried in the water. Therefore, streams move both water and sediments.

How can we, as watershed residents, make decisions that protect our real estate, minimize conflicts with our neighbors, and foster a healthy watershed? The Vermont Rivers Program is encouraging Vermonters to allow our unstable streams to re-balance themselves, which may mean allowing a straightened stream to meander, or an eroding stream to deposit sediments downstream of the disturbance. We can also remove a berm along a stream (or punch a hole in it) to allow floodwaters to spread out over floodplains, which dissipates the water's energy and absorbs excess water volumes. And replanting riparian zones with trees or other kinds of vegetation has numerous benefits. (See the BACKGROUND in Lesson C. – Streambanks). These restoration actions help the stream to regain its *dynamic equilibrium*, which makes it more stable and less susceptible to flood damage and erosion in the long run.

More info:

Living in Harmony with Streams booklet

- Pages 12 – 14
- Pages 29 - 36

After the Flood Videos

http://www.youtube.com/watch?v=Wx7EQAY8CuA&list=PLX5V6zW7pAiYEC3bIrK3ymOegGrPwg0xT

- Video 1: river stability; starting at 2:14 minutes
- Video 2: water flows and floodplain functions; starting at 0:00 minute (beginning)
- Video 2: the need for river corridor maps; starting at 4:55 minutes
- Video 3: berms; starting at 8:50 minutes
- Video 4: equipment in streams, re-engineering channels; starting at 0:53 minute

Youtube video: Steve Nelle explaining Lane's Balance (http://www.youtube.com/watch?v=Js7wDZE4I7o

Activity Instructions

MATERIALS	SET-UP
Items with stream table • Lane's Balance • items that represent farms and cities: houses, roads, farm fences, livestock, etc. **Items you supply** • FARM TO CITY STUDENT ACTIVITY SHEET, or CITY TO FARM STUDENT ACTIVITY SHEET (below) • DESIGNING A SOLUTION STUDENT ACTIVITY SHEET (below)	• **TIMEFRAME** 60 minutes

Lesson 6.1. – Upstream, Downstream

Please note: Lesson F.2.a. and Lesson F.2.b. teach the same basic concepts. You can choose to do either one, depending on which better represents your students' experiences. Or you can do both to encourage your students to adopt different perspectives on watershed resource use and cause and effect.

Lesson 6.1.a. - Farm to City

On the stream table, have students create a farm along the stream and build a city downstream of the farm along the stream. The farm and/or city can be built on both sides of the stream with a bridge connecting the two halves.

Hand out the FARM TO CITY STUDENT ACTIVITY SHEET. Ask students to set up one or more of the scenarios on the sheet, each of which reflects some ways in which the farm might change the flow of surface water, groundwater, and/or streambanks, and affect the city downstream.

As students run these scenarios, have them complete the activity sheet.

Class Discussion Ideas

After the scenario(s) is/are run, ask students to discuss the following questions:

- Do activities that occur upstream affect downstream people and activities? Explain.
- Do activities that occur downstream affect upstream people and activities? Explain.
- We share our watershed with many people, human settlements, and businesses. Do we have a responsibility to each other when it comes to land and water resources? That is, should we try to minimize negative impacts and maximize positive impacts for our watershed neighbors?

If we reduce the area in which the stream can move, flood, and/or store sediments in our farming areas, how can we reduce negative impacts downstream? Discuss student recommendations from their activity sheets. Here are some possible options:

- The farmer can establish a forested buffer between his/her farmland and the stream to absorb the volume and force of floodwaters, and reduce erosion of the farmfields. The restored riparian buffer will also lessen flood damage downstream in the city.
- The farmer can allow the stream to meander, which flattens the streambed's slope and slows down floodwaters.

LESSON 6.1.A. FARM TO CITY	**Student Activity Sheet** **Emriver Em2 Geomodel (stream table)**

Name: ____ Date: ______________

Check the Scenarios (one or more) that you are running:

- ❒ farm narrows the stream and ripraps the banks
- ❒ farm builds a berm along the stream to prevent flooding onto its fields
- ❒ farm straightens the channel to deliver high water downstream, past the farm

Prediction: What do you think will happen:	
	to surface water at the farm?
	to the streambanks and streambed at the farm?
	to surface water at the city?
	to the streambanks and streambed at the city?
Investigation: Create your scenario(s). Write and sketch your observations.	

Analysis: Summarize the important findings of your investigation.	
Conclusions: Review your Predictions. What did you learn from this investigation?	
Recommendations for improvement (designing possible solutions): Make 3 recommendations of actions that the farm can take to protect its land and water resources and minimize impacts on the city.	
	1.
	2.
	3.

Lesson 6.1.b. - City to Farm

On the stream table, have students build a city along the stream and create a farm downstream of the city along the stream. The city and/or farm can be built on both sides of the stream with a bridge connecting the two halves.

Hand out the City to Farm Student Activity Sheet. Ask students to set up one or more of the scenarios on the sheet, each of which reflects some ways in which the city might change the flow of surface water, groundwater, and/or streambanks, and affect the farm downstream.

As students run these scenarios, have them complete the activity sheet.

Class Discussion Ideas

After the scenario(s) is/are run, ask students to discuss the following questions:

- Do activities that occur upstream affect downstream people and activities? Explain.
- Do activities that occur downstream affect upstream people and activities? Explain.
- We share our watershed with many people, human settlements, and businesses. Do we have a responsibility to each other when it comes to land and water resources? That is, should we try to minimize negative impacts and maximize positive impacts for our watershed neighbors?

If we reduce the area in which the stream can move, flood, and/or store sediments in our urban centers, how can we reduce negative impacts downstream? Here are some possible options:

- The city can buy floodplain land between the city and the farm to absorb floodwater volume and force.
- The city can establish parks and other green spaces along the stream that can absorb floodwater forces to reduce flood damage downstream.
- The city can reimburse the farmer for lost crops whenever the land floods.

LESSON 6.1.B. CITY TO FARM

Student Activity Sheet
Emriver Em2 Geomodel (stream table)

Name: ____ Date: _____________

Check the Scenarios (one or more) you are running:

- ❒ city narrows the stream and ripraps the banks
- ❒ city builds concrete walls along both sides of the stream.
- ❒ city straightens the channel, from just upstream to just downstream of the city

Prediction: What do you think will happen:	
	to surface water at the city?
	to the streambanks and streambed at the city?
	to surface water at the farm?
	to the streambanks and streambed at the farm?
Investigation: Create your scenario(s). Write and sketch your observations.	

Prediction: What do you think will happen:	
	to surface water at the city?
	to the streambanks and streambed at the city?
	to surface water at the farm?
	to the streambanks and streambed at the farm?
Investigation: Create your scenario(s). Write and sketch your observations.	
Analysis: Summarize the important findings of your investigation.	

Conclusions: Review your Predictions. What did you learn from this investigation?	
Recommendations for improvement (designing possible solutions): Make 3 recommendations of actions that the city can take to protect its land and water resources and minimize impacts on the farm.	
	1.
	2.
	3.

Lesson 6.2. Designing a Solution *(most appropriate with older students)*

In Lesson 6.1., students explored the impacts that upstream neighbors (farm or city) have on downstream neighbors (city or farm). To conclude this lesson, students made 3 recommendations of actions that "upstreamers" can take to protect their land and water resources while minimizing impacts to "downstreamers."

1. Have students review their recommendations, and create a class list of their ideas on flipchart paper. Add any new ideas that emerge from this brainstorm session.
2. In pairs or small groups, have students choose one of these recommendations to implement in their farm-city or city-farm community.
3. Give students the DESIGNING A SOLUTION STUDENT ACTIVITY SHEET (below) and ask them to outline a plan for designing, implementing, and assessing their proposed solution. Some suggestions:
    - If you still have time with the stream table, allow groups to take turns using the table to assess their proposed solution to the problem they identified. After experimenting with the table, they can refine their solution plan using a fresh piece of paper.
    - Ask each group to present its proposed solution to the class and receive feedback and input on it. Then each group can revise their solution plan.
    - Have each group assess the proposed solution of another group.

LESSON 6.2. DESIGNING A SOLUTION	Student Activity Sheet Emriver Em2 Geomodel (stream table)

Names in your group: ____

Date: ______________ Check one: ❐ Farm to City ❐ City to Farm

The ***purpose*** of this activity is to develop a possible solution to a problem created by upstream neighbors along a stream. Your goals are to:

- protect land resources upstream
- protect water resources upstream
- minimize negative impacts on upstream residents
- minimize negative impacts on upstream businesses

- protect land resources downstream
- protect water resources downstream
- minimize negative impacts on downstream residents
- minimize negative impacts on downstream businesses

Describe the **problem** that you are addressing.
Describe the **recommendation** that you chose to address this problem.

Sketch the stream section that is experiencing the problem you identified. Include features of the stream and the community that lies along this stream section. Label parts and write a caption for each label.

Sketch your *proposed solution* here. Show how it would protect land and water resources, and minimize negative impacts on people and businesses. Label parts and write a caption for each label.

Use your best judgment to **assess** your proposed solution using the table below.					
Rank each statement from 1 to 5. To what degree would your design…	Not at all		A little		A lot
	1	2	3	4	5
• protect land resources upstream					
• protect water resources upstream					
• minimize negative impacts on upstream resident					
• minimize negative impacts on upstream businesses					
• protect land resources downstream					
• protect water resources downstream					
• minimize negative impacts on downstream residents					
• minimize negative impacts on downstream businesses					
Describe a ***weakness*** of your possible solution.					
Describe a ***strength*** of your possible solution.					

Glossary

Definitions adapted from Living in Harmony with Streams, the Vermont Stream Geomorphic Assessment, Appendix Q, the dictionary tool in Microsoft Word, and other sources of definitions.

aggradation (see Lane's Balance) -- a progressive buildup, or raising, of the channel bed and floodplain due to sediment deposition; opposite of degradation.

alluvial – refers to a stream or river that flows through sedimentary deposits, which it sorts, carries downstream, and deposits.

bankfull – the typical high water mark along a stream that is reached about every two years. In Vermont, this usually happens in spring with snowmelt. The bankfull "line" is often indicated by a change in soil color or a change in vegetation. Bankfull flow forms and maintains the channel over time.

bankfull channel depth -- the maximum depth of a channel within a riffle segment when flowing at a bankfull discharge.

Bankfull channel width - the distance across the channel from bankfull on one bank to bankfull on the other bank.

bankfull discharge -- the stream discharge corresponding to the water stage that first overtops the natural banks. This flow occurs, on average, about once every 1 to 2 years.

benthic – refers to the streambed and other underwater surfaces in a stream, such as a submerged log, and the bottom-dwelling organisms that live there.

berm – a mound of soil or other materials, constructed along a stream, a road, or other area, to protect against flooding and/or erosion.

channel -- an area confined by the banks and streambed that contains continuously or periodically flowing water; the path in which the water is flowing.

channelization -- the process of changing (usually straightening) the natural path of a waterway.

corridor -- the lands adjacent to and including the present channel of a stream where the stream is likely to move over time. Includes the lateral [side to side] extent of stable meanders.

culvert -- a buried pipe that allows flowing water to pass under a road.

degradation (of a streambed) **--** a progressive lowering of the stream's channel bed due to scour. Degradation is an indicator that the stream's discharge and/or sediment load is changing. The opposite of aggradation.

dredging -- removing material (usually sediments) from wetlands or waterways to make them deeper or wider.

dynamic equilibrium – describes a stream system that has achieved a balance in transporting its water and sediments over time without building up sediments, cutting into its streambed, or migrating laterally (eroding its banks and changing course). A stream in dynamic equilibrium resists flood damage, resists erosion, and provides good aquatic habitat.

floodplain -- land built of sediment that is regularly covered with water as a result of the flooding of a nearby stream.

groundwater -- subsurface water and underground streams that can be collected with wells, or that flow naturally to the earth's surface through springs.

head cut – a marked change in the slope of a streambed that creates a small waterfall with increased water velocity, which causes erosion of the streambed that eats its way upstream.

headwaters – small, flowing waters that form in the upper elevations of a watershed.

Lane's Balance – a model with balance beam arms that demonstrates some of the interactions in a stream between water, slope (gradient), and sediments.

mainstem – the largest river in a watershed; it collects all flowing water within the watershed and occupies the lowest valley in that watershed.

meander – *noun:* a bend in a stream; *verb:* to wind back and forth through the landscape. A meandering stream generally exhibits a characteristic pattern of bank erosion (outer bend) and point bar deposition (inner bend).

meander belt – the side to side (lateral) extent of stable meanders in a stream.

point bar – a gradual shelf extending out from the inner bend of a stream that forms when slow water drops its load of sediments.

pool -- a reach of stream that is characterized by deep, low-velocity water and a smooth surface.

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

riparian – the strip of land along a streambank in which vegetation directly influences stream processes.

riparian buffer – a vegetated zone along a streambank that helps to stabilize the bank and fosters a healthy terrestrial habitat on one side and a healthy aquatic habitat on the other side.

riprap -- rock or other material used to stabilize streambanks or riverbanks from erosion or to create habitat features in a stream.

river corridor – the land that includes the active channel of a stream, its meander belt, the riparian buffer along the stream, and the stream's floodplain. The corridor is the area within which the channel can meander to distribute sediments and the energy of flowing water, which leads to a balanced condition called dynamic equilibrium.

river system – the mainstem of a river and all of the waters that flow into it. It forms a branching pattern that resembles a tree, with the trunk being the mainstem, the major tributaries being the large branches, and the high-elevation streams being the twigs.

run (in stream or river) **--** a reach of stream characterized by fast-flowing, low-turbulence water.

sediments – materials eroded from soil or rocks that are carried by water, wind, or ice and deposited somewhere else.

slope (gradient) – the amount of change in elevation as a stream flows across the landscape.

thalweg – a line connecting the deepest areas of a stream channel or valley.

tributary – a stream that flows into another stream or river; it is usually smaller than the mainstem.

watershed – a basin of land in which all water flows to a common water body, such as a river, lake, pond, wetland, or the ocean.

Teaching Resources

An Annotated List

Internet Publications

Living in Harmony with Streams: A Citizen's Handbook to How Streams Work, Friends of the Winooski River, White River Natural Resources Conservation District, Winooski Natural Resources Conservation District, 2012. http://www.winooskiriver.org/images/userfiles/files/Stream%20Guide%201-25-2012%20FINAL.pdf.

Very concise but very informative handbook for laypersons. Lots of useful photos and illustrations.

Vermont Stream Crossing Handbook, Vermont Fish and Wildlife Department, Vermont Agency of Natural Resources. http://www.vtfishandwildlife.com/library/Reports_and_Documents/Aquatic%20Organism%20Passage%20at%20Stream%20Crossings/__AOP_%20Handbook.pdf

A great reference, full of color photographs, that describes the issues concerning culverts. Includes two case studies that show how old culverts were reconstructed to enhance aquatic habitats.

Basin 10 Water Quality Management Plan: Ottauquechee River & Black River, Vermont Agency of Natural Resources, May 2012. http://www.vtwaterquality.org/mapp/docs/mp_basin10final.pdf

Comprehensive plan that describes these two river systems and lays out a plan for improving and maintaining their watershed conditions over time.

Next Generation Science Standards. http://www.nextgenscience.org/.

Adopted by Vermont in spring 2013, these new science standards integrate *Science and Engineering Practices, Disciplinary Core Ideas,* and *Cross-Cutting Concepts.*

Vermont Geomorphic Assessment, Appendix Q

A glossary of stream terms published by the Vermont Agency of Natural Resources in 2009.

Internet Videos

Emriver Em2 Geomodel Educational Videos, Little River Research and Design: http://www.emriver.com/?page_id=1521.

A series of short videos that show the process of meandering, a straightened river re-meandering, sediment movement, and the effects of gravel mining in a stream (shows a head cut).

After the Flood: Vermont's Rivers and the Legacy of Irene, Riverbank Media, June 2013. http://www.youtube.com/playlist?list=PLX5V6zW7pAiYEC3bIrK3ymOegGrPwg0xT

A series of 4 videos that explore the condition of rivers in the Green Mountain State following the devastating flooding from Tropical Storm Irene. Topics include: river dynamics, floodplains and flood resiliency, impact of improperly sized culverts and the benefits of upgrading, consequences of river modification, and the current state of Vermont's fisheries.

Vermont Rivers Program Videos, Vermont Agency of Natural Resources, May 2012.

A somewhat technical series of videos made by the Vermont Rivers Program that shows how to minimize flood damage by better understanding river dynamics.

Segment One: Vermont Rivers Program. http://www.youtube.com/watch?v=w8BWjRM-ptI

Segment Two: River Dynamics. http://www.youtube.com/watch?v=0Va7E7KOz94

Segment Three: Meanders and Floodplains. http://www.youtube.com/watch?v=RQ6oyf9C8Lc

Segment Six: River Restoration. http://www.youtube.com/watch?v=E_a-nYl9Ak4

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Agency of Education

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Gail Hall, Grade 6-12 science and math assessment coordinator: gail.hall@state.vt.us, 802-828-0156.

Books

Stream Ecology: Structure and Function of Running Waters, by J. David Allen, School of Natural Resources and Environment, University of Michigan. 2006. ISBN: 0-412-35530-2.

A textbook that covers the stream's chemical, physical, and biological factors, and how they interact to create the unique conditions of a particular stream. Includes a chapter on modification of running waters by humankind.

The River Book, by James Grant MacBroom, Natural Resources Center, Connecticut Department of Environmental Protection. 1998. ISBN: 0-942085-06-X.

A book written for a variety of audiences that covers hydrologic, biologic, water quality, hydraulic, and geologic disciplines of stream study. Includes information on ways in which human activities affect natural stream processes.

APPENDIX 1

BASIN 10 WATERSHED MAP

From the

Basin 10 Water Quality Management Plan

Ottauquechee River & Black River
Vermont Agency of Natural Resources
May 2012
http://www.vtwaterquality.org/mapp/docs/mp_basin10final.pdf

APPENDIX 2

EXTENSION ACTIVITY: MASS, FORCE, AND MOTION

MATERIALS	SET-UP
Items that come with the stream table • Channel Board A, with Straight Channel 1 and Meandering Channel 2 • Channel Board B, with Straight Channel 3 • Run-Out Channel Board • jar of assorted marbles	• none beforehand **TIMEFRAME** 30 minutes

INSTRUCTIONS

1. Set the Run-Out Board at the bottom of Channel Board 1 and place a small, stationary marble where each channel meets the Run-Out Board.
2. Let a small marble run down the straight channel and bump into the stationary marble and measure how far the stationary marble is pushed. Repeat by letting the same small marble run down the meander channel and measure how far the stationary marble is pushed.
3. Replace the small marble with a medium marble, and repeat the experiment.
4. Replace the medium marble with a large marble, and repeat the experiment.
5. Weigh the small, medium, and large marbles and consider how the size of the marble affects how far the stationary marbles are pushed.
6. Discussion: How does this relate to the power of a river that is running deep versus the power of a river when it is running shallow?

EXTENSION ACTIVITY: ROCKS & VELOCITY

On the stream table with the water moving, release a float down the channel along a given distance (say, 20 centimeters) and time it. Place some rocks in this section of the channel, release and time the float again, and see how the rocks affect the velocity of the float. Have students complete the table below.

Channel Condition	Velocity Formula	
no rocks	________ cm distance ÷ _______ seconds =	cm/sec
rocks	________ cm distance ÷ _______ seconds =	cm/sec