Watershed Restoration: Culverts

A Monitoring the White River Curriculum Unit

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Watershed Restoration: Introduction to Culverts

Culverts are **FLOOD RESILIENT** when they are able to pass water, sediment and debris at high flows, and when the culvert and the land around it are not damaged during flood events.

Culverts are **FISH FRIENDLY** when there is no change in the stream from a fish's point of view, and it can move freely through the culvert to reach upstream and downstream habitat.

Usually, FLOOD RESILIENT culverts are also FISH FRIENDLY!

The relationship between culvert width and **bankfull width** is an important factor in both flood resiliency and fish passage**.** In 2016, The Vermont Agency of Natural Resources requires new culverts to be at least 100% or 1.0 x *bankfull width* of a stream. Culverts wider than bankfull width are encouraged because they are more flood resilient and more fish friendly. Many of the culverts that failed during Tropical Storm Irene did not span the bankfull width (measured upstream, away from the influence of the culvert), and were not able to pass flood waters and debris.

Undersized culverts restrict water flow, increasing the power of the water passing through – just like placing your thumb over a garden hose increases the power of the spray. Water coming out of an undersized culvert can scour out the bottom of the streambed downstream of the culvert outlet, creating a plunge pool. Erosion is a natural process and occurs in all streams, but the increased power of water coming out of an undersized culvert can cause too much erosion too quickly.

Undersized culverts can also cause problems upstream. If high water flows cannot pass freely through the culvert, water pools upstream of the culvert inlet, turning like a whirlpool in a draining bathtub. The whirlpool action can scour out the streambed and streambanks upstream of the culvert inlet. In addition, sediment and debris being carried by the water settles out and creates piles upstream of the culvert inlet. This can further block the culvert and lead to more flooding and erosion.

These issues can also present physical barriers for fish or reduce the quality of stream habitat. This Monitoring the White River Unit explores these connections and why correctly sized and installed culverts are an important piece of watershed restoration.

Monitoring the White River
Watershed Restoration Unit: Culverts

Overview

	Activities or Documents	**Purpose**
Pre-fieldwork	Powerpoint presentation (*White River Partnership*)	*Introducing culverts*
	Glossary	*Learning Vocabulary*
	Bankfull Powerpoint activity (*White River Partnership*)	*Identifying bankfull*
	Bankfull math activity	*Calculating the size of a more flood-resilient and fish-friendly culvert*
Fieldwork	Student Fieldsheet	*Making observations, taking measurements, collecting data*
Post-fieldwork	Post-fieldwork Discussion and Activities Overview	*Leading post-fieldwork discussion and activities*
	Culvert Notes	*Interpreting observations made in the field (could be used by a discussion leader or by students themselves)*
	Culvert Conclusions	*Synthesizing data and drawing conclusions*

Glossary

assess – to examine something (as a river) in order to evaluate it.

bankfull – the point [along a riverbank] at which water fills the river channel just before beginning to spill onto the surrounding land. A bankfull flow typically occurs every 1 to 2 years, (often associated with spring runoff), but the frequency of a bankfull flow occurrence can vary.

bankfull width – the distance across the river channel from bankfull on one side of the river to bankfull on the other side of the river.

culvert – a structure that allows water to flow under a road, railroad, or trail.

data (singular: datum) – pieces of information that are gathered from experiments, surveys, or other investigations to make calculations or draw conclusions.

downstream – downstream is always relative to another point. Water flows downhill from higher areas (upstream) to lower areas (downstream).

erosion – the movement of sediment or rock along the river by water or ice.

fish passage – the free movement of fish.

flood resiliency –how quickly a stream can return to its previous state following a flood event.

floodplain – the flat or almost flat land along a stream that receives excess water and sediments during floods.

monitor – to check something (as a river) at regular intervals in order to find out whether and how it is changing.

perched culvert – is a culvert where water falls through the air, like a waterfall, from the outlet to the streambed downstream

perch – a measure of the distance from the bottom of the outlet of a culvert to the bottom of the streambed below.

plunge pool – a basin created by the erosional force of falling water and rocks

riparian zone – the area along a stream channel where vegetation and land uses directly influence stream processes.

scour – another word for erosion

sediment – material such as sand and stones typically moved by the water in a stream

stream bed – the bottom of the stream between the two banks

stream channel – a path for water and sediment flowing between stream banks

tributary – a stream that flows into another stream or river

watershed – a basin of land in which all water drains down to a common body of water (stream, river, lake, pond, wetland, ocean).

Bankfull Math Activity (Grades 4-6)

Overview

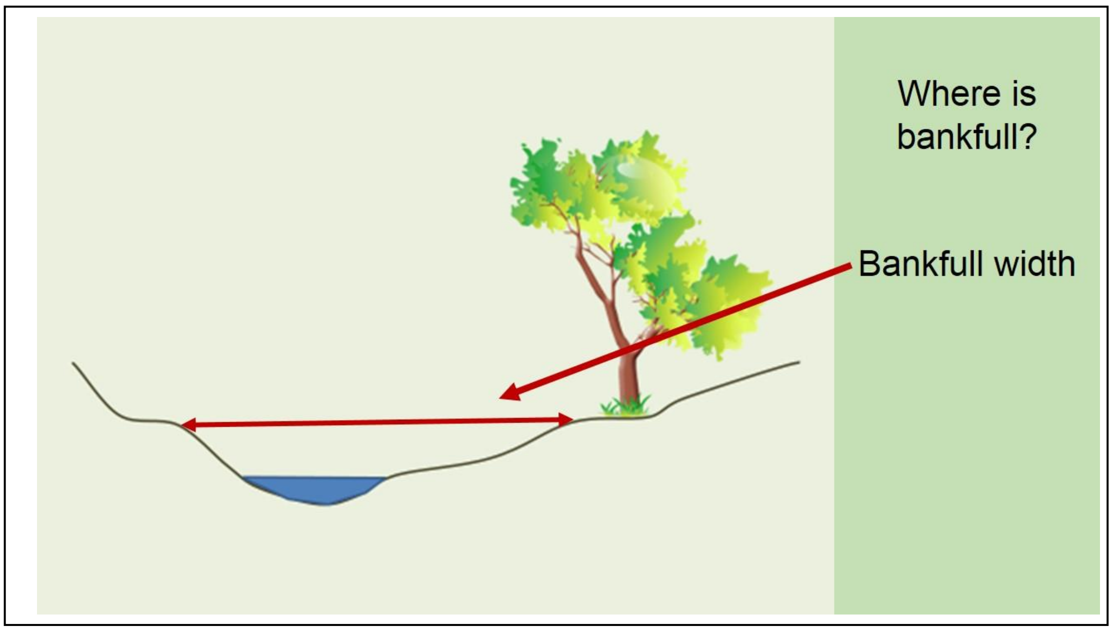
In this activity, students use math to determine an appropriate size for each of three culverts. The Vermont Agency of Natural Resources requires new culverts to be at least 100% or 1.0 x *bankfull width* of a stream. Culverts wider than bankfull width are encouraged because they are more flood resilient and more fish friendly.

Let's start with some definitions:

Bankfull – the location along a streambank at which water fills the stream channel just before beginning to spill onto the floodplain.

A bankfull flow typically occurs every 1 to 2 years, and is sometimes associated with spring runoff in Vermont. However, the frequency of a bankfull flow occurrence can vary.

Bankfull width – the distance across the stream channel from bankfull on one side of the stream to bankfull on the other side of the stream.



In this activity, students are asked to imagine that they are civil engineers who have been asked to size a culvert for each of three streams that blew out their previous culverts in the last big storm. These student engineers are given a cross-sectional diagram of each of the three streams. For each diagram, students will measure the bankfull width and multiply it by 1.0 to find the **minimum** width a culvert must be for this stream, as required by the Vermont Agency of Natural Resources.

If you feel that this activity would be challenging for your students, we suggest that you do the first example as a class discussion. Students should be able to do the next two examples in small groups or as individuals.

Bankfull Math Activity Teacher Key

Stream A

Line 2 is bankfull width; 4 inches long, or 8 feet long
Minimum replacement culvert: 8 feet wide

Stream B

Line 2 is bankfull width; 2 inches long, or 4 feet long
Minimum replacement culvert: 4 feet wide

Stream C

Line 1 is bankfull width; 3.5 inches long, or 7 feet long
Minimum replacement culvert: 7 feet wide

Bankfull Width Student Worksheet

Name: ______________________________________ Date: ___________

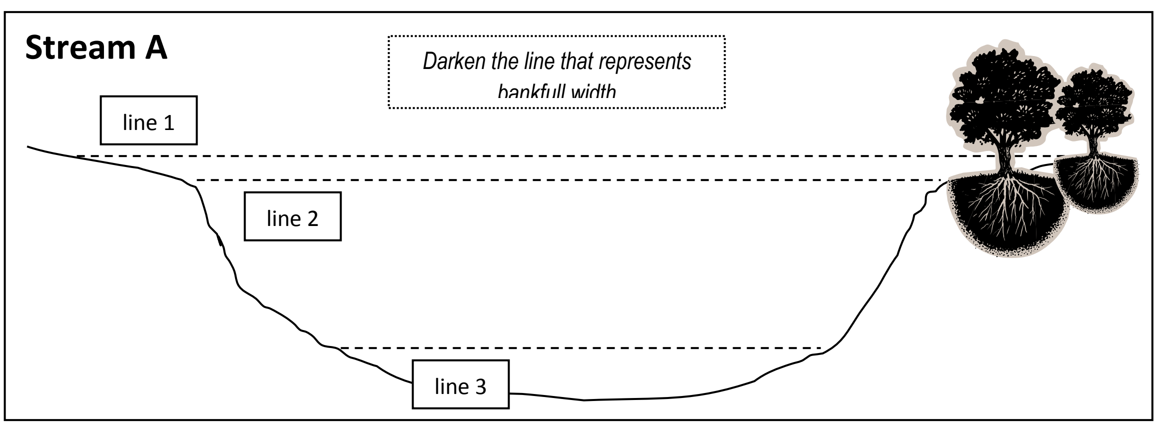
Three streams are shown in cross-section below. For each stream, follow these instructions:

1. Find the dotted line that represents bankfull for that stream. Darken that line by drawing over it with your pencil. Your darkened line shows the stream's bankfull width.
2. Use a ruler to measure the length of that bankfull width line, and record it in the space provided.
3. Convert the length to feet, using this scale:

   ½ inch on paper = 1 foot on imaginary stream
   (Round to the nearest ½ inch)

   Example: The bankfull width line on your paper is 3 inches long. Using the scale above, 3 inches on the paper = 3 x 2 = 6 feet bankfull width for this stream.

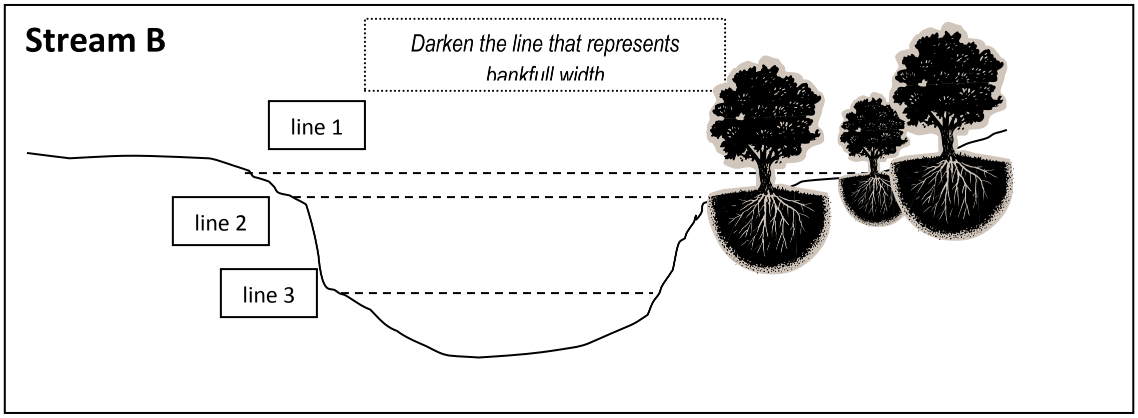
4. Multiply your bankfull width by 1 to get the *minimum* culvert width required by the State of Vermont.



Bankfull width: ___________ inches x 2 = ___________ feet
(length of line)

Minimum culvert width: ___________ x 1 = ________ feet
(bankfull width)

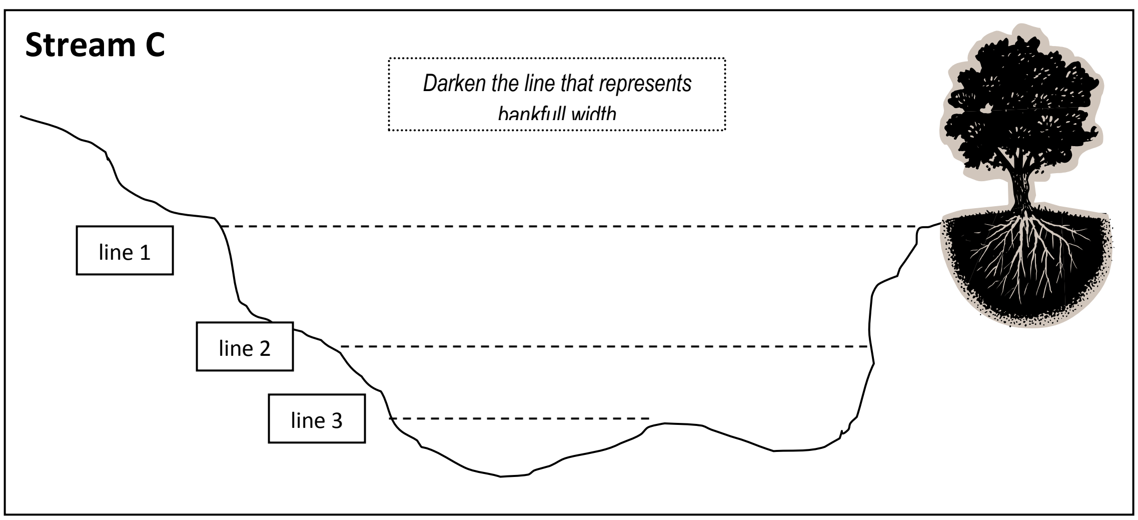
Stream B



Bankfull width: ___________ inches x 2 = ___________ feet
(length of line)

Minimum culvert width: ____________ x 1 = ________ feet
(bankfull width)

Stream C



Bankfull width: ___________ inches x 2 = ___________ feet
(length of line)

Minimum culvert width: ____________ x 1 = ________ feet
(bankfull width)

Common Core Math Standards Addressed in this activity

4th grade:

CCSS.Math.Content.4.NF.C.6 Use decimal notation for fractions with denominators 10 or 100. *For example, rewrite 0.62 as 62/100; describe a length as 0.62 meters; locate 0.62 on a number line diagram*.

CCSS.Math.Content.4.MD.A.1 Know relative sizes of measurement units within one system of units including km, m, cm; kg, g; lb, oz.; l, ml; hr, min, sec. Within a single system of measurement, express measurements in a larger unit in terms of a smaller unit. Record measurement equivalents in a two-column table. *For example, know that 1 ft is 12 times as long as 1 in. Express the length of a 4 ft snake as 48 in. Generate a conversion table for feet and inches listing the number pairs (1, 12), (2, 24), (3, 36), ...*

5th grade:

CCSS.Math.Content.5.NF.B.5 Interpret multiplication as scaling (resizing), by:

> CCSS.Math.Content.5.NF.B.5a Comparing the size of a product to the size of one factor on the basis of the size of the other factor, without performing the indicated multiplication.
>
> CCSS.Math.Content.5.NF.B.5b Explaining why multiplying a given number by a fraction greater than 1 results in a product greater than the given number (recognizing multiplication by whole numbers greater than 1 as a familiar case); explaining why multiplying a given number by a fraction less than 1 results in a product smaller than the given number; and relating the principle of fraction equivalence $a/b = (n \times a)/(n \times b)$ to the effect of multiplying a/b by 1.

6th grade:

CCSS.Math.Content.6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.

> CCSS.Math.Content.6.RP.A.3d Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

Bankfull Math Activity (Middle School)

Overview

In this activity, students use math to determine an appropriate size for each of three culverts. The Vermont Agency of Natural Resources requires new culverts to be at least 1.0 times the *bankfull width* of a stream. In some sensitive streams, culverts are required to be at least 1.2 times bankfull width because they are more flood resilient and fish friendly.

Vermont Agency of Natural Resources, Department of Environmental Conservation
Stream Alteration General Permit (Section C.2.2.5)

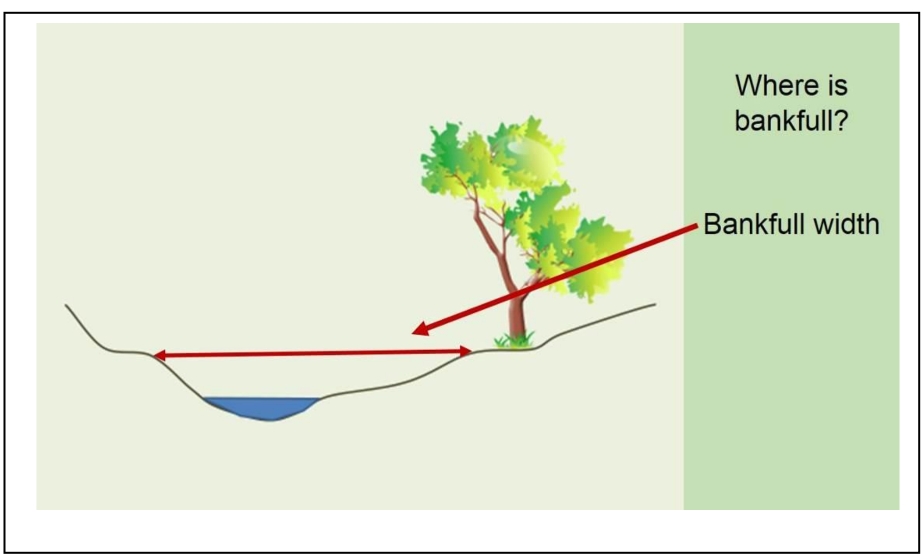
i. Span Length
   1. Minimum span length = 1.0X the bank full width of the stream; or
   2. Minimum span length ≥ 1.2X the bank full width of the stream, as determined by the Secretary, in reaches having high risk of excessive erosion or deposition, based on stream process and geomorphic conditions, as specified in the most current updated version of the Vermont Standard River Management Principles and Practices;

Let's start with some definitions:

Bankfull – the location along a streambank at which water fills the stream channel just before beginning to spill onto the floodplain.

A bankfull flow typically occurs every 1 to 2 years, and is sometimes associated with spring runoff in Vermont. However, the frequency of a bankfull flow occurrence can vary.

Bankfull width – the distance across the stream channel from bankfull on one side of the stream to bankfull on the other side of the stream.



In this activity, students are asked to imagine that they are civil engineers who have been asked to size a culvert for each of three streams that blew out their previous culverts in the last big storm. All three of these streams are considered to be at high risk for erosion and require larger structures than usual. These student engineers are given a cross-sectional diagram of each of the three streams. For each diagram, students will measure the bankfull width and multiply it first by 1.0 and then by 1.2 to find the **minimum** width a culvert must be for this stream, as required in sensitive streams by the Vermont Agency of Natural Resources.

If you feel that this activity would be challenging for your students, we suggest that you do the first example as a class discussion. Students should be able to do the next two examples in small groups or as individuals.

Bankfull Math Activity Teacher Key

Stream A

Line 2 is bankfull width; 4 inches long, or 8 feet long
Minimum replacement culvert: 9.6 feet wide

Stream B

Line 2 is bankfull width; 2 inches long, or 4 feet long
Minimum replacement culvert: 4.8 feet wide

Stream C

Line 1 is bankfull width; 3.5 inches long, or 7 feet long
Minimum replacement culvert: 8.4 feet wide

Bankfull Width Student Worksheet

Name: ____________________________________ Date: ___________

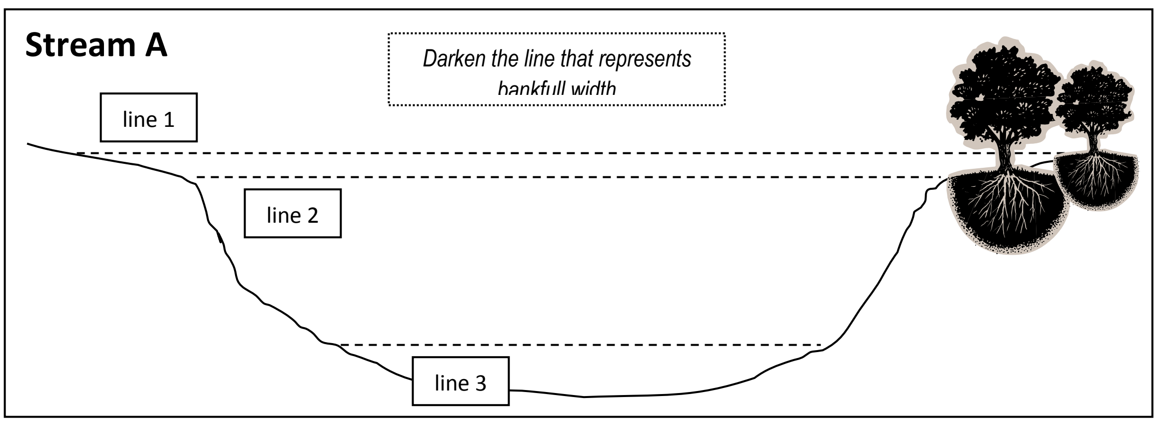
Three streams are shown in cross-section below. For each stream, follow these instructions:

4. Find the dotted line that represents bankfull for that stream. Darken that line by drawing over it with your pencil. Your darkened line shows the stream's bankfull width.
5. Use a ruler to measure the length of that bankfull width line, and record it in the space provided.
6. Convert the length to feet, using this scale:

   ½ inch on paper = 1 foot on imaginary stream
   (Round to the nearest ½ inch)

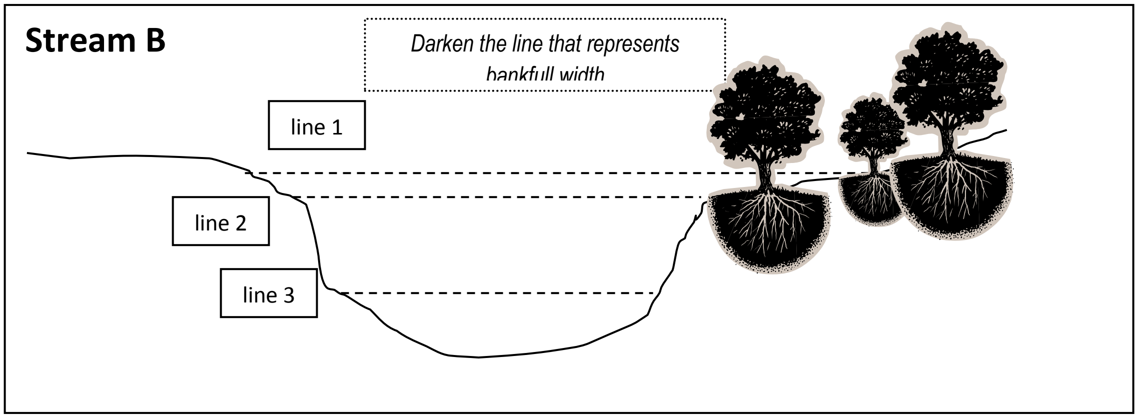
   Example: The bankfull width line on your paper is 3 inches long. Using the scale above, 3 inches on the paper = 3 x 2 = 6 feet bankfull width for this stream.

5. Multiply your bankfull width by 1.2 to get the *minimum* culvert width required by the State of Vermont for sensitive streams.



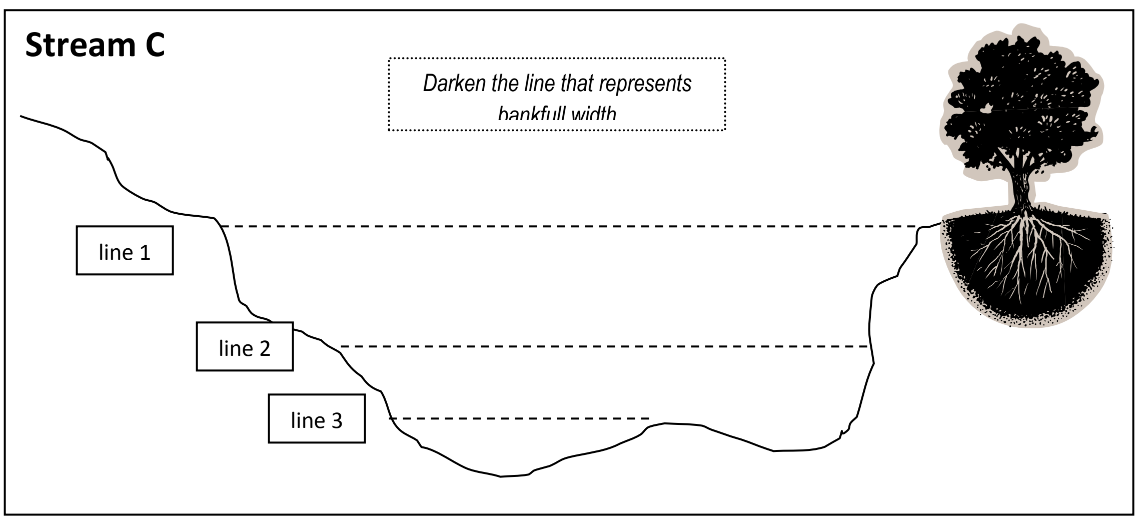
Bankfull width: ___________ inches x 2 = ___________ feet
(length of line)

Minimum culvert width: ____________ x 1.2 = ________ feet
(bankfull width)



Bankfull width: __________ inches x 2 = __________ feet
(length of line)

Minimum culvert width: ___________ x 1.2 = ________ feet
(bankfull width)



Bankfull width: __________ inches x 2 = __________ feet
(length of line)

Minimum culvert width: ___________ x 1.2 = ________ feet
(bankfull width)

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Culvert Field Sheet

Name: ______________________________ Date: ______________________

Culvert Location			
Description of Location			
Road Name		Latitude	
		Longitude	
Road Type	paved	dirt/gravel	trail / railroad
Stream Name			

Measurements			
Bankfull Widths (measure in 3 different locations upstream of culvert)		Culvert Height (measured at inlet)	ft in
	ft in		
	ft in		
	ft in	Culvert Width (measured at inlet)	ft in
Average Bankfull Width (use the readings above to get an average)			
	ft in		

Culvert Description		
Culvert Material (circle one or more)	Culvert Shape (circle one)	
concrete	round	
metal- corrugated	oval	or
metal- smooth	arch	
stone	box/square	
tank (recycled fuel tank, etc.)	squashed	

	Usually **negative** for flood resiliency and fish passage:	Usually **positive** for flood resiliency and fish passage:
Condition of the culvert (circle best description)	poor (lots of rust, holes, falling apart)	okay (some rust is fine)
Culvert is as wide as or wider than average bankfull	no	yes
Culvert inlet is blocked	yes	no
• If yes, circle material(s) present	wood debris sediment	
Water inside the culvert is as deep as in the stream above the culvert	no	yes
Streambed inside culvert looks like a natural streambed	no	yes
• If no, circle best description of the streambed in culvert	just looks like metal or concrete there are a few rocks or a little debris present	
Erosion around culvert (trees falling in, raw banks)	yes	no
• If yes, circle location(s) of erosion	upstream downstream	
Culvert outlet perched	yes	no
• If yes, measure distance of drop from bottom of culvert to bottom of stream	ft in	

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Culvert Conclusions Worksheet

(to be filled out after fieldwork and review of data)

Name(s): ____________________________________ Date: _____________________

Flood Resiliency

Is the culvert flood resilient?

Why? Support your conclusion with at least 2 pieces of evidence observed in the field.

Fish Passage

Is the culvert fish friendly?

Why? Support your conclusion with at least 2 pieces of evidence observed in the field.

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How would you improve the culvert to make it more flood resilient and fish friendly? Suggest at least 2 changes in the space below.

Bonus

At least how big should the culvert be in order to be considered flood resilient?	
Current culvert width	
Bankfull width	
Better culvert width (1.2 x bankfull width)	
Show your work:	

Post-fieldwork Discussion and Activities

<u>Before Beginning</u>, please gather the following papers:

- ❒ *Culvert Notes* (for discussion leader)
- ❒ Students' *Culvert Field Sheets*
- ❒ Students' *Culvert Conclusions* worksheets

After fieldwork has been completed and you've returned to the classroom, it's time to go over the data that was collected in the field. We suggest that you review all data with students to ensure accuracy and discuss the meaning of the data. This discussion can be led by MWR staff or by a teacher equipped with the *Culvert Notes* sheet.

Step 1: **Make sure data in field sheets is consistent and accurate**

Gather students together and ensure all students have their completed field sheets in front of them. (If you designated a note-taker in the field, each student should have a blank field sheet in front of him/her to complete during discussion, except for the teacher or note-taker). If possible, project a nice photo of the culvert on the board.

- Go through each field (section) on the field sheet, making sure the data is accurate and complete.

- As you go, use the *Culvert Notes* to facilitate a discussion about the answers and why the question is important. The *Culvert Notes* are organized in the same order as the field sheet and are coded to note which factors are important to flood resiliency and fish passage.

  Students may not have answered all questions in the same way, but through discussion you should be able to all agree on an answer so that everyone ends up with the same data. ** Students should notice that all of the "bad" symptoms are on the left and all of the "good" symptoms are on the far right of the field sheet (this will be helpful in the next step).**

- A few additional thoughts:

  - Students may have different measurements for bankfull because it is a subjective measurement and can vary slightly along the length of the stream. If you'll be calculating the width of a well-sized culvert (one that is >120% of bankfull), it will be easiest if everyone uses the same number for bankfull. (You can calculate an average, or use the most common value if averaging is an unfamiliar concept to the class). Also make sure that everyone is using the same units! (The field sheet uses feet and inches rather than meters and centimeters.)

- If there is disagreement about the size of the culvert, go with whatever number was recorded by the majority of students (not the average).

Step 2: **Synthesizing data: use evidence to make and support conclusions**

Working as a class, as individuals, or in small groups, students decide if the culvert is flood resilient and/or fish friendly and support those conclusions with evidence in the *Culvert Conclusions (post-fieldwork)* worksheet.

Have students describe their suggested changes to make the culvert more flood resilient and/or fish friendly, and explain their reasoning.

Step 3: **Where do we go from here? Optional extensions**

These questions can be part of a class discussion, can be explored in small groups, or can be completed as an individual assignment.

- *Describe what happened during a storm like Irene when culverts weren't able to function properly.*

- *Investigate why [habitat connectivity] is such an important issue for native brook trout or salamanders.*

- *Mapping: find your culvert on a map or Google Earth. If it's not fish friendly, figure out how much fish habitat you could open up by making it fish friendly (For example, by replacing a pipe with an arch or increasing its wide to bankfull width). Are there other road crossings that need to be [improved too? Are they above or below your culvert? How would you prioritize culvert replacement?*

- *Calculating costs: compare the installation of a large permanent culvert to the installation of a smaller one that washes out frequently. In reality this is a difficult comparison to make because there are so many unknowns. Factors that go into cost estimates including excavation, the culvert itself, road-fill and contractor time as well as the potential costs of road washouts and property damage that may result from an undersized culvert.*

- *Sketch the stream in cross-section, show what the culvert looks like now and how much bigger an appropriately sized culvert would be.* ***(Note: If you would like to do this to scale, you will need to take measurements in the field.)*** *Here is the simplest way to do this:*
    - *Start on the right bank as you face upstream. Run a tape measure across the stream, starting at the point on the bank that indicates bankfull. (Make sure that the tape is anchored well by students or rocks and is as taut as possible - it should be above the water). Your first measurement will occur at the start of the tape and will be "Bankfull river right, 0 inches".*
    - *Move along the measuring tape down the bank and across the river. At each 1 foot interval along the tape, measure the height from the streambed to the tape, and record the measurement in feet and/or inches. Continue taking height measurements at each 1 foot interval along the tape until you reach "Bankfull river left, 0 inches".*
    - *Back in the classroom, you can use a computer program like Excel to draw the cross-section or you can do it by hand using graph paper.*
    - *After your cross-section is drawn, you can figure out the scale and draw the current culvert as well as an appropriately sized culvert on the graph.*

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Culvert Notes

Culverts are **FLOOD RESILIENT** when they are able to pass water, sediment and debris at high flows, and when the culvert and the land around it are not damaged during flood events.

Culverts are **FISH FRIENDLY** when there is no change in the stream from a fish's point of view, and it can move freely through the culvert to reach upstream and downstream habitat.

Usually, FLOOD RESILIENT culverts are also FISH FRIENDLY!

Here are some factors that affect whether a culvert is flood resilient and fish friendly:

The **condition of the culvert** influences flood resiliency. A culvert that is in poor condition (lots of rust, crumbling concrete) will not be able to withstand the increased pressure of high water events. This can cause the culvert to fail, which can lead to flood damage downstream (see below).

The relationship between culvert width and **bankfull width** is an important factor in both flood resiliency and fish passage**.** In 2013, the Vermont Agency of Natural Resources Stream Alteration Permit requires new culverts to be at least 20% (one-fifth) wider than the bankfull width to accommodate high water events. Many of the culverts that failed during Tropical Storm Irene did not span the bankfull width (measured upstream, away from the influence of the culvert), and were not able to pass flood waters and debris.

Undersized culverts restrict water flow, increasing the power of the water passing through – just like placing your thumb over a garden hose increases the power of the spray. Water coming out of an undersized culvert can scour out the bottom of the streambed downstream of the culvert outlet, creating a plunge pool. Erosion is a natural process and occurs in all streams, but the increased power of water coming out of an undersized culvert can cause too much erosion too quickly.

Undersized culverts can also cause problems upstream. If high water flows cannot pass freely through the culvert, water pools upstream of the culvert inlet, turning like a whirlpool in a draining bathtub. The whirlpool action can scour out the streambed and streambanks upstream of the culvert inlet. In addition, sediment and debris being carried by the water settles out and creates piles upstream of the culvert inlet. This can further block the culvert and lead to more flooding and erosion.

If **debris is blocking the culvert inlet**, the culvert may not be wide enough to pass high water and debris. The debris may also be a barrier to fish passing upstream through the culvert. Restricting flow through the culvert increases the power of the water (remember the garden hose) and can cause erosion both upstream and downstream of the culvert. If the culvert becomes completely blocked or "plugged" with debris during a high water event, water will find another way around – often washing away the road or other structures nearby.

If the **water inside the culvert is shallower than in the stream above the culvert**, fish may not be able to remain submerged and move through the culvert. This is a physical barrier to fish passage.

If **the bottom of the culvert looks different than the natural streambed above the culvert**, the culvert may be a barrier to fish passage. Streambeds and culvert beds that are covered by various materials (rocks, sand, wood, etc.) have added "roughness" that slows down the water and provides resting spots for fish as they move upstream.

Sometimes it is difficult to determine bankfull width accurately, so we look for evidence that the culvert is undersized and causing erosion. **Evidence of erosion** includes: raw (eroded) banks, trees falling in, a pool at the culvert inlet, a deep plunge pool at the culvert outlet, and a "perched" culvert (see below). As mentioned above, undersized culverts restrict the flow of water during flood events (just like placing your thumb over a garden hose increases the power of the spray), causing increased erosion.

A **perched culvert** has a significant drop between the culvert outlet and the streambed below. Although native trout can "jump" over certain obstacles as they move upstream, the drop between the culvert outlet and the streambed can be higher than native trout can jump. As a result, a perched culvert can be a barrier to fish passage