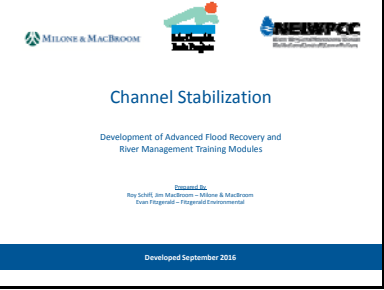
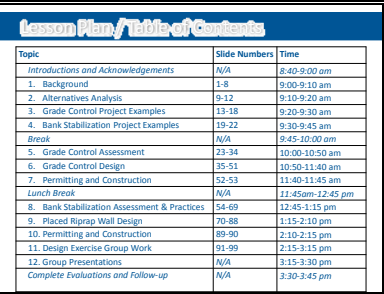



<p><b>Slide 1</b></p>	 <p>The slide features logos for Melrose &amp; MacBroome, a Vermont State logo, and NEWPPCC. The title is "Channel Stabilization". Below it, the subtitle reads "Development of Advanced Flood Recovery and River Management Training Modules". At the bottom, it says "Developed September 2016".</p>	<ul style="list-style-type: none"> <li>• Goals: Accelerate post flood infrastructure recovery, reduce future flood risks, and reduce river impacts.</li> <li>• Recall that this is Tier 3 of the Vermont Rivers and Roads Training. See if attendees have taken Tiers 1 and 2. If not direct them to Tier 1 online (<a href="http://wsmd.vt.gov/rivers/roadstraining/">http://wsmd.vt.gov/rivers/roadstraining/</a>) and to VTDEC for Tier 2.</li> </ul>																																																			
<p><b>Slide 2</b></p>	 <p>The slide is titled "Lesson Plan/ Table of Contents" and contains a table with the following data:</p> <table border="1"> <thead> <tr> <th>Topic</th> <th>Slide Numbers</th> <th>Time</th> </tr> </thead> <tbody> <tr> <td>Introductions and Acknowledgements</td> <td>N/A</td> <td>8:40-9:00 am</td> </tr> <tr> <td>1. Background</td> <td>1-8</td> <td>9:00-9:10 am</td> </tr> <tr> <td>2. Alternatives Analysis</td> <td>9-12</td> <td>9:10-9:20 am</td> </tr> <tr> <td>3. Grade Control Project Examples</td> <td>13-18</td> <td>9:20-9:30 am</td> </tr> <tr> <td>4. Bank Stabilization Project Examples</td> <td>19-22</td> <td>9:30-9:45 am</td> </tr> <tr> <td>Break</td> <td>N/A</td> <td>9:45-10:00 am</td> </tr> <tr> <td>5. Grade Control Assessment</td> <td>23-34</td> <td>10:00-10:50 am</td> </tr> <tr> <td>6. Grade Control Design</td> <td>35-51</td> <td>10:50-11:40 am</td> </tr> <tr> <td>7. Permitting and Construction</td> <td>52-53</td> <td>11:40-11:45 am</td> </tr> <tr> <td>Lunch Break</td> <td>N/A</td> <td>11:45am-12:45 pm</td> </tr> <tr> <td>8. Bank Stabilization Assessment &amp; Practices</td> <td>54-69</td> <td>12:45-1:15 pm</td> </tr> <tr> <td>9. Placed Riprap Wall Design</td> <td>70-88</td> <td>1:15-2:10 pm</td> </tr> <tr> <td>10. Permitting and Construction</td> <td>89-90</td> <td>2:10-2:15 pm</td> </tr> <tr> <td>11. Design Exercise Group Work</td> <td>91-99</td> <td>2:15-3:15 pm</td> </tr> <tr> <td>12. Group Presentations</td> <td>N/A</td> <td>3:15-3:30 pm</td> </tr> <tr> <td>Complete Evaluations and Follow-up</td> <td>N/A</td> <td>3:30-3:45 pm</td> </tr> </tbody> </table>	Topic	Slide Numbers	Time	Introductions and Acknowledgements	N/A	8:40-9:00 am	1. Background	1-8	9:00-9:10 am	2. Alternatives Analysis	9-12	9:10-9:20 am	3. Grade Control Project Examples	13-18	9:20-9:30 am	4. Bank Stabilization Project Examples	19-22	9:30-9:45 am	Break	N/A	9:45-10:00 am	5. Grade Control Assessment	23-34	10:00-10:50 am	6. Grade Control Design	35-51	10:50-11:40 am	7. Permitting and Construction	52-53	11:40-11:45 am	Lunch Break	N/A	11:45am-12:45 pm	8. Bank Stabilization Assessment & Practices	54-69	12:45-1:15 pm	9. Placed Riprap Wall Design	70-88	1:15-2:10 pm	10. Permitting and Construction	89-90	2:10-2:15 pm	11. Design Exercise Group Work	91-99	2:15-3:15 pm	12. Group Presentations	N/A	3:15-3:30 pm	Complete Evaluations and Follow-up	N/A	3:30-3:45 pm	<ul style="list-style-type: none"> <li>• Review lesson plan and slide ranges that serves as table of contents.</li> </ul>
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<p><b>Slide 3</b></p>	 <p>The slide is titled "Large-Scale Damages" and shows a photograph of a river with significant erosion and debris on the banks. Two people are standing on the right bank, looking at the damage.</p>	<ul style="list-style-type: none"> <li>• Set stage that this is not comprehensive on softer stabilization methods, especially where risk is lower.</li> <li>• This is how to minimize impacts and need for repeat work, typically at high risk sites.</li> </ul>																																																			

## Slide 4



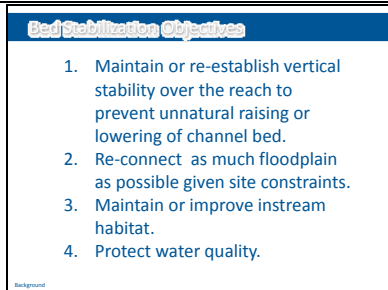
- Set stage that this is not comprehensive on softer stabilization methods, especially where risk is lower.
- This is how to minimize impacts and need for repeat work, typically at high risk sites.

## Slide 5

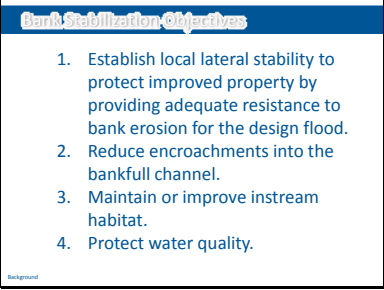
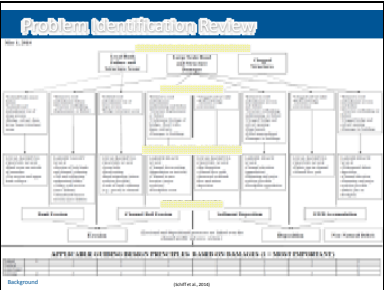
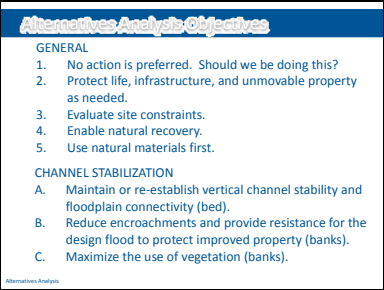


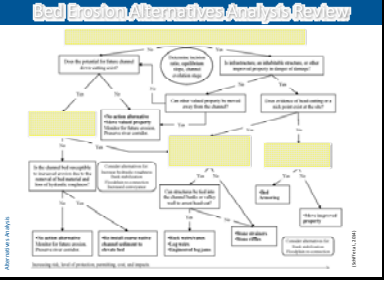
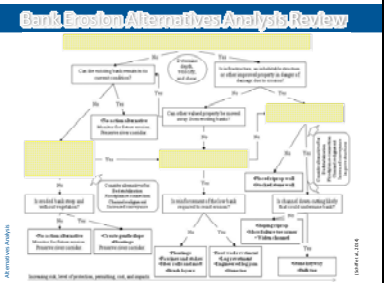
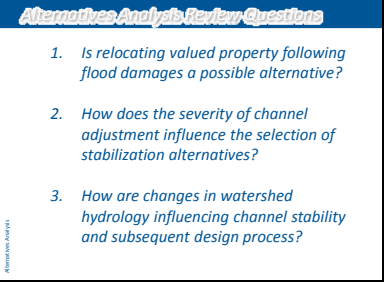
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- This is how to minimize impacts and need for repeat work, typically at high risk sites.


## Slide 6

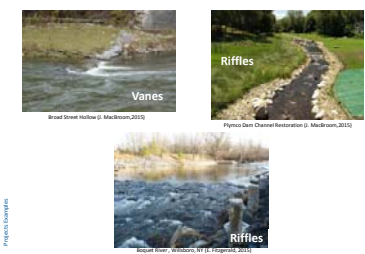





Review overarching bed stabilization objectives from Vermont Standard River Management Principals and Practices (<http://www.anr.state.vt.us/dec/waterq/rivers.htm>).

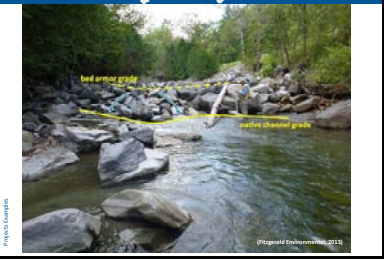


<p><b>Slide 7</b></p>	 <p><b>Bank Stabilization Objectives</b></p> <ol style="list-style-type: none"> <li>1. Establish local lateral stability to protect improved property by providing adequate resistance to bank erosion for the design flood.</li> <li>2. Reduce encroachments into the bankfull channel.</li> <li>3. Maintain or improve instream habitat.</li> <li>4. Protect water quality.</li> </ol> <p>Background</p>	<p>Review overarching bank stabilization objectives from Vermont Standard River Management Principles and Practices (<a href="http://www.anr.state.vt.us/dec/waterq/rivers.htm">http://www.anr.state.vt.us/dec/waterq/rivers.htm</a>).</p>
<p><b>Slide 8</b></p>	 <p><b>Problem Identification Review</b></p> <p>Slide 8, 2014</p> <p>Background</p>	<ul style="list-style-type: none"> <li>• This table is from the Vermont Standard River Management Principles and Practices (Schiff et al., 2014) (<a href="http://www.anr.state.vt.us/dec/waterq/rivers/docs/SRMPP_1.3.pdf">http://www.anr.state.vt.us/dec/waterq/rivers/docs/SRMPP_1.3.pdf</a>).</li> <li>• Quick review as attendees should be familiar with this document or should review it on own.</li> <li>• Link observed damages to river channel conditions to river processes.</li> <li>• What is ultimately driving damages?</li> </ul>
<p><b>Slide 9</b></p>	 <p><b>Alternatives Analysis Objectives</b></p> <p>GENERAL</p> <ol style="list-style-type: none"> <li>1. No action is preferred. Should we be doing this?</li> <li>2. Protect life, infrastructure, and unmovable property as needed.</li> <li>3. Evaluate site constraints.</li> <li>4. Enable natural recovery.</li> <li>5. Use natural materials first.</li> </ol> <p>CHANNEL STABILIZATION</p> <ol style="list-style-type: none"> <li>A. Maintain or re-establish vertical channel stability and floodplain connectivity (bed).</li> <li>B. Reduce encroachments and provide resistance for the design flood to protect improved property (banks).</li> <li>C. Maximize the use of vegetation (banks).</li> </ol> <p>Alternatives Analysis</p>	<ul style="list-style-type: none"> <li>• Review list of general and practice-specific alternatives analysis objectives.</li> </ul>

<p><b>Slide 10</b></p>	 <p>The flowchart 'Bed Erosion Alternatives Analysis Review' starts with 'Does the property have a threat of bed erosion?' and branches into 'Yes' and 'No'. The 'Yes' path leads to 'Can the erosion be stopped by natural means?' and then to 'Can the erosion be stopped by structural means?' before reaching 'Can the erosion be stopped by a combination of natural and structural means?'. The 'No' path leads to 'Can the erosion be stopped by natural means?' and then to 'Can the erosion be stopped by structural means?'. The flowchart includes various decision points and outcomes, such as 'The erosion alternative is not feasible', 'The erosion alternative is feasible', 'The erosion alternative is not feasible due to cost', and 'The erosion alternative is not feasible due to environmental impact'.</p>	<ul style="list-style-type: none"> <li>• Review the chart that is from Vermont Standard River Management Principles and Practices.</li> <li>• Key questions and turning points in analysis are highlighted.</li> <li>• Minimize work / impact / cost where possible.</li> <li>• Note lower risk actions.</li> </ul>
<p><b>Slide 11</b></p>	 <p>The flowchart 'Bank Erosion Alternatives Analysis Review' starts with 'Does the property have a threat of bank erosion?' and branches into 'Yes' and 'No'. The 'Yes' path leads to 'Can the erosion be stopped by natural means?' and then to 'Can the erosion be stopped by structural means?'. The 'No' path leads to 'Can the erosion be stopped by natural means?' and then to 'Can the erosion be stopped by structural means?'. The flowchart includes various decision points and outcomes, such as 'The erosion alternative is not feasible', 'The erosion alternative is feasible', 'The erosion alternative is not feasible due to cost', and 'The erosion alternative is not feasible due to environmental impact'.</p>	<ul style="list-style-type: none"> <li>• Review the chart that is from Vermont Standard River Management Principles and Practices.</li> <li>• Key questions and turning points in analysis are highlighted.</li> <li>• Minimize work / impact / cost where possible.</li> <li>• Note lower risk actions.</li> </ul>
<p><b>Slide 12</b></p>	 <p>The flowchart 'Alternatives Analysis Review Questions' lists three key questions for river management alternatives:</p> <ol style="list-style-type: none"> <li>1. Is relocating valued property following flood damages a possible alternative?</li> <li>2. How does the severity of channel adjustment influence the selection of stabilization alternatives?</li> <li>3. How are changes in watershed hydrology influencing channel stability and subsequent design process?</li> </ol>	<p><b>ANSWERS:</b></p> <ul style="list-style-type: none"> <li>• Definitely. Get out of the way wherever possible. It is the safest and cheapest approach in the long run.</li> <li>• The severity of erosion drives the selection of alternatives. First and foremost, if the erosion is not severe and/or not threatening property or infrastructure, there is no need for action and the river can be left to heal at its own pace. Where property is threatened the severity of erosion, along with the site constraints, dictates which practice is appropriate and will resist the erosion forces specific to the site; i.e., sites with lower power/erosion potential may</li> </ul>


		<p>call for less invasive, natural approaches such as bioengineering.</p> <ul style="list-style-type: none"> <li>• We know that climate change and upstream development are changing watershed hydrology, which in turn affects the rate and magnitude of channel adjustments caused by floods. Need to consider using conservative hydrology estimates to evaluate flood velocity, surface water elevation, etc.</li> </ul>
Slide 13		<ul style="list-style-type: none"> <li>• Next series of slides are examples of grade control practices, going from least invasive/structural to most (bed armoring).</li> <li>• Pictures of the South Branch Tweed River along VT Route 100 in Killington, VT.</li> <li>• Dozens of sites along the Vermont State Highway System called for a combination of bank stabilization and minor bed stabilization through the re-installation of native bed material that was pulled out the bed and draped along the embankment during the emergency repair work.</li> <li>• This work is typically done in conjunction with bank stabilization such as a placed riprap wall, and serves to reestablish roughness in the bed, restore a more natural longitudinal profile and bed features, thereby setting the river up for reforming smaller scale habitat features.</li> </ul>

<p><b>Slide 14</b></p>	<p><b>Grade Control Project Examples: Vanes, Riffles, Streamers</b></p>  <p>The image contains three photographs of stream restoration projects. The top left photo shows 'Vanes' installed in a stream at Broad Street Hollow, VT. The top right photo shows 'Riffles' installed in a stream at Pymmett Dam Channel, VT. The bottom photo shows 'Riffles' installed in a stream at Broad Street Hollow, VT.</p>	<ul style="list-style-type: none"> <li>Reconstructed riffles typically following disturbance to the channel bed during construction, such as dam removal or temporary in-stream diversions during construction. These can range from dozens of intentionally placed boulders to simply seeding the bed with a few boulders.</li> <li>Vanes or spurs do not span the entire channel and are used to deflect flow away from vulnerable banks or infrastructure, and create habitat complexity.</li> <li>Proper sizing of rock sizes requires force-resistance calculations.</li> </ul>
<p><b>Slide 15</b></p>	<p><b>Grade Control Project Examples: Weirs</b></p>  <p>The image contains four photographs of stream restoration projects using weirs. The top left photo shows a weir at Green Brook, VT. The top right photo shows a weir at Green Brook, VT. The bottom left photo shows a weir at Green Brook, VT. The bottom right photo shows a weir at Broad Street Hollow, VT.</p>	<ul style="list-style-type: none"> <li>Weirs are used to set the profile of the channel, prevent incision, and create habitat features.</li> <li>Spacing along channel and configuration depends on natural channel tendencies.</li> <li>Proper sizing of rock sizes requires force-resistance calculations.</li> <li>We will get into the design of these features in more detail.</li> </ul>

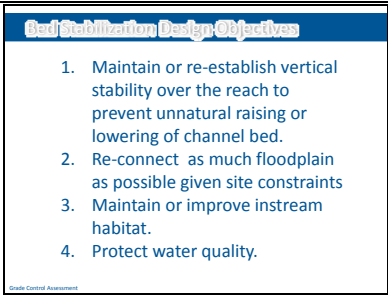
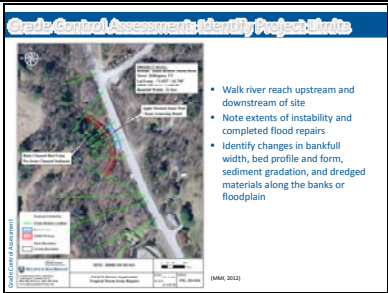
<p><b>Slide 16</b></p>	<p><b>Grade Control Project Examples: Bed Armor</b></p>  <p>Successful Bed Armor Project Post-Irene South Branch of the Tweed River, VT Route 100, Killington</p> <p>Projects Examples</p>	<ul style="list-style-type: none"> <li>• Bed armor is the most extreme, invasive approach to stabilizing an incising stream. It has become more common in flood recovery work and makes good economic sense in some cases, but it requires some design work up front to avoid problems – can't just end dump Type IV rock in channel and walk away.</li> <li>• Numerous case studies of bed armor – good and bad – during Tropical Storm Irene recovery in Vermont.</li> <li>• Pictures from an example of a successful bed armor installation as part of permanent repairs along Route 100 in Killington.</li> <li>• Bed armor is not visible on right because it was buried beneath native substrate. Sequence is specified in the Vermont Standard River Management Principles and Practices.</li> </ul>
<p><b>Slide 17</b></p>	<p><b>Grade Control Project Examples: Bed Armor</b></p>  <p>Problematic Irene Bed Armor Projects: Whetstone Brook, VT Route 9, Marlboro, VT Dover Brook, VT Route 100, Wardsboro, VT</p> <p>Projects Examples</p>	<ul style="list-style-type: none"> <li>• Many examples of aggressive bed armor projects in Vermont needing follow up work to address AOP barriers.</li> <li>• Projects were “successful” in preventing incision in channel and protecting the adjacent road embankment.</li> <li>• However rock depth and gradation (no fines) resulted in subsurface flow for many hundred feet in some cases.</li> </ul>

<p><b>Slide 18</b></p>	<p><b>Grade Control Project Examples: Bed Armor</b></p> 	<p>Even when the flow is not subsurface through the bed armor, the downstream transition to the natural bed can be a problem for AOP if it is too abrupt. Example of AOP barrier on the Sleepers River in Danville, VT.</p>
<p><b>Slide 19</b></p>	<p><b>Bank Stabilization Project Examples: Sloping Riprap</b></p> 	<ul style="list-style-type: none"> <li>• Traditional post-Irene slope stabilization along 4<sup>th</sup> order channel in Pittsfield, VT.</li> <li>• 1V:2H or 1V:1.5H slope with grubblings and seeding on upper slope above common flood levels.</li> <li>• Key depth depends on scour risk. Rock sizing depends on flood velocity and elevation.</li> </ul>
<p><b>Slide 20</b></p>	<p><b>Bank Stabilization Project Examples: Placed Riprap</b></p> 	<ul style="list-style-type: none"> <li>• Placed riprap wall (i.e., stacked stone wall) very common practice in Vermont for permanent Irene repairs. Gains space for a bankfull channel in confined settings.</li> <li>• Most common and appropriate in confined 3<sup>rd</sup> and 4<sup>th</sup> order channels where roadway occupies a large portion of the narrow valley/floodplain, and lateral space is a premium.</li> <li>• May not be appropriate on larger rivers due to potential instability with greater scour depths. Relatively little space gained on a large river over sloping armor approach.</li> <li>• Large, blocky rock at base keyed into the channel bed to a depth below</li> </ul>

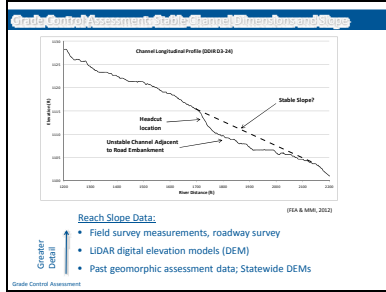


		<p>predicted scour.</p> <ul style="list-style-type: none"> <li>• Type III or II stone above wall depending on large flood elevations and velocities.</li> <li>• Grubbings and seeding on slope above wall.</li> </ul>
Slide 21		<ul style="list-style-type: none"> <li>• Bioengineering describes a variety of practices that are well documented in stream restoration literature. Includes combinations of fabrics (ie, coir), plantings, and seeding.</li> <li>• Appropriate for lower power/energy settings or higher on banks where velocity and shear potential is lower. Bioengineering methods can fail when designers underestimated the erosion forces.</li> <li>• Bioengineering practices complement traditional armoring approaches by working to naturalize the banks and riparian corridor.</li> <li>• Engineered log jams (ELJs) are large masses of trees and soil/stones projecting from the bank. They are used to deflect flow, push the thalweg away from the bank, and create habitat complexity in the channel.</li> </ul>



		discussion.
Slide 25		Review overarching bed stabilization objectives from Vermont Standard River Management Principals and Practices ( <a href="http://www.anr.state.vt.us/dec/waterq/rivers.htm">http://www.anr.state.vt.us/dec/waterq/rivers.htm</a> ).
Slide 26		<ul style="list-style-type: none"> <li>• Review bed stabilization assessment steps from Vermont Standard River Management Principals and Practices (<a href="http://www.anr.state.vt.us/dec/waterq/rivers.htm">http://www.anr.state.vt.us/dec/waterq/rivers.htm</a>)</li> <li>• Need to observe reach to put the damage site characteristics into context of river adjustments</li> <li>• Look at changes in channel morphology through the damage site and upstream/downstream reach that may influence project site.</li> </ul>

## Slide 27



- Evaluate reach slope and channel dimensions.
- Field survey data needed for larger projects during non-emergency work.
- LiDAR is an appropriate tool to evaluate reach channel slope and dimensions but has limitations (does not penetrate water well).
- Past geomorphic assessment data may be available for reach, including cross-sections and reference bankfull dimensions.
- We will get into hydraulic geometry and channel sizing in more detail in the bank stabilization module.
- Observe longitudinal profile to understand reach and local slope (fit site scale into reach scale appropriately).

## Slide 28

**Channel Slope**

What is reach slope as determined from field survey and Manning's equation?

Compare reach and valley slope to calculated equilibrium slopes below.

**Stable channel dimensions:**

$V = 48.3 \cdot R^{2/3} \cdot S^{1/2}$  (Manning's equation)

$V = \frac{Q}{A}$  (Continuity equation)

$Q = 100 \text{ cfs}$  (Discharge)

$A = 100 \text{ ft}^2$  (Cross-sectional area)

$R = \frac{A}{P}$  (Hydraulic radius)

$P = 100 \text{ ft}$  (Wetted perimeter)

$S = \frac{V^2}{48.3^2 \cdot R^{4/3}}$  (Slope)

**Stable channel dimensions:**

$V = 48.3 \cdot R^{2/3} \cdot S^{1/2}$  (Manning's equation)

$V = \frac{Q}{A}$  (Continuity equation)

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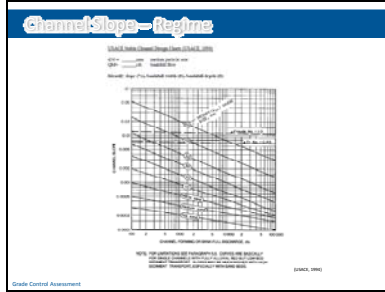
$P = 100 \text{ ft}$  (Wetted perimeter)

$S = \frac{V^2}{48.3^2 \cdot R^{4/3}}$  (Slope)

Reach Control Assessment

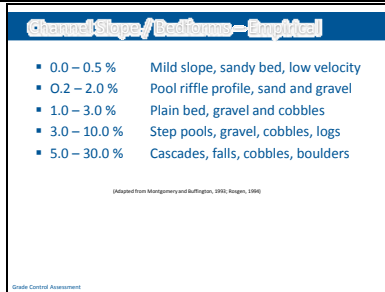
- Slope is a key parameter in channel design to leave a stable channel once work is complete.
- What is reference reach slope?
- Use equations to determine what the slope is based on sediment size and channel dimensions.
- Army Corps has handy plot for this.
- Compare slope predictions from reference reach, sediment stability equation, and regime equation, and compare to current conditions.
- Solve for S

# Slide 29



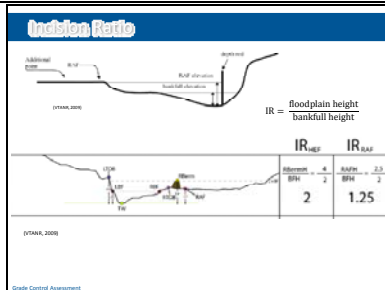
- Use regime equation or plot as a first prediction since it is quick.
- Compare to local observations.

# Slide 30

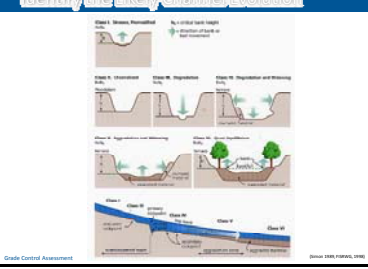
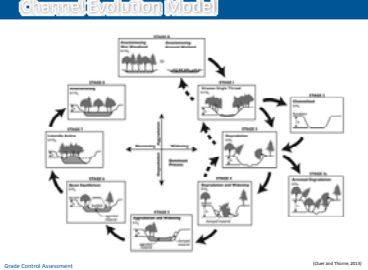
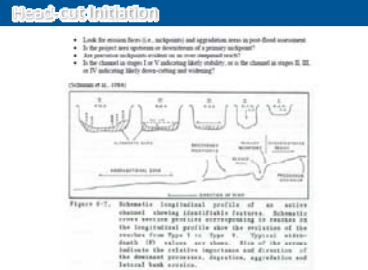


- This is a guide for initial thinking to relate slope to channel type / bedforms.
- The range for braided and wandering channels can be wide and overlap several of these ranges.
- Caution that this list does not explicitly account for channel size.

# Slide 31

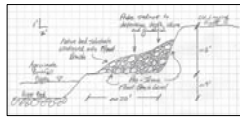


- Builds on Tier 2 introduction of definition.
- Incision ratio is a more local and current indicator of floodplain access.
- $IR = \text{floodplain height} / \text{bankfull height}$ .  $IR = 1$  is well-connected floodplain during bankfull flood. Higher IR is less connected.
- Note change in IR due to berms.

<p><b>Slide 32</b></p>	<p><b>Identify the Likely Channel Evolution</b></p>  <p>Slide 32: Channel Evolution</p>	<ul style="list-style-type: none"> <li>• Quick review as covered in Tier 2. Does everyone get this?</li> <li>• Temporal change trajectory illustrated by channel evolution models (CEMs).</li> <li>• This model assumes that bedrock and natural bed armor is absent.</li> <li>• Most actively adjusting are CEM 2, 3, and 4.</li> <li>• This plot has recently been upgraded.</li> </ul>
<p><b>Slide 33</b></p>	<p><b>Channel Evolution Model</b></p>  <p>Slide 33: Channel Evolution Model</p>	<ul style="list-style-type: none"> <li>• This is a recent upgrade to CEM that includes habitat and ecosystem benefits</li> <li>• Notice additional steps that tend to fit altered channels better than the original models. See stage 3s.</li> <li>• Note state 7 could simulate high sediment load event.</li> </ul>
<p><b>Slide 34</b></p>	<p><b>Head-cut Initiation</b></p>  <p>Slide 34: Head-cut Initiation</p>	<ul style="list-style-type: none"> <li>• Original CEM, but also shows longitudinal profile with nickpoints.</li> <li>• See if nickpoints exist in the field up- or downstream of project.</li> <li>• Do aggradation areas exist?</li> <li>• Use the CEM and head-cut potential to understand how channel exists and may react to sediment removal.</li> <li>• Difference in scale is important as this trajectory and process can play out on tributaries and mainstem rivers. For example, Lilliesville Brook meeting the White River in Bethel where major sediment loading and then headcutting.</li> </ul>

### Slide 35

- Probe coarse sediments on channel margins, berms, and floodplains
- Estimate sediment gradation
- Test pit or exploratory trench may be necessary
- Use end-area method to estimate volume of deposit



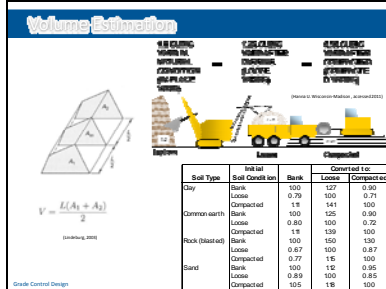
Profile of sediment material along the Henry Yellow Brook and VT Route 100 A-11 Bridgehead, between William Tupper Brook (Engelhardt Environmental, 2012)

Natural bed stabilization is commonly used:

- When historic flood recovery work resulted in excessive coarse sediment removal from the channel;
- When natural bed armor was stripped from the channel due to excessive stream power during a flood;
- In a channel that has cut down and is disconnected from its floodplain; and
- When historic berms are being removed to restore floodplain connection.

Need to begin by quantifying the sediment volume and gradation along the banks and windrows.

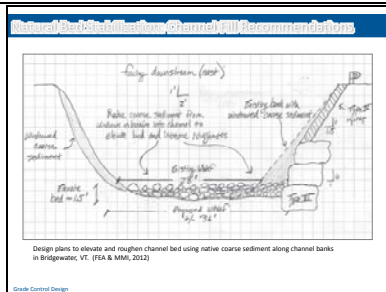
## Slide 36



If the bed stabilization work involves a large volume of sediment consider the following:

- Consider consolidation in your sediment volume estimates.
- Consolidation accounting can lead to changes in cost on the order of \$100,000's for large deposition events.  $(250,000 \text{ CY} * \$10/\text{CY} * 0.1 = \$250,000)$
- Agree upon consolidation factor at START of project after observing early excavations, transports, and compactions with contractor.
- Invest time up front in the project to agree upon consolidation factor, especially if the removal volume is over 10,000 CY.

## Slide 37



- Example of simple sketch from Irene repairs of bed roughening in conjunction with placed riprap wall.
- In this example relief of roadway not a concern so bed elevated to maximize channel width in a confined channel setting.

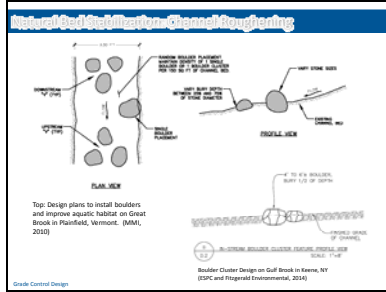


## Slide 38



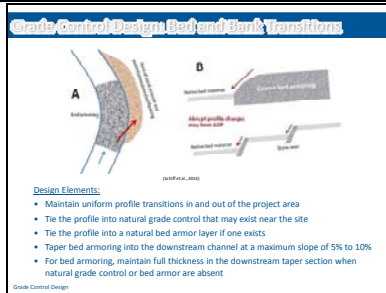
- After Irene this practice most commonly used in conjunction with bank stabilization where the coarse native bed material was stripped from the channel and placed on the bank. The pictures are from VT Route 73 in Goshen along the Neshobe River.
- Objective is to regain natural channel morphology and roughness as much as possible, and reconnect floodplain while minimizing risks to adjacent infrastructure.
- Evaluate reference channel morphology and incision ratio in the reach for targets.
- When working with contractors be clear on what you want to see in the channel roughness – “random” boulder placement is sometimes interpreted as uniform spacing of large boulders instead of clusters of boulders that resemble natural habitat. Take contractor down the river to view natural bedforms you want as end product!
- This is a corrective action for poor flood recovery and to reduce incision that typically is not performed away from floods since it would be channel/floodplain fill.

### Slide 39



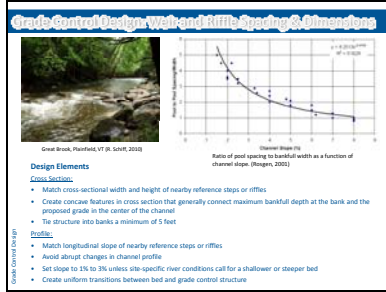
- Example plans of “random” boulder placement.
- These example shows boulders and boulder clusters that do not have “footers” and are not imbricated. Designs should consider the channel dimensions and expected forces (i.e., velocity and shear) in determining appropriate embedded depth and cluster configuration to remain stable during design floods.
- Largest boulders embedded into the channel so they will stay put in floods and recruit sediment/wood and create scour features downstream
- Remember that messy looking channels have the features fish are seeking!

### Slide 40



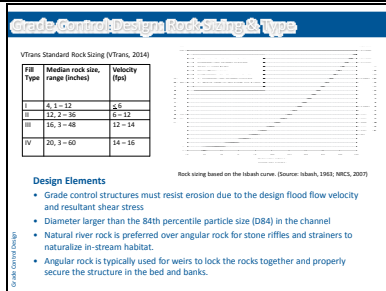
- Critical first step in evaluation/design is fitting grade control features into the reach profile.
- Account for natural grade control and/or bed armor elevations/profiles in upstream and downstream areas.
- Avoid common mistake of a steep transition of bed armor or weirs to in the downstream project area that might be an AOP barrier.

## Slide 41



- Riffle and step features often spaced naturally in channels based on channel slope and dimensions.
- Use spacing chart as a first cut guide, but observe natural spacing in the reach to confirm. Study the spacing, configuration, and rock size of natural steps/riffles to mimic in design.
- Ensure proper bank ties with weirs and concavity in cross-section to concentrate low flows in center of channel. Low flow channel width is typically 1/3 to 1/2 bankfull width.

## Slide 42



- Natural channels are instructive for immobile bed material. Observe average largest particle size at riffle heads or in steps to verify D84 or greater.
- For smaller projects cursory hydraulic analysis (e.g., single uniform flow calculation) may suffice for estimating velocity and sizing rock.
- For complex projects on larger rivers and with multiple grade control features hydraulic modeling may be required.
- Note differences in rock shape for weirs vs. riffles or strainers.

## Slide 43

**Grade Control Design: Rock Slopes & Types**

Table TR-10-1 Summary of techniques

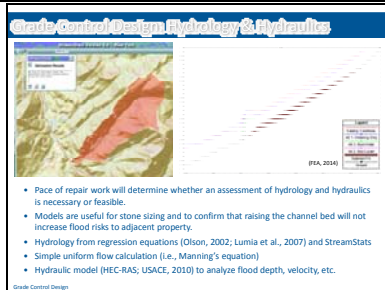
Technique	High or low average	Slopes	Type of application(s)
Reinforced	Both	Not specified	Bank reinforcement, sliding basins, river channels
RR Riprap	Both	<10%	Spill & overtopping for stable water impoundment
Monocut	Low	<2%	Bank reinforcement, bank protection, stream bed
RR and J-Riprap	High	10% to 10%	Overtopping, grade protection
RR and J-Riprap	High	10% to 10%	Overtopping, grade protection, grade protection
RR and J-Riprap	High	Not specified	Riprap before a rolling basin
USACE Steep Slope Riprap	Both	Not specified	Riprap stability
USACE Habitat Riprap	High	25% to 10%	Bank channel, grade protection
USACE Habitat Riprap	High	Not specified	Stream bank for habitat enhancement
USACE Habitat Riprap	Low	<10%	Bank reinforcement, bank protection, stream bed
USACE Habitat Riprap	Low	<10%	Stream bank protection, stream bed, stream bed

USACE (2010)


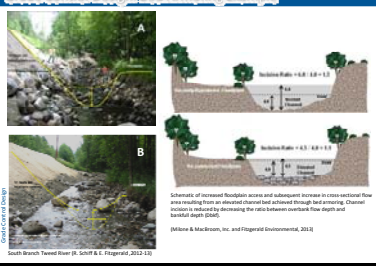
USACE (2010)

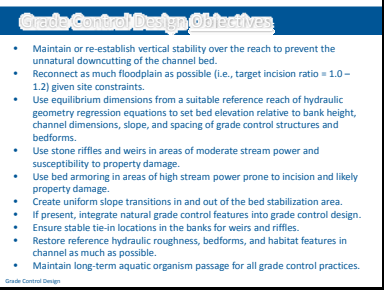
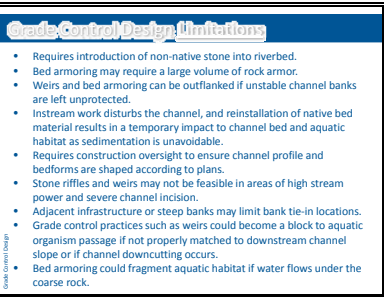
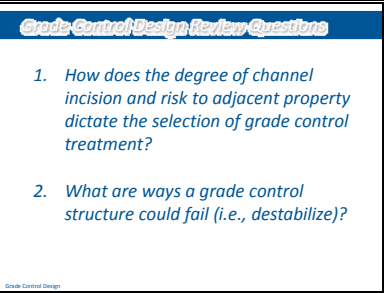
- Many rock sizing methods.
- See Isbash method common and good over wide range of slopes and energy levels.
- Maynard method commonly used for riffle-pool or flatter channels.
- USACE steep slope method applies to many steep streams in our region.

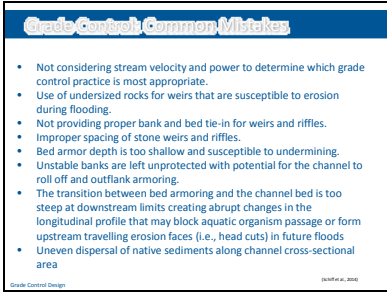
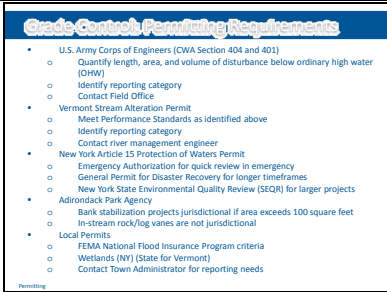
## Slide 44

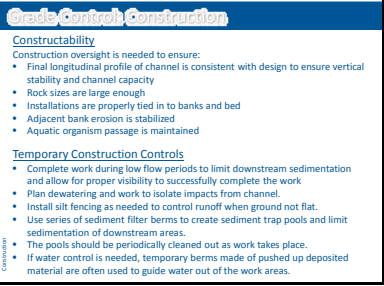

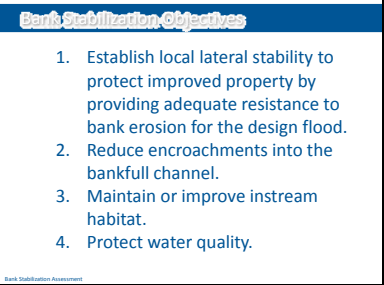


- If the project is large or complex or situated near infrastructure a full hydrology and hydraulic analysis may be required. This is usually not feasible during emergency repair work.
- Watershed hydrology readily available through USGS records and Streamstats, but flows on ungaged rivers may be underestimated where watershed slope is very high or soils are impervious.
- Climate change since 1970's appears to be causing increases in peak flows in the Northeast –consider adding 10% to design flows.
- Return flows should be checked against high water marks at site whenever possible.
- Smaller projects may only need a single velocity estimate.

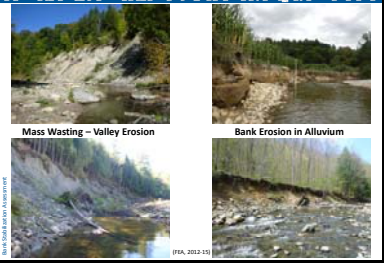

<p><b>Slide 45</b></p>	<p><b>Grade Control Design: Bed Armor Performance Standards</b></p>  <p><small>(Duke, 2004) (Figgs and Environmental, 2012)</small></p> <p><b>Vermont Standard River Management Principles and Practices</b></p> <ul style="list-style-type: none"> <li>• Halt channel downcutting.</li> <li>• Halt horizontal channel migration threatening infrastructure and unmovable habitable buildings. (Avoid horizontal channel migration along opposite bank of threatened infrastructure.)</li> <li>• Provide aquatic organism passage and continuous surface flow.</li> <li>• Create final channel dimensions and cross sections similar to adjacent channel</li> </ul> <p><small>Grade Control Design</small></p>	<p>Bed armor performance standards from VSRMPP.</p> <ul style="list-style-type: none"> <li>• Naturalize channel as much as possible.</li> <li>• Install rock in lifts by swapping native bed with imported rock.</li> </ul>
<p><b>Slide 46</b></p>	<p><b>Grade Control Design: Bed Armor Example</b></p>  <p><small>(Duke &amp; MacBrien, Inc. and Figgs and Environmental, 2012)</small></p> <p><small>South Branch Tweed River (A, 2007) B, C, Figgs and Environmental, 2012</small></p>	<ul style="list-style-type: none"> <li>• On right is schematic of elevated channel and reduced incision. Disconnected floodplain might only be inundated in large floods but after reconnection is accessed in more frequent floods (ie, 5 or 10-year flood)</li> <li>• Example of reinstallation of native bed material following a bed armor install on South Branch Tweed River in Killington, VT.</li> <li>• Note the bed has expected features including gravel bar on inside bend, low flow channel on outside bend, etc.</li> </ul>
<p><b>Slide 47</b></p>	<p><b>Summary – Grade Control Design</b></p> <p><u>Assessment</u></p> <ul style="list-style-type: none"> <li>• Longitudinal profile</li> <li>• Geomorphic stream type</li> <li>• Bankfull width and depth</li> <li>• Profile bed forms</li> <li>• Equilibrium sediment slope</li> <li>• Incision ratio</li> <li>• Channel evolution</li> </ul> <p><u>Design</u></p> <ul style="list-style-type: none"> <li>• Upstream and downstream limits</li> <li>• Channel profile and bed forms</li> <li>• Bed elevation and floodplain access</li> <li>• Bankfull and floodplain dimensions</li> <li>• Volume and gradation of native sediment (natural bed stabilization)</li> <li>• Channel and floodplain hydraulics</li> <li>• Structure spacing and dimensions (strainers, riffles, and weirs)</li> <li>• Rock type and sizing</li> <li>• Construction sequence and reinstallation of native river substrate for bed armor</li> </ul> <p><small>Grade Control Design</small></p>	<ul style="list-style-type: none"> <li>• Summary / checklist for future design use.</li> <li>• Mostly for future reference since we have covered throughout presentation.</li> </ul>


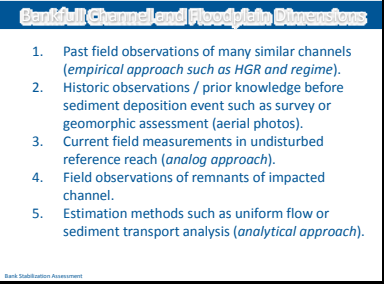
<p><b>Slide 48</b></p>	 <ul style="list-style-type: none"> <li>• Maintain or re-establish vertical stability over the reach to prevent the unnatural downcutting of the channel bed.</li> <li>• Reconnect as much floodplain as possible (i.e., target incision ratio = 1.0 – 1.2) given site constraints.</li> <li>• Use equilibrium dimensions from a suitable reference reach of hydraulic geometry regression equations to set bed elevation relative to bank height, channel dimensions, slope, and spacing of grade control structures and bedforms.</li> <li>• Use stone riffles and weirs in areas of moderate stream power and susceptibility to property damage.</li> <li>• Use bed armoring in areas of high stream power prone to incision and likely property damage.</li> <li>• Create uniform slope transitions in and out of the bed stabilization area.</li> <li>• If present, integrate natural grade control features into grade control design.</li> <li>• Ensure stable tie-in locations in the banks for weirs and riffles.</li> <li>• Restore reference hydraulic roughness, bedforms, and habitat features in channel as much as possible.</li> <li>• Maintain long-term aquatic organism passage for all grade control practices.</li> </ul>	<ul style="list-style-type: none"> <li>• Summary of key design objectives for future use.</li> <li>• Mostly for future reference since we have covered throughout presentation.</li> </ul>
<p><b>Slide 49</b></p>	 <ul style="list-style-type: none"> <li>• Requires introduction of non-native stone into riverbed.</li> <li>• Bed armoring may require a large volume of rock armor.</li> <li>• Weirs and bed armoring can be outflanked if unstable channel banks are left unprotected.</li> <li>• Instream work disturbs the channel, and reinstallation of native bed material results in a temporary impact to channel bed and aquatic habitat as sedimentation is unavoidable.</li> <li>• Requires construction oversight to ensure channel profile and bedforms are shaped according to plans.</li> <li>• Stone riffles and weirs may not be feasible in areas of high stream power and severe channel incision.</li> <li>• Adjacent infrastructure or steep banks may limit bank tie-in locations.</li> <li>• Grade control practices such as weirs could become a block to aquatic organism passage if not properly matched to downstream channel slope or if channel downcutting occurs.</li> <li>• Bed armoring could fragment aquatic habitat if water flows under the coarse rock.</li> </ul>	<ul style="list-style-type: none"> <li>• Summary of key limitations for future design use.</li> <li>• Mostly for future reference since we have covered throughout presentation.</li> </ul>
<p><b>Slide 50</b></p>	 <ol style="list-style-type: none"> <li>1. <i>How does the degree of channel incision and risk to adjacent property dictate the selection of grade control treatment?</i></li> <li>2. <i>What are ways a grade control structure could fail (i.e., destabilize)?</i></li> </ol>	<ul style="list-style-type: none"> <li>• The severity of erosion and risk to infrastructure drives the design process. If the erosion is not severe and/or not threatening property or infrastructure, there is no need for action and the river can be left to heal at its own pace. Deeply incised channels along infrastructure that cannot be moved (e.g., major state highway) will require the most aggressive bed stabilization measures. Discrete grade control features such as weirs may be appropriate for moderately incised channels in lower power settings.</li> <li>• Grade control failure: <ul style="list-style-type: none"> <li>• Structures inappropriate for reach/channel setting.</li> </ul> </li> </ul>

		<ul style="list-style-type: none"> <li>Stream power underestimated during design.</li> <li>Structures not keyed into bed/banks.</li> <li>Severe lateral channel migration and/or bank erosion outflanks structure due to deposition behind grade control.</li> </ul>
Slide 51	 <p><b>Grade Control Common Mistakes</b></p> <ul style="list-style-type: none"> <li>Not considering stream velocity and power to determine which grade control practice is most appropriate.</li> <li>Use of undersized rocks for weirs that are susceptible to erosion during flooding.</li> <li>Not providing proper bank and bed tie-in for weirs and riffles.</li> <li>Improper spacing of stone weirs and riffles.</li> <li>Bed armor depth is too shallow and susceptible to undermining.</li> <li>Unstable banks are left unprotected with potential for the channel to roll off and outflank armoring.</li> <li>The transition between bed armoring and the channel bed is too steep at downstream limits creating abrupt changes in the longitudinal profile that may block aquatic organism passage or form upstream travelling erosion faces (i.e., head cuts) in future floods</li> <li>Uneven dispersal of native sediments along channel cross-sectional area</li> </ul> <p><small>Grade Control Design JWH/PAW, 2004</small></p>	Follow up for answer to question #2 on previous slide. Taken from Vermont Standard River Management Principles and Practices.
Slide 52	 <p><b>Grade Control Permitting Requirements</b></p> <ul style="list-style-type: none"> <li>U.S. Army Corps of Engineers (CWA Section 404 and 401)       <ul style="list-style-type: none"> <li>Quantify length, area, and volume of disturbance below ordinary high water (OHW)</li> <li>Identify reporting category</li> <li>Contact Field Office</li> </ul> </li> <li>Vermont Stream Alteration Permit       <ul style="list-style-type: none"> <li>Meet Performance Standards as identified above</li> <li>Identify reporting category</li> <li>Contact river management engineer</li> </ul> </li> <li>New York Article 15 Protection of Waters Permit       <ul style="list-style-type: none"> <li>Emergency Authorization for quick review in emergency</li> <li>General Permit for Disaster Recovery for longer timeframes</li> <li>New York State Environmental Quality Review (SEQR) for larger projects</li> </ul> </li> <li>Adirondack Park Agency       <ul style="list-style-type: none"> <li>Bank stabilization projects jurisdictional if area exceeds 100 square feet</li> <li>In-stream rock/log vanes are not jurisdictional</li> </ul> </li> <li>Local Permits       <ul style="list-style-type: none"> <li>FEMA National Flood Insurance Program criteria</li> <li>Wetlands (W1) (State for Vermont)</li> <li>Contact Town Administrator for reporting needs</li> </ul> </li> </ul> <p><small>Permitting</small></p>	List of common permitting requirements in VT and NY.

<p><b>Slide 53</b></p>		<p>Taken from Vermont Standard River Management Principles and Practices.</p> <ul style="list-style-type: none"> <li>• Review of check list for construction oversight.</li> <li>• Review of temporary construction controls during the work to minimize channel impacts.</li> </ul>
<p><b>Slide 54</b></p>		
<p><b>Slide 55</b></p>		<p>Review overarching bank stabilization objectives from Vermont Standard River Management Principles and Practices (<a href="http://www.anr.state.vt.us/dec/waterq/rivers.htm">http://www.anr.state.vt.us/dec/waterq/rivers.htm</a>).</p>



<p><b>Slide 56</b></p>	<p><b>Bank Stabilization Assessment: Section 2: Valley &amp; Alluvium</b></p>  <p>Mass Wasting – Valley Erosion</p> <p>Bank Erosion in Alluvium</p> <p><small>Photo Credit: USGS, 2012-15</small></p>	<ul style="list-style-type: none"> <li>• Understanding basics of erosion terminology and what is realistic for stabilization.</li> <li>• Mass wasting or valley erosion encompasses a large chunk of the valley wall.</li> <li>• Bank erosion encompasses alluvial or glacial deposits down in the valley and along the banks.</li> <li>• Helpful to know the soil parent material and the landform. Some soil types are more easily eroded (e.g., fine sandy loams) whereas others may have cohesivity properties that resist erosion (e.g., clay loams, dense till).</li> </ul>
<p><b>Slide 57</b></p>	<p><b>Bank Stabilization Assessment: Section 3: Adjacent Land &amp; Property</b></p>  <p><small>Photo Credit: USGS, 2012-15</small></p>	<ul style="list-style-type: none"> <li>• Presence or absence of adjacent improved property drives risk and design process.</li> <li>• State highways and larger town roads are generally not movable; stabilization necessary.</li> <li>• Homes subject to repeat erosion damage could be bought out, obviating bank hardening.</li> </ul>

<p><b>Slide 58</b></p>		<ul style="list-style-type: none"> <li>• Top pictures: Adams Brook in Newfane, VT. Continued high risk of erosion due to bedload and high power channel.</li> <li>• Bottom left: Green River in Halifax, VT. Channel overwidened and took out bridge to house across from Town road. House was a FEMA buyout after Irene. No need to stabilize bank to protect infrastructure.</li> <li>• Bottom right: South Branch Tweed River along Route 100 in Killington, VT. Moderate scour along embankment toe, naturally high channel roughness. Watch erosion over time but no immediate action needed.</li> </ul>
<p><b>Slide 59</b></p>		<ul style="list-style-type: none"> <li>• Review empirical, analog, and analytical approaches to getting dimensions.</li> <li>• Simplest to complex – HGR, past info, current measurements, current observations, modeling</li> <li>• Be sure to compare results from multiple methods to bracket answer since not exact science and local variability common.</li> </ul>

**Slide 60**



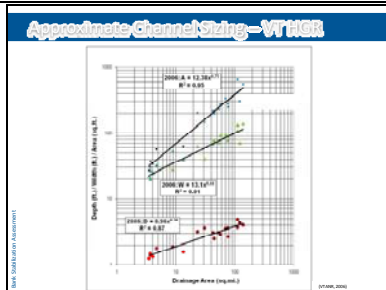
- Quick review as covered in Tier 2. Does everyone get this?
- Note that it is difficult to ID bankfull indicators post flood so past geomorphic assessments are very helpful, if not essential in damage prone areas.
- Be sure to consider bankfull relative to larger flood indicators that are typically linked to damages.

**Slide 61**



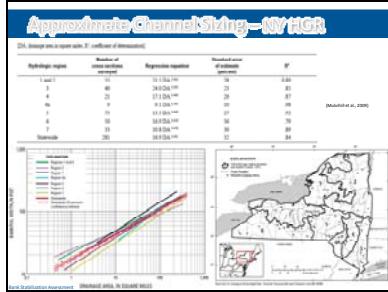
- Quick review as covered in Tier 2. Does everyone get this?

**Slide 62**



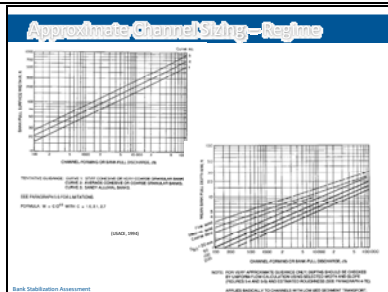
- Quick review as covered in Tier 2. Does everyone get this?
- Note that there are limitations to this – disturbed channels, different geomorphic settings, etc.
- HGRs are notorious for under-estimating widths on braided or wandering channels.
- Consider how changes in climate may be dating these regressions – consider adding +/-10% to predicted dimensions.

# Slide 63



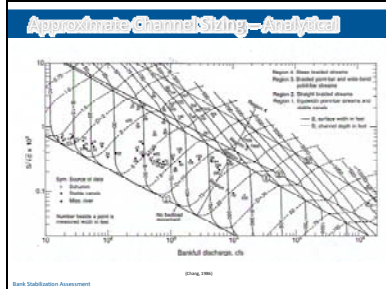
- Many states separate regions for HGRs.
- HGRs are notorious for under-estimating widths on braided or wandering channels, and overestimating widths on “slow winders” or Rosgen E-type channels.
- Quick review as covered in Tier 2. Does everyone get this?
- Consider how changes in climate may be dating these regressions – consider adding +/-10% to predicted dimensions.
- The USGS developed an enhanced web-based streamstats application to estimate the impact of climate change scenarios on flood flows: <http://ny.water.usgs.gov/maps/floodf req-climate/>

# Slide 64



- Note that regime equations are based on bankfull discharge or Q2, and not drainage area.
- Regime equations consider sediment grain size or bank cover since the origin was the ability for canals to convey water and not fill in.
- Regime equations are more appropriate for changing hydrology as seen in region since Q is the independent variable rather than drainage area.
- Can use equation or plot for width.

## Slide 65



- Chang performed computer simulations for sandbed rivers and made this plot for quick reference that is often used for larger substrates as well.
- What dimensions to carry water and sediment?
- This is an attempt to solve the extremal hypothesis - an alternative to solving the reach scale 3-dimensional conservation laws for fluid and sediment, to provide a first order means of predicting channel dimensions in an objective and reproducible manner.
- Calculate vertical axis variable, locate point on graph, read region, width, depth.

## Slide 66



Clockwise from upper left:

- Traditional slope stabilization: 1V:2H or 1V:1.5H slope with grubblings and seeding on upper slope above common flood levels.
- Placed riprap wall common practice after Irene – we will work through design process for this practice.
- Bioengineering practices complement traditional armoring approaches by working to naturalize the banks and riparian corridor.
- Engineered log jams (ELJs) are large masses of trees and soil/stones projecting from the bank. They are used to deflect flow, push the thalweg away from the bank, and create habitat complexity in the channel.

**Slide 67**

## Bioengineering

### Bioengineering Purpose and Design

- Increase roughness
- Enhance riparian habitat
- Low slope/power settings
- Hydraulic modeling needed to check velocity
- Soils and geotechnical concerns
- Fabrics, wood species, etc





Photo: Don Currier/Restoration Jr., Middleboro, 2012



Crane Brook, Middleboro, VT (J. Grogan, 2008)

Bank Stabilization Practices


1. Bioengineering is not suitable for many sites with higher power/velocity.
2. Need to understand processes and where the site sits on the spectrum of stream power/velocity.
3. Selection of appropriate fabrics and wood species is very important for success of project.

**Slide 68**

## Bank Stabilization Techniques

### EU Purpose and Design

- Increase roughness
- Push thalweg away from bank
- Enhance habitat
- Hydraulic modeling needed
- Force-balance analysis
- Piles, wood species, etc.



Erasmus River, Williams, W. G. Fraedrich, 2010

Bank Stabilization Practices

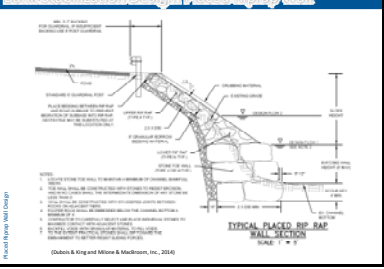
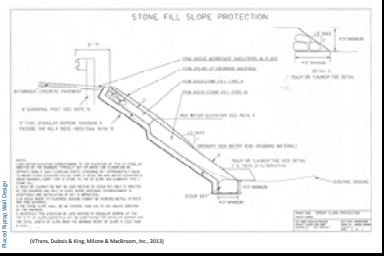

- In some settings ELJs may be as effective or more than bank hardening.
- Toe wood is a lighter option for sites with limited power and less tendency for lateral migration.
- These practices enhance habitat by creating heterogeneity in the bed.
- Typically not appropriate along highways or in high-risk areas with infrastructure.

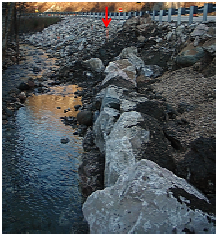


## Slide 69

Material/Process	Repeating Unit	Percentage by Weight	Percentage by Volume	
Matrix	1. Epoxy resin	67.5%	4	A
	2. Hardener	32.5%	1	A
	3. Fiberglass	0.0%	0	A
	4. Resin fill (concentrated)	0.00-0.05	0	A
	5. Glass fibers (random)	0.00-0.05	1.0-2.0	A
	6. Glass fibers (woven)	0.00-0.05	0	A
	7. Glass fibers (chopped)	0.00-0.05	0	A
	8. Glass fibers (continuous)	0.00-0.05	0	A
	9. Glass fibers (woven)	0.00-0.05	0	A
	10. Glass fibers (chopped)	0.00-0.05	0	A
Glass/Cloth	1. Glass fibers (random)	0.00-0.05	1.0-2.0	A
	2. Glass fibers (woven)	0.00-0.05	0	A
	3. Glass fibers (chopped)	0.00-0.05	0	A
	4. Glass fibers (continuous)	0.00-0.05	0	A
	5. Glass fibers (woven)	0.00-0.05	0	A
	6. Glass fibers (chopped)	0.00-0.05	0	A
	7. Glass fibers (continuous)	0.00-0.05	0	A
	8. Glass fibers (woven)	0.00-0.05	0	A
	9. Glass fibers (chopped)	0.00-0.05	0	A
	10. Glass fibers (continuous)	0.00-0.05	0	A
Inclusions	1. Glass fibers (random)	0.00-0.05	1.0-2.0	A
	2. Glass fibers (woven)	0.00-0.05	0	A
	3. Glass fibers (chopped)	0.00-0.05	0	A
	4. Glass fibers (continuous)	0.00-0.05	0	A
	5. Glass fibers (woven)	0.00-0.05	0	A
	6. Glass fibers (chopped)	0.00-0.05	0	A
	7. Glass fibers (continuous)	0.00-0.05	0	A
	8. Glass fibers (woven)	0.00-0.05	0	A
	9. Glass fibers (chopped)	0.00-0.05	0	A
	10. Glass fibers (continuous)	0.00-0.05	0	A
Reinforcing Characteristics (R/C)	1. Glass fibers (random)	0.00-0.05	1.0-2.0	A
	2. Glass fibers (woven)	0.00-0.05	0	A
	3. Glass fibers (chopped)	0.00-0.05	0	A
	4. Glass fibers (continuous)	0.00-0.05	0	A
	5. Glass fibers (woven)	0.00-0.05	0	A
	6. Glass fibers (chopped)	0.00-0.05	0	A
	7. Glass fibers (continuous)	0.00-0.05	0	A
	8. Glass fibers (woven)	0.00-0.05	0	A
	9. Glass fibers (chopped)	0.00-0.05	0	A
	10. Glass fibers (continuous)	0.00-0.05	0	A
Non-Reinforcing Characteristics (N/C)	1. Glass fibers (random)	0.00-0.05	1.0-2.0	A
	2. Glass fibers (woven)	0.00-0.05	0	A
	3. Glass fibers (chopped)	0.00-0.05	0	A
	4. Glass fibers (continuous)	0.00-0.05	0	A
	5. Glass fibers (woven)	0.00-0.05	0	A
	6. Glass fibers (chopped)	0.00-0.05	0	A
	7. Glass fibers (continuous)	0.00-0.05	0	A
	8. Glass fibers (woven)	0.00-0.05	0	A
	9. Glass fibers (chopped)	0.00-0.05	0	A
	10. Glass fibers (continuous)	0.00-0.05	0	A
Other	1. Glass fibers (random)	0.00-0.05	1.0-2.0	A
	2. Glass fibers (woven)	0.00-0.05	0	A
	3. Glass fibers (chopped)	0.00-0.05	0	A
	4. Glass fibers (continuous)	0.00-0.05	0	A
	5. Glass fibers (woven)	0.00-0.05	0	A
	6. Glass fibers (chopped)	0.00-0.05	0	A
	7. Glass fibers (continuous)	0.00-0.05	0	A
	8. Glass fibers (woven)	0.00-0.05	0	A
	9. Glass fibers (chopped)	0.00-0.05	0	A
	10. Glass fibers (continuous)	0.00-0.05	0	A
Other Characteristics	1. Glass fibers (random)	0.00-0.05	1.0-2.0	A
	2. Glass fibers (woven)	0.00-0.05	0	A
	3. Glass fibers (chopped)	0.00-0.05	0	A
	4. Glass fibers (continuous)	0.00-0.05	0	A
	5. Glass fibers (woven)	0.00-0.05	0	A
	6. Glass fibers (chopped)	0.00-0.05	0	A
	7. Glass fibers (continuous)	0.00-0.05	0	A
	8. Glass fibers (woven)	0.00-0.05	0	A
	9. Glass fibers (chopped)	0.00-0.05	0	A
	10. Glass fibers (continuous)	0.00-0.05	0	A

(Continued)

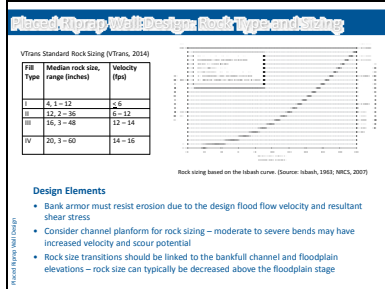
- Permissible or critical velocity.  
Note gradient from bioengineering approaches through rock riprap.
- Note values from example.

<p><b>Slide 70</b></p>	<p><b>Bank Stabilization Design: Placed Riprap Wall</b></p>  <p><b>TYPICAL PLACED RIP RAP WALL SECTION</b> SCALE: 1" = 1'</p> <p>(Dubois &amp; King and Milne &amp; Macdonald, Inc., 2014)</p>	<ul style="list-style-type: none"> <li>• Typical section from Post-Irene repairs on VT State Highways. Point out key features:</li> <li>• Blocky armor for building wall – wall height does not exceed 6ft unless a geotechnical evaluation is to be completed.</li> <li>• Key below channel bottom depending on scour potential.</li> <li>• Gravel bedding behind wall and upper riprap.</li> <li>• Upper riprap with grubbing/seed depending on flood elevations.</li> </ul>
<p><b>Slide 71</b></p>	<p><b>Bank Stabilization Design: Riprap Slope</b></p>  <p><b>STONE FILL SLOPE PROTECTION</b></p> <p>(YTrans, Dubois &amp; King, Milne &amp; Macdonald, Inc., 2012)</p>	<ul style="list-style-type: none"> <li>• Another typical from Irene repairs in VT.</li> <li>• Lower slope is Type IV stone, sometimes with a bulk toe depending on scour potential.</li> <li>• Upper slope very similar to placed riprap wall.</li> <li>• Gravel bedding instead of geotextile behind riprap, unless soils and piping are a concern.</li> </ul>
<p><b>Slide 72</b></p>	<p><b>Placed Riprap Wall Design: Rock Type and Sizing</b></p> <p><b>Rock Type</b></p> <ul style="list-style-type: none"> <li>• Large (3-6 ft diameter), blocky rock for stacking</li> <li>• Special sourcing and selection at quarry</li> <li>• Maintain voids at bottom of wall at water interface for fish refuge during high flows</li> </ul>  <p>VT Route 225 repairs, Mt. Holly, VT (J. Fitzgerald, 2013)</p>	<ul style="list-style-type: none"> <li>• May requires coordination with quarry ahead of time to blast/sort appropriate rock dimensions.</li> <li>• Due to size there is a lot of wear and tear on dump trucks – sometimes higher trucking price.</li> <li>• Many loads – some trips only have 4-5 stones in truck.</li> <li>• Habitat note: explain to contractor not to fill voids in large rocks at bottom of wall at water interface to provide refuge for fish during high flows.</li> </ul>

<p><b>Slide 73</b></p>	<p><b>Placed Riprap Wall Design: Wall Location &amp; Alignment</b></p>  <p><b>Design Elements</b></p> <ul style="list-style-type: none"> <li>• The toe of the riprap wall on the face closest to the channel must be properly located in the field to retain at least the target bankfull channel width.</li> <li>• Paint marks, flagging, or offsets should be used to set the toe location during construction.</li> </ul> <p><small>(R. Fitzgerald, 2013)</small></p>	<ul style="list-style-type: none"> <li>• This is key step in pre-construction layout to confirm desired channel width/dimensions will be achieved.</li> <li>• Common issues:             <ul style="list-style-type: none"> <li>• Make sure contractor knows the stake is for the face of wall in the channel vs. the top of wall (red arrow).</li> <li>• Spacing of stakes too wide resulting in wall face that is wavy or not smooth/uniform</li> </ul> </li> </ul>
<p><b>Slide 74</b></p>	<p><b>Placed Riprap Wall Design: Height and Slope</b></p>  <p><b>Design Elements</b></p> <ul style="list-style-type: none"> <li>• Set wall height based on elevation of the bankfull channel and floodplain and to keep the wall structurally stable.</li> <li>• A maximum wall height of 6 to 8 feet is recommended unless a geotechnical analysis is performed</li> <li>• Maximum wall slope 6V:1H; gentle batter of 6V:2H is more common</li> <li>• The target slope of the sloping riprap above the wall is 2H:1V, with a maximum of 1.5H:1V</li> </ul> <p><small>(R. Fitzgerald, 2013)</small></p>	<ul style="list-style-type: none"> <li>• Need to identify floodplain or flood bench elevation opposite bank to relate to wall transitions.</li> <li>• Hydraulic modeling not necessary for small projects or if floodplain is wide – use adjacent floodplain +1ft for wall or upper riprap transition.</li> <li>• VTrans Geotechnical staff not comfortable with walls &gt;6ft (reveal) without a geotechnical analysis.</li> </ul>
<p><b>Slide 75</b></p>	<p><b>Placed Riprap Wall Design: Height and Slope</b></p>  <p><small>GDH D3-96, VT Route 155, Mount Holly 260 ft placed riprap wall</small></p> <p><small>Type VI stone stacked below, Type IV stone @ 1V:1.5H above</small></p> <p><small>(R. Fitzgerald, 2013)</small></p>	<ul style="list-style-type: none"> <li>• Example of challenging but well-built wall along a larger channel (bankfull width 50-60ft) in Mt. Holly, VT.</li> </ul>

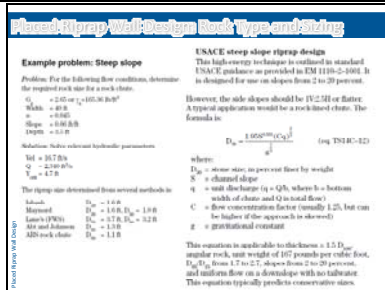


## Slide 76



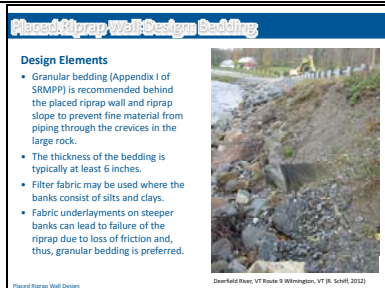
- Very useful to triangulate on sizing using multiple methods.
- If the project is large or complex or situated near infrastructure a full hydrology and hydraulic analysis may be required. This is usually not feasible during emergency repair work.
- For smaller projects cursory hydraulic analysis (e.g., single uniform flow calculation) may suffice for estimating velocity and sizing rock.

## Slide 77



- Check several methods and range of rock size results to land on design size.
- Steep slope riprap sizing applicable to many of our high-energy channels.

## Slide 78



- Geotextile filter fabric traditionally used behind rip rap on river slopes, but observations after Irene that these can lead to armor failure due to slipping, shear behind/along fabric.
- Soils prone to piping may still need fabric.

## Slide 79



Lower left hand picture is a nice cross-section of steep (1V:1.5H) upper riprap slope above wall with granular bedding, Type IV stone above, and grubbing, seed, erosion control blanket.

## Slide 80

**Placed Riprap Wall Design Keyway Thickness & Depth**

Keyway Depths Based on Channel Incision and Evolution (Schiff et al., 2014)

Depth Below Channel Bottom (feet)	Incision Ratio	CMA Stage	Predicted Channel Change
1-2	1.0 - 1.2	I, V	Constant or aggrading
2-4	1.2 - 1.4	II, III, IV	Moderate incision
4-6	1.4 - 1.6	II, III, IV	Moderate to severe incision
>6	>2.6	II, III	Severe incision or entrenchment

Predicted Scour (or Keyway) Depth Based on Location in Channel Alignment. (Source: TAC, 2003)

Depth (Multiple of Channel)	Channel Alignment Location
1.25	Straight
1.5	Moderate bend
1.75	Severe bend
2.0	Abrupt right-angle turn
3.5	Sub-surface sill


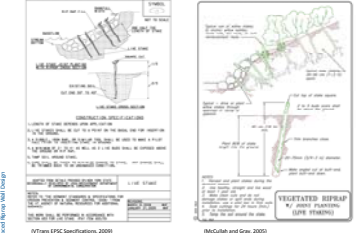
IF: Hesperid, 2013

- Edge of keyway in channel should be clearly staked at appropriate intervals.
- Solid keyway is essential to stability of wall.
- Dewatering allows for better keyway installation – use native bed materials to create temporary diversion berms and work pads.

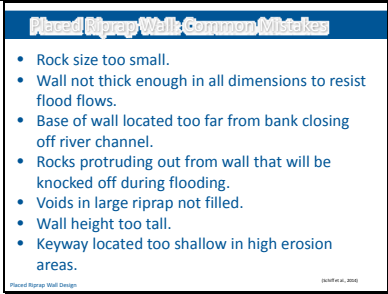
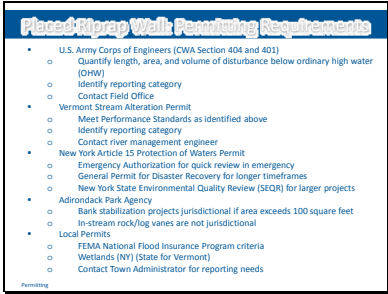
## Slide 81

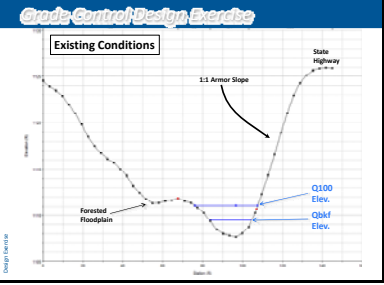


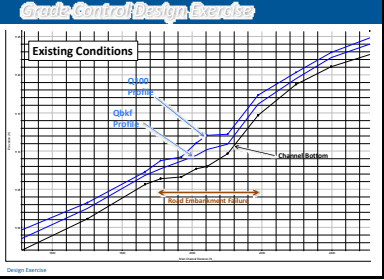
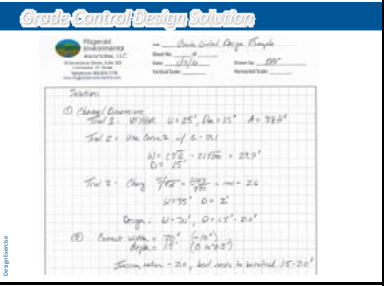
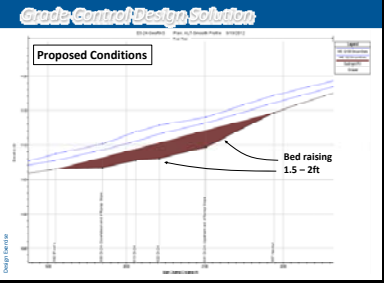
- Note dewatering and ability to see keyway depth in channel.

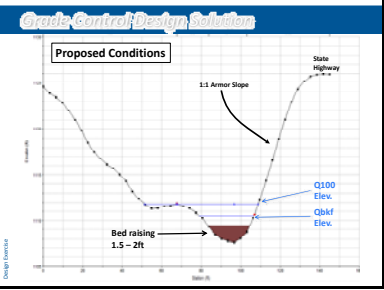
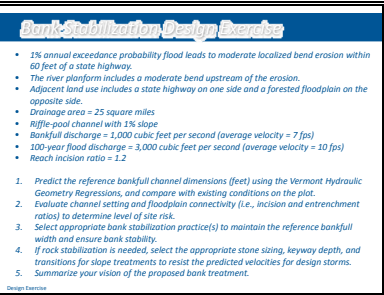
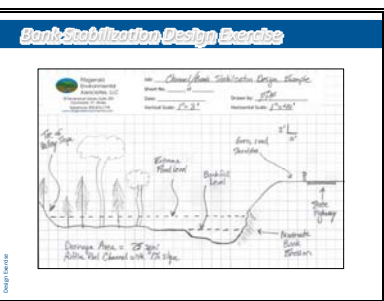
<p><b>Slide 82</b></p>	<p><b>Placed Riprap Wall Design, Revegetation</b></p> <p>Post-Irene Repairs – Placed Riprap Wall with Vegetated Slope South Branch of the Tweak River, VT Route 100, Killington</p>  <p>(B. Fitzgerald, 2013)</p> <p>Placed Riprap Wall Design</p>	<ul style="list-style-type: none"> <li>• Vegetation on upper slope serves to stabilize topsoil, filter runoff from adjacent road, and enhance near-bank habitat.</li> <li>• Upper slope vegetation along highways typically needs to be herbaceous for mowing and FHWA requirements. However native trees will likely volunteer over time.</li> <li>• If work is done in early spring or late fall, provide a conservation mix with winter rye or other fast growing seed to establish cover.</li> </ul>
<p><b>Slide 83</b></p>	<p><b>Placed Riprap Wall Design, Revegetation</b></p>  <p>(From FHWA Specifications, 2005)</p> <p>(McGowan and Gony, 2005)</p>	<ul style="list-style-type: none"> <li>• Rock armor + Vegetation = Long-term Stability!</li> <li>• Where this approach is possible, joint plantings are good option but require planning re: time of year for plant dormancy and collection of stakes.</li> <li>• Higher costs - joint plantings slows the rock installation and an additional laborer is needed.</li> </ul>
<p><b>Slide 84</b></p>	<p><b>Summary – Placed Riprap Wall Design</b></p> <p><u>Assessment</u></p> <ul style="list-style-type: none"> <li>• Location, length, width, and height of bank erosion</li> <li>• Bankfull channel dimensions</li> <li>• Adjacent land use and property</li> <li>• Risk of continued erosion and damages</li> </ul> <p><u>Design</u></p> <ul style="list-style-type: none"> <li>• Rock type and sizing</li> <li>• Wall location and alignment</li> <li>• Keyway thickness and depth</li> <li>• Height and slope</li> <li>• Bedding</li> <li>• Revegetation</li> </ul> <p>Placed Riprap Wall Design</p>	<ul style="list-style-type: none"> <li>• Summary / checklist for future design use.</li> <li>• Mostly for future reference since we have covered throughout presentation.</li> </ul>

<p><b>Slide 85</b></p>	<p><b>Placed Riprap Wall Design: Design Objectives</b></p> <ul style="list-style-type: none"> <li>• Create lateral channel stability while retaining target channel bankfull width in confined settings and reducing fill compared to common uniformly sloping riprap.</li> <li>• Set keyway invert elevation based on history of channel downcutting to maximize wall and vertical channel stability. Link to other vertical channel stability practices at sites with excessive bed erosion.</li> <li>• Return native boulders to riverbed often located in bank to offset historic channel downcutting, improve floodplain access, increase channel roughness, decrease energy grade, reduce flood velocity, and improve instream habitat.</li> <li>• Establish low or flood benches where possible to lower flood velocities and reduce future erosion risks.</li> </ul> <p><small>Placed Riprap Wall Design</small></p>	<ul style="list-style-type: none"> <li>• Summary of key design objectives for future use.</li> <li>• Mostly for future reference since we have covered throughout presentation.</li> </ul>
<p><b>Slide 86</b></p>	<p><b>Placed Riprap Wall Design: Limitations</b></p> <ul style="list-style-type: none"> <li>• Introduction of non-native stone to riverbank.</li> <li>• Difficult to re-establish bank vegetation.</li> <li>• Sourcing large angular or blocky rock can be difficult and expensive.</li> <li>• Installation requires more skill by machine operator to construct wall, transitions, and tie-backs. Building a placed riprap wall can take longer than installing a traditional riprap application and is thus more costly.</li> <li>• Geotechnical analysis is typically required for taller slopes where the height of the wall is larger than 6 feet and in areas dominated by silts and clays.</li> </ul> <p><small>Placed Riprap Wall Design</small></p>	<ul style="list-style-type: none"> <li>• Summary of key limitations for future design use.</li> <li>• Mostly for future reference since we have covered throughout presentation.</li> </ul>
<p><b>Slide 87</b></p>	<p><b>Placed Riprap Wall Design: Review Questions</b></p> <ol style="list-style-type: none"> <li>1. <i>How does the degree of channel encroachment and risk to adjacent property dictate the selection of bank stabilization treatment?</i></li> <li>2. <i>Where is a placed riprap wall preferred over sloping riprap? Vice versa?</i></li> </ol> <p><small>Placed Riprap Wall Design</small></p>	<ul style="list-style-type: none"> <li>• Need to put the site into the reach and confinement context. <ul style="list-style-type: none"> <li>• What is the natural valley/floodplain look like and to what degree is encroachment taking up this space?</li> <li>• Is the channel/floodplain depth and velocity significantly changed at the site due to encroachment?</li> <li>• If a severe encroachment on 3<sup>rd</sup> or 4<sup>th</sup> order stream, placed riprap wall will buy more space compared to settings on larger rivers.</li> <li>• Adjacent property risk drives the stabilization needs: high</li> </ul> </li> </ul>

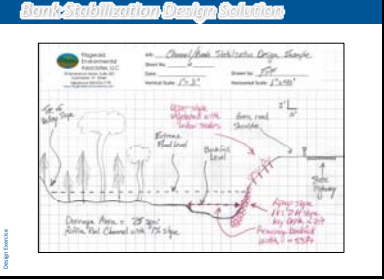
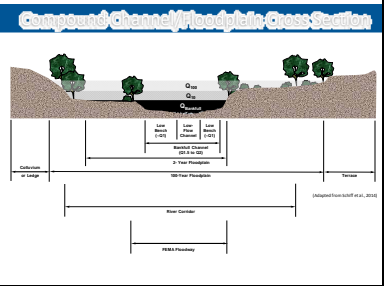
		<p>risk sites require hardening to arrest of erosion; lower risk sites may be suitable for “softer” approaches.</p> <ul style="list-style-type: none"> <li>Sloping riprap may be suitable in these locations: <ul style="list-style-type: none"> <li>Larger rivers or wide/braided rivers where relative gain in channel width is minor with a placed riprap wall.</li> <li>Sites with limited machine access to base of slope.</li> <li>Sites with geotechnical concerns.</li> </ul> </li> </ul>
Slide 88	 <p><b>Placed Riprap Wall: Common Mistakes</b></p> <ul style="list-style-type: none"> <li>Rock size too small.</li> <li>Wall not thick enough in all dimensions to resist flood flows.</li> <li>Base of wall located too far from bank closing off river channel.</li> <li>Rocks protruding out from wall that will be knocked off during flooding.</li> <li>Voids in large riprap not filled.</li> <li>Wall height too tall.</li> <li>Keyway located too shallow in high erosion areas.</li> </ul> <p><small>Placed Riprap Wall Design (2019) (4/11/2020)</small></p>	<ul style="list-style-type: none"> <li>Summary of common mistakes for future design use.</li> <li>Mostly for future reference since we have covered throughout presentation.</li> </ul>
Slide 89	 <p><b>Placed Riprap Wall: Permitting Requirements</b></p> <ul style="list-style-type: none"> <li>U.S. Army Corps of Engineers (CWA Section 404 and 401) <ul style="list-style-type: none"> <li>Quantify length, area, and volume of disturbance below ordinary high water (DHW)</li> <li>Identify reporting category</li> <li>Contact Field Office</li> </ul> </li> <li>Vermont Stream Alteration Permit <ul style="list-style-type: none"> <li>Meet Performance Standards as identified above</li> <li>Identify reporting category</li> <li>Contact river management engineer</li> </ul> </li> <li>New York Article 15 Protection of Waters Permit <ul style="list-style-type: none"> <li>Emergency Authorization for quick review in emergency</li> <li>General Permit for Disaster Recovery for longer timeframes</li> <li>New York State Environmental Quality Review (SEQR) for larger projects</li> </ul> </li> <li>Adirondack Park Agency <ul style="list-style-type: none"> <li>Bank stabilization projects jurisdictional if area exceeds 100 square feet</li> <li>In-stream rock/log vanes are not jurisdictional</li> </ul> </li> <li>Local Permits <ul style="list-style-type: none"> <li>FEMA National Flood Insurance Program criteria</li> <li>Wetlands (NY) (State for Vermont)</li> <li>Contact Town Administrator for reporting needs</li> </ul> </li> </ul> <p><small>Permitting</small></p>	<p>List of common permitting requirements in VT and NY.</p>

<p><b>Slide 90</b></p>	<p><b>Placed-Riprap Wall Construction</b></p> <p><u>Constructability</u></p> <ul style="list-style-type: none"> <li>• Application has become much more common since TS Irene in 2011</li> <li>• Need large machinery and good supply of large rock</li> <li>• Closure of single lane often required</li> <li>• Taller road embankments may require removal and replacement of travel lane to establish a work platform to reach channel bottom for keyway, etc.</li> </ul> <p><u>Temporary Construction Controls</u></p> <ul style="list-style-type: none"> <li>• Complete work during low flow periods to limit downstream sedimentation and allow for proper visibility to successfully complete the work.</li> <li>• Temporary berm made of pushed up deposited material are often used to guide water out of the work areas and provide a work platform to keep machinery out of main channel bed.</li> <li>• Use series of sediment filter berms to create sediment trap pools and limit sedimentation of downstream areas.</li> <li>• The pools should be periodically cleaned out as work takes place.</li> <li>• Install silt fencing as needed to control runoff when ground not flat and soils or grubbings are stockpiled.</li> </ul> <p>Construction</p>	<ul style="list-style-type: none"> <li>• Taken from Vermont Standard River Management Principles and Practices.</li> <li>• Review considerations for rock supply, traffic interruptions.</li> <li>• Review of temporary construction controls during the work to minimize channel impacts.</li> </ul>
<p><b>Slide 91</b></p>	<p><b>Grade Control Design Exercise</b></p> <ul style="list-style-type: none"> <li>• 1% annual exceedance probability flood leads to severe localized channel bed erosion and failure of an adjacent road embankment for 300 linear feet.</li> <li>• The embankment slope was repaired during emergency recovery with a steep riprap slope 1V:1H. The rock size is adequate but the top and toe of slope cannot be moved, and the toe of slope remains vulnerable to erosion due to channel downcutting.</li> <li>• See channel and flood profiles and section on following pages.</li> <li>• There is a forested floodplain across the river from the road embankment.</li> <li>• Drainage area = 4.5 square miles; Channel Slope = 2.3%</li> <li>• Cobble bed with median bed sediment size (<math>D_{50}</math>) = 80 millimeters</li> <li>• Bankfull discharge = 200 cubic feet per second (average velocity = 6 fps)</li> <li>• 100-year flood discharge = 830 cubic feet per second (average velocity = 9 fps)</li> <li>• Reach incision ratio = 1.3; Site incision ratio = 2.0</li> </ul> <ol style="list-style-type: none"> <li>1. Predict the reference bankfull channel dimensions (feet): VTHGR (Trial 1); Regime (Trial 2); and Chang (Trial 3).</li> <li>2. Evaluate the departure of existing channel dimensions from reference dimensions.</li> <li>3. Evaluate changes in channel dimensions required to reduce erosion vulnerability.</li> <li>4. Select an appropriate bed stabilization practice to restore reference channel dimensions and reduce threat of erosion along embankment toe.</li> <li>5. Summarize your vision of the proposed grade control design.</li> </ol> <p>Design Exercise</p>	<ul style="list-style-type: none"> <li>• This example is a real site along Route 100 in Killington, VT that was repaired during the permanent repair phase.</li> <li>• 30 minutes group work, 5-minute presentation</li> </ul>
<p><b>Slide 92</b></p>	<p><b>Grade Control Design Exercise</b></p> 	<p>Existing conditions cross-section of site with flood elevations based on hydraulic model.</p> <ul style="list-style-type: none"> <li>• Note forested floodplain on left bank that is currently not accessed during large floods (incised channel)</li> <li>• Note 1:1 riprap armor slope on highway bank</li> </ul>

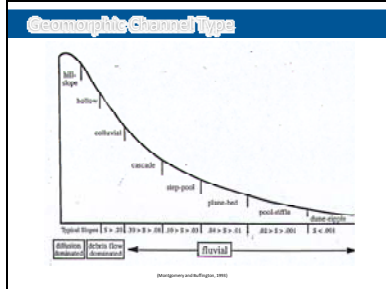
<p><b>Slide 93</b></p>		<p>Longitudinal profile of site with flood profiles based on hydraulic model.</p> <ol style="list-style-type: none"> <li>1. Note the gouge in the channel profile below the headcut</li> <li>2. Note the wobble in the 100-year flood profile as it passes over the head cut, indicating significant changes in velocity and shear (i.e., super critical flow).</li> </ol>
<p><b>Slide 94</b></p>		<p>Bankfull channel dimensions:</p> <p>Width = 30ft (average of 25, 30, 35 from 3 trials)</p> <p>Depth = 1.5 – 2ft (average of 1.5, 1.5, 2 from 3 trials)</p> <p>Departure from reference:</p> <p>Width: -10ft</p> <p>Depth: -0.5ft</p> <p>Raising bed 1.5 – 2ft will achieve bankfull width of ~30ft and depth of ~2ft</p>
<p><b>Slide 95</b></p>		<p>Profile with bed raised 1.5-2.0 feet and smoothing of flood profiles.</p>

<p><b>Slide 96</b></p>		<p>Cross-section with bed raised 1.5-2.0 feet and restored floodplain access for large flood resulting in lower bank velocity and erosion risk.</p>
<p><b>Slide 97</b></p>	 <p><b>Bank Stabilization Design Exercise</b></p> <ul style="list-style-type: none"> <li>1% annual exceedance probability flood leads to moderate localized bend erosion within 60 feet of a state highway.</li> <li>The river planform includes a moderate bend upstream of the erosion.</li> <li>Adjacent land use includes a state highway on one side and a forested floodplain on the opposite side.</li> <li>Drainage area = 25 square miles</li> <li>Riffle-pool channel with 1% slope</li> <li>Bankfull discharge = 1,000 cubic feet per second (average velocity = 7 fps)</li> <li>100-year flood discharge = 3,000 cubic feet per second (average velocity = 10 fps)</li> <li>Reach incision ratio = 1.2</li> </ul> <ol style="list-style-type: none"> <li>Predict the reference bankfull channel dimensions (feet) using the Vermont Hydraulic Geometry Regressions, and compare with existing conditions on the plot.</li> <li>Evaluate channel setting and floodplain connectivity (i.e., incision and entrenchment ratios) to determine level of site risk.</li> <li>Select appropriate bank stabilization practice(s) to maintain the reference bankfull width and ensure bank stability.</li> <li>If rock stabilization is needed, select the appropriate stone sizing, keyway depth, and transitions for slope treatments to resist the predicted velocities for design storms.</li> <li>Summarize your vision of the proposed bank treatment.</li> </ol> <p><small>Design Exercise</small></p>	<ul style="list-style-type: none"> <li>This is a fictitious example of a low risk bank stabilization setting.</li> <li>30 minutes group work, 5-minute presentation</li> </ul>
<p><b>Slide 98</b></p>		<ul style="list-style-type: none"> <li>Road is situated 30ft from top of slope, and 60ft from eroded slope.</li> <li>Existing slope is 1V:5H with scour at toe.</li> <li>Existing bankfull width is 60ft, max depth is 3ft.</li> <li>Incision ratio 1.0-1.2.</li> <li>Entrenchment ratio is ~3.5.</li> <li>Rosgen C-type channel with 1% slope.</li> <li>Reference bankfull dimensions based on drainage area of 25 sqmi: Width = 54ft, Mean Depth = 2.5ft</li> </ul>



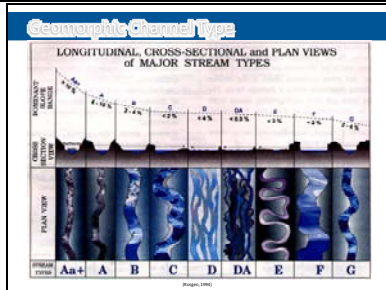
<p><b>Slide 99</b></p>	 <p>The diagram, titled "Bank Stabilization Design Solution", shows a plan view of a river channel bend. It includes a "Design Area" of 15,300 sq ft and a "Final Bankfull Width" of 55 ft. Key features include a "Sloped riprap 1V:2H" along the low bank, a "2ft key depth" at the channel bend, and a "Link top of rock to high flows or foot or two over floodplain". The diagram also shows a "Revegetate upper slopes with willow stakes" and a "Final bankfull width ~55ft which matches reference width from HGRs".</p>	<ul style="list-style-type: none"> <li>• May want to just monitor bank if perceived risk level is low.</li> <li>• Vegetation only is option.</li> <li>• Sloped riprap 1V:2H along low bank.</li> <li>• 2ft key depth given no incision, good floodplain access, and moderate channel bend.</li> <li>• Link top of rock to high flows or foot or two over floodplain since erosion potential lowers at this flood level.</li> <li>• Revegetate upper slopes with willow stakes.</li> <li>• Final bankfull width ~55ft which matches reference width from HGRs.</li> </ul>
<p><b>Slide 100</b></p>	<p>EXTRA SLIDES</p> <p>Basic Geomorphic Assessment</p>	
<p><b>Slide 101</b></p>	 <p>The diagram, titled "Compound Channel/Floodplain Cross Section", shows a cross-section of a river channel and its floodplain. It includes a "Channel" with a "Bankfull Channel" and a "Floodplain". The diagram also shows a "River Corridor" and a "Floodplain Boundary". The diagram is credited to "Adapted from Kelliff et al., 2001".</p>	<p>Note boundaries of the river corridor and floodway not located at edges of floodplain. Regulatory areas are not the only consideration when reducing flood risks.</p>

## Slide 102



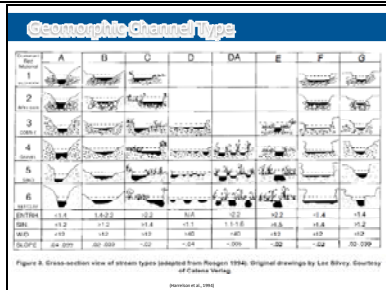
Slope can help with initial prediction of channel pattern and dominant process.

## Slide 103



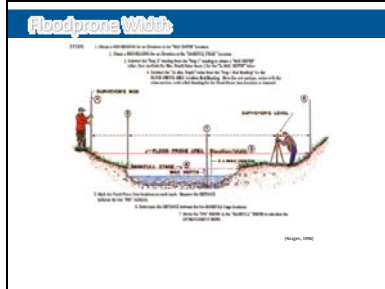
If you are going to modify channel, have vision of channel type and trajectory. Need target, and that typically comes initially from channel classification.

## Slide 104

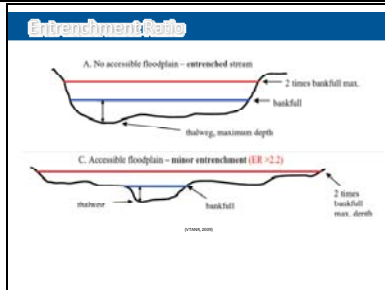


Relationship between substrate, slope, and type.  
Keep synchronized or you will see large adjustments post debris removal.

Slide 105

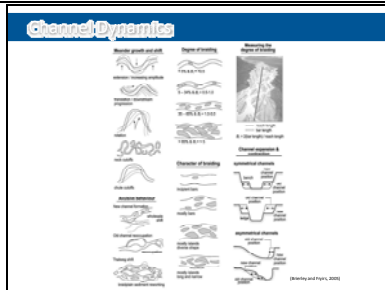


Slide 106



Entrenchment and incision ratios key for connectivity. Shapes channel dynamics.  
Most of our channels are now incised and disconnected from floodplains.

Slide 107



Dynamics = channel adjustment.  
Expected processes.

## Slide 108

## Channel-Context

### Independent Variables

- Flow
- Valley Slope
- Stream Power ( $\Omega = \gamma QS$ )
- Sediment Size and Load
- Bed and Bank Material
- Confinement

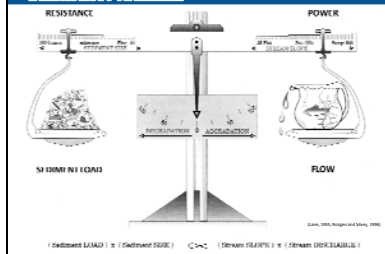
### Dependent Variables

- Channel Dimensions
- Channel Slope
- Channel Pattern
- Bed Forms
- Side Slope
- Velocity
- Floodplain Features

Understand what you are changing and what responds to that change.

## Slide 109

## Sediment Processes



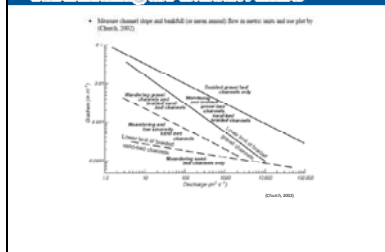
Balance between sediment and water is key...really power and resistance.  
Fundamental to all channel and bank work.

Manage towards the most stable equilibrium state, or at least a place where the system is not further driven from EQU.

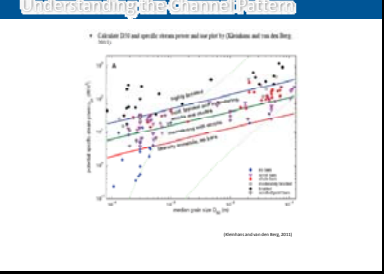
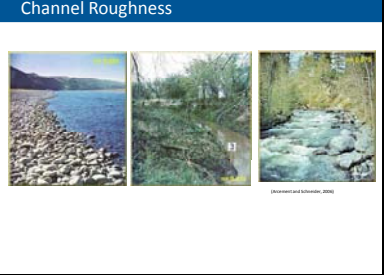
Slope changes = sinuosity, length

## Slide 110

## Understanding the Channel Pattern

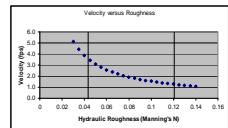


Braiding, wandering, meandering.  
Substrate explicitly included in this empirical predictor. Has shown good results in east coast US projects. Note metric units.  
Supersedes Leopold and Wolman, 1955

<p><b>Slide 111</b></p>	<p>Understanding the Channel Pattern</p> 	<p>Mobile bed features? <math>SSP = \gamma \cdot Q \cdot S / w</math>  Works well based on our past projects.  Fines to 4 inches (gravel).</p>
<p><b>Slide 112</b></p>	<p>EXTRA SLIDES</p> <p>Channel roughness Slides</p>	
<p><b>Slide 113</b></p>	<p>Channel Roughness</p> 	

# Slide 114

## Channel Roughness



Small vegetated channel  
Young growth and stubble perennials  
N=0.04

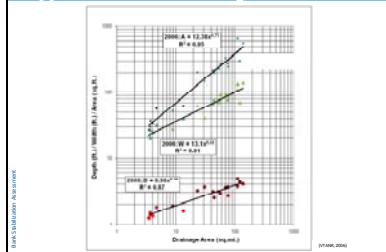
Small vegetated channel  
Tall, dense perennials  
N=0.12

$$\text{MANNING'S EQUATION}$$

$$V = \frac{1.486}{N} R^{2/3} S^{1/2}$$

# Slide 115

## Approximate Channel Sizing - VTRCR



- Quick review as covered in Tier 2. Does everyone get this?
- Note that there are limitations to this – disturbed channels, different geomorphic settings, etc.
- HGRs are notorious for under-estimating widths on braided or wandering channels.
- Consider how changes in climate may be dating these regressions – consider adding +/-10% to predicted dimensions.

# Slide 116

## Approximate Channel Sizing - HGR

Single Channel Dimensions for the Bear River  
Barnington, VT  
9/3/2011

Drainage Area (Square Miles)	Bankfull Width (feet)	Bankfull Depth (feet)	Gross Section Area (Square Feet)	Location
2	18	1	21	
4	24	1	35	
5	27	2	41	
10	36	2	70	
15	43	2	94	
20	49	2	117	
25	54	3	138	
30	59	3	159	
35	63	3	178	
40	66	3	197	Barnington/Woodford
45	70	3	215	
50	73	3	233	
55	76	3	250	
60	79	3	267	
100	102	5	634	
150	133	5	949	
200	155	5	1258	

Source: VTDEC, 2008.  $R^2 = 0.75$   $R^2 = 0.75$   $R^2 = 0.75$   $R^2 = 0.75$

- Tabular for easier for quick calculations.
- Quick review as covered in Tier 2. Does everyone get this?