Vermont Rivers and Roads Training Program

River Modeling Exercises

Vermont Department of Environmental Conservation
Vermont Department of Fish and Wildlife
Vermont Agency of Transportation

2015

The Rationale for Physical River Modelling

The Rivers and Roads training program strives to equip a diverse audience with the skills necessary to identify the type of river instability responsible for infrastructure damage, determine whether technical assistance is required to address the instability, and where it is not, design and construct a restoration project that leaves the infrastructure and the river and habitat it provides as, if not more flood resilient than it was prior to the occurrence of the damage. In order to develop these skill participants are challenged to absorb, and as importantly, retain a tremendous amount of knowledge over the course of two days. The hands-on river modeling exercises provide a learning experience that allows participants to fully absorb the lessons taught in the presentations and field exercises.

The subject matter of the Rivers and Roads training includes dynamic river processes that occur across multiple time and spatial scales, the interaction of those processes with the constructed environment, and design and construction of infrastructure that is compatible with those processes. The subject matter is complex, multi-dimensional and physical in nature. Understanding of dynamic river processes requires observation of those processes across the time-scales in which they happen. Appreciation for design challenges and construction constraints created by site characteristics comes with experience. The river modelling exercises allow participants to observe geologic time-scale processes play out in minutes, explore the multi-dimensional problems that design solutions must overcome and physically manipulate the site to construct those solutions.

The river modeling exercises provide a kinetic “learn by doing” experience. With knowledge provided by auditory and visual presentation fresh in their minds, participants can engage in practical hands-on exercises, without fear of failure. This is where the diverse group of participants truly learn what is being taught, where they develop the “muscle memory” that they will need to successfully meet the challenges of managing river-side infrastructure.

Restoring a River Modeling Exercise

Overview

The river restoration exercise gives participants an opportunity to first diagnose river instability, and then design and construct restoration schemes. One of the fundamental tenants of restoring or preserving river stability when conducting work within the river corridor is to simulate the floodplain, and channel characteristics of stable rivers. This is often referred to as the “reference reach” approach. A key to the reference reach approach is to design that is appropriate for the valley setting. This exercise will reinforce participant’s understanding of river characteristics and how those characteristics relate to each other and the valley setting.

Before participating in this exercise, participants will have attended image-based presentations on fluvial geomorphology and aquatic habitat and have taken guided walks along rivers representing the equilibrium condition found in various valley settings. This exercise helps participants to assimilate what they’ve learned about valley settings and how the valley setting influences the physical characteristics of the river. In building an equilibrium channel, they solidify their understanding of important channel characteristics. This understanding will be important for later exercises and real world experiences. In this exercise, participants will be focused primarily on the physical characteristics of river channels and how they are put together so that when the job is to rebuild a road embankment or install a culvert, considering river characteristics and accommodating river processes won’t be a foreign concept.

Setup

This exercise requires 35 – 40 gallons of media to fill the model tray nearly to the top of the sidewalls. In order to minimize the volume of media required, insert lengths of rigid foam along the sidewalls to take up volume in the tray. The foam should be as high as the sidewalls and 4 inches wide. Fill the tray with 35 gallons of media and grade. Fill the water reservoir with only 11 gallons (1/2 the total required to run the flume). This will allow reservoir capacity for water that will be added when saturating the media prior to conducting the exercise.

Set the base of the energy dissipater at the upper end of the model tray as normal and at a height of 3 inches above the tray bottom. Use netting fabric and ¾-inch stones to build a secondary energy dissipater at the outfall of the primary dissipater as shown in figures 1,2 and 3 of Appendix A. Set the stand-pipe to a height of 2 inches above the tray bottom.

In order to provide students a starting point and sense of scale and context, the instructor should establish multiple valley settings along the length of the model with a narrow and steep valley in the upper third of the tray, a moderate valley in the middle third and a broad flat valley in the lower third. Participants will be instructed to construct a four-inch wide channel so the narrow valley width should be approximately eight-inches wide.

Establish the general valley and channel morphologies along the length of the tray. Take care to create floodplain and terrace features with sharp corners to make it easier for participants to identify and distinguish between features. Keeping the media sufficiently moist to create particle cohesion and using the carving tool helps in creating sharp feature corners.

Create a narrow valley with an entrenched and steep channel that is incised along the upper third of the tray. Transition the channel to be slightly entrenched and moderately steep within a moderately confined valley along the middle third of the tray. This section of channel should contain channel adjustments such as widening, incision and aggradation. Within the lower third of the tray create a broad valley with an un-entrenched meandering channel. This section of channel should contain adjustments such as severe aggradation, unstable planform geometry including avulsions and lateral migration.

Materials for the exercise include the following:

- Three size classes of stone to be used as gravels, cobbles and boulders. The three size classes should be ¼-inch, ½-inch, and ¾-inch,
- Twigs approximately 1/8 - ¼ inches in diameter and three to six inches long to simulate large wood debris,
- Simulation live shrubs and trees,
- Plastic mesh netting to be used as geo-textile in construction of bed features (although participants will be constructing natural bed features, the use of geo-textile enhances performance when flow is run through the model).

Conducting the Exercise

The task of the instructor is to set the stage for the exercise and walk participants through the process of first diagnosing the existing channel instabilities and then developing a restoration design and finally constructing the restoration. Referring to the Rivers and Roads Field Manual, a good series of diagnostic questions might include the following:

- What valley types does the channel lie within and what does that tell us about the channel morphologies?
- What is the drainage area and what does that tell us about the expected channel dimensions?
- How do channel dimensions compare to what is expected?
- How does the longitudinal profile compare to what is expected?
- How do planform geometries compare to what is expected?

Once these questions are discussed, quick sketches of channel morphology should be developed that compare the existing to the expected. With these sketches serving as design templates the instructor can re-grade the valley bottoms to eliminate the channel and guide participants through construction of the new channel. Specific point of focus include the following:

- Typical width to depth ratios of 12 (steep confined streams) and 22 (flat unconfined)
- Cross section entrenchment
- Bed form spacing (3 – 5 for steps and 5 – 7 for riffles)
- Typical arch shape of step features and how that relates to strength
- Typical riffle shape and particle sizes
- Pool structure
- Run features
- Variation of particle gradations at different bed features
- Mid - channel and point bars

- Presence of channel avulsions and debris jams
- Lack of meanders
- Channel bank connection to valley walls
- Lack of substantial floodplain
- Channel roughness and aquatic habitat elements

Food Recovery River Modeling Exercise

Overview

The flood recovery exercise places participants in a post-flood recovery scenario in which they must respond to multiple infrastructure damages that have been caused by vertical and lateral channel adjustments. Participants are challenged to use their understanding of fluvial geomorphology and river management practices to identify the natural geomorphic condition of the river, link the infrastructure damages to specific channel adjustments, and design and build infrastructure repairs that provide for channel stability and aquatic habitat. This exercise requires participants to call upon everything they've learned in the training to this point, and in so doing provides an experience that cements those individual pieces of information into a comprehensive appreciation for the use of fluvial geomorphology in designing, constructing and maintaining riverside infrastructure.

Setup

In this exercise students are presented with multiple infrastructure damages and channel adjustment types. A clogged culvert, channel downcutting and associated nickpoints, channel aggradation, and large-scale bank failure are some of the issues participants have to contend with. Attention to detail in scenario setup is key to the success of this exercise. In order to truly challenge participants it is important that the scenario presents the constraints and challenges presented by real-world scenarios.

True constraints and challenges are overcome with a limited set of solutions. Creating such constraints and challenges requires thoughtful and detail oriented scenario set-up. Horizontal distances between roadways, the river, and floodplain terraces must be just right if the goal is for participants to identify floodplain restoration as the preferred recovery solution. Vertical distances between the road surface, top of bank, bankfull stage and the channel bed must be precisely presented if the goal if for participants to identify a vertically stacked wall as the ideal practice for dealing with a failed embankment. If structures aren't located along the roadways to indicate that the road may not be moved, the first action of the recovery team will be to move the roadway; while this may be easy in the river model, it is rarely practical in the real world. If glacial erratics are available for armoring the river bank, they will be used. Creating a real-world scenario requires attention to detail of set-up.

The small scale of the river model makes it nearly impossible to construct detail elements to scale. However, the fact that the model is not to-scale does not diminish the value of discussing the characteristics of the scenario quantitatively and shifts participants' focus from accuracy of construction to selection of management practices and sound design. Nonetheless, an effort has been made to embed some level of accuracy of scale as complete disregard for scale does take away from the effectiveness of the exercise. The hypothetical dimensions provided below will support robust discussion around process diagnosis, equilibrium condition and ultimately recovery design.

This exercise requires 35 – 40 gallons of media to fill the model tray nearly to the top of the sidewalls. In order to minimize the volume of media required, insert lengths of rigid foam along the sidewalls to take up volume in the tray. The foam should be as high as the sidewalls and 4 inches wide. Fill the tray with 35 gallons of media and grade. Fill the water reservoir with only 11 gallons (1/2 the total required to run the flume). This will allow reservoir capacity for water that will be added when saturating the media prior to conducting the exercise.

Set the base of the energy dissipater at the upper end of the model tray as normal and at a height of 3 inches above the tray bottom. Use netting fabric and ¾-inch stones to build a secondary energy dissipater at the outfall of the primary dissipater as shown in figures 1,2 and 3 of Appendix A. Set the stand-pipe to a height of 2 inches above the tray bottom.

Referring to Figures 1, 2 and 3 of Appendix A, establish the general valley and pre-flood channel morphologies along the length of the tray. Take care to create floodplain and terrace features with sharp corners to make it easier for participants to identify and distinguish between features. Keeping the media sufficiently moist to create particle cohesion and using the carving tool helps in creating sharp feature corners. Create a narrow valley with an entrenched and steep channel along the upper third of the tray. Transition the channel to be slightly entrenched and moderately steep within a moderately confined valley along the middle third of the tray. Within the lower third of the tray create a broad valley with an un-entrenched meandering channel and a flood created avulsion channel. Make the channel 4-inches wide and 1-inch deep. Locate roadways and the culvert as shown in the figures contained in Appendix A. Use a circular tube that is 2-inches in diameter to represent an undersized culvert (50% of channel width). Buildings should be placed along the side of the road opposite the river to establish that the road cannot be moved.

Table 1. Valley and Channel Morphology

	Upper Third	Middle Third	Lower Third
Valley Setting	Steep/Narrow	Abrupt Transition	Flat/ Broad
Entrenchment Ratio	2.0	Transition	4.0
Width/Depth Ratio	12 - 20	Transition	10 - 12
Bed Feature Spacing	2.0	Plane Bed	3.0
Wavelength/Width Ratio	N/A	N/A	5.0
Amplitude/Width Ratio	N/A	N/A	3.0
Radius Curvature/ Width Ratio	N/A	N/A	2.0

With the general pre-flood valley and channel morphologies in place the next step is to create the channel adjustments and then install the channel scenario features. Refer to the set-up plans and channel section and feature descriptions for set-up details.

Materials for the exercise include the following:

- Three size classes of stone to be used as gravels, cobbles and boulders. The three size classes should be ¼-inch, ½-inch, and ¾-inch,
- ¾-inch crushed stone to simulate rip-rap,
- Twigs approximately 1/8 - ¼ inches in diameter and three to six inches long to simulate large wood debris,
- Simulation live shrubs and trees,
- Plastic mesh netting to be used as geo-textile in construction of bed features,
- Alternative culvert materials
- Culvert headwall materials

Conducting the Exercise

The task of the instructor is to assist students to use this infrastructure failure scenario as a starting point from which to describe valley and channel morphologies, identify physical features along the channel, explain the mechanisms that created those features and in so doing develop an understanding of what channel reconstruction activities need to be implemented to move the channel to the equilibrium condition and restore the infrastructure. The success of this exercise is highly dependent on the time spent introducing the scenario and leading participants through the thought process of linking observed damages to channel adjustments and developing an effective recovery plan before any work in the model begins.

Begin by introducing the scenario by walking through the step-wise design procedure in the Rivers and Roads Field Manual. Discuss valley, expected and existing channel morphologies. Assume the drainage area and channel dimension values provided in table 1. Use the river model, the Rivers and Roads Field Manual and cross-sections in Appendix A to physically and graphically explain the parameters being discussed. Next engage participants in describing the channel adjustment processes that led to the existing channel morphologies and forecasting further adjustments. Finally, discuss potential recovery alternatives.

Table 2. Drainage Area and Channel Dimensions	
Drainage Area	4 sq.mi.
Bankfull Width	24 ft.
Bankfull Depth	1.5 ft.

Before work begins in the models ask participants to establish teams that will work on specific sections of the river and a coordinator who will ensure that work of the individual teams will work in concert. Have teams sketch recovery designs in section, plan and profile views. Once the teams have sketched the proposed designs, discuss and modify as necessary (Refer to possible reconstructions listed by cross-section in Appendix A). This simple design process will give participants a level of comfort sketching river project designs, a practice that greatly enhances the thought process that goes into design work. As participants begin construction in the models the instructor plays an important role of guiding work and making sure it is consistent with established designs and thinking through modifications if necessary.

Once the teams have completed construction have the members present the design and construction work. The presentation should begin with an overview of the damages and channel adjustments, include an explanation of the considerations that influenced specific design options including risks and advantages of the design, and any construction challenges. Once the presentation has been given, run flow through the model and observe performance. At this point, participants typically become fully engaged in making any necessary corrections to the project and trying different design options. This less structured time provides ample opportunity for wide-ranging discussion around all topics covered during the training.

Appendix A: Disaster Scenario Plans Profile and Cross Sections

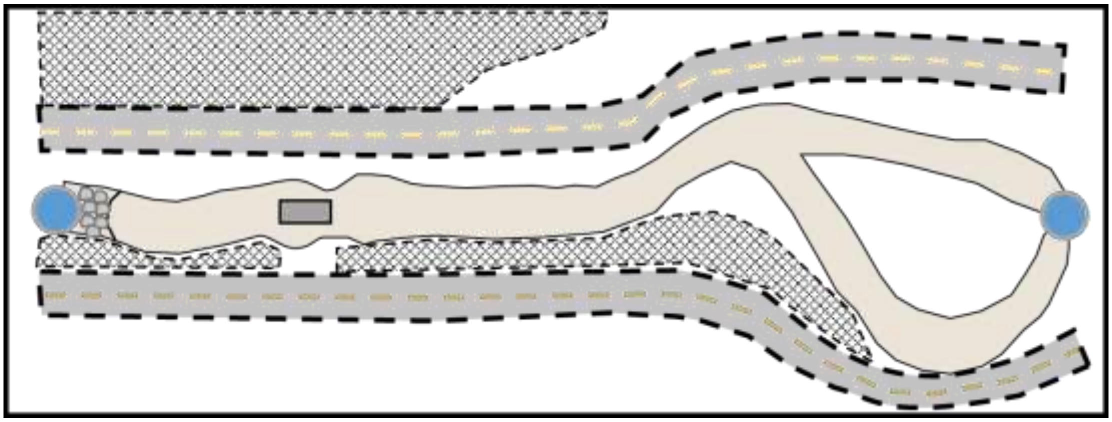


Figure 1. Planview of river model showing general valley and river morphology and road layout. Hatched areas represent terraces.

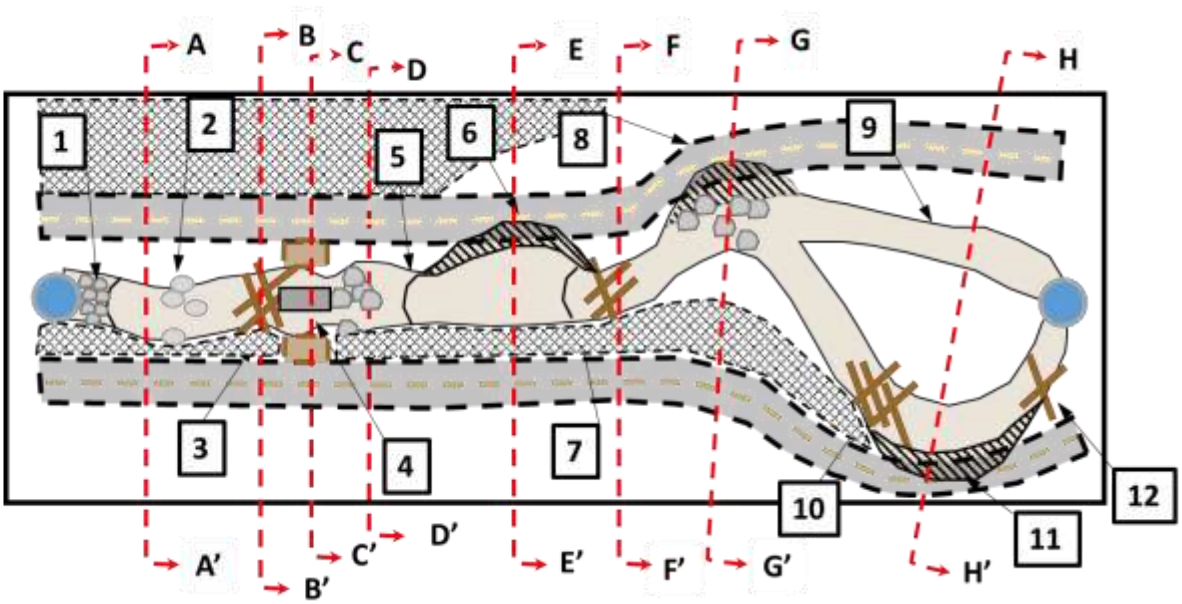


Figure 2. Planview of river model showing cross section locations and scenario features.

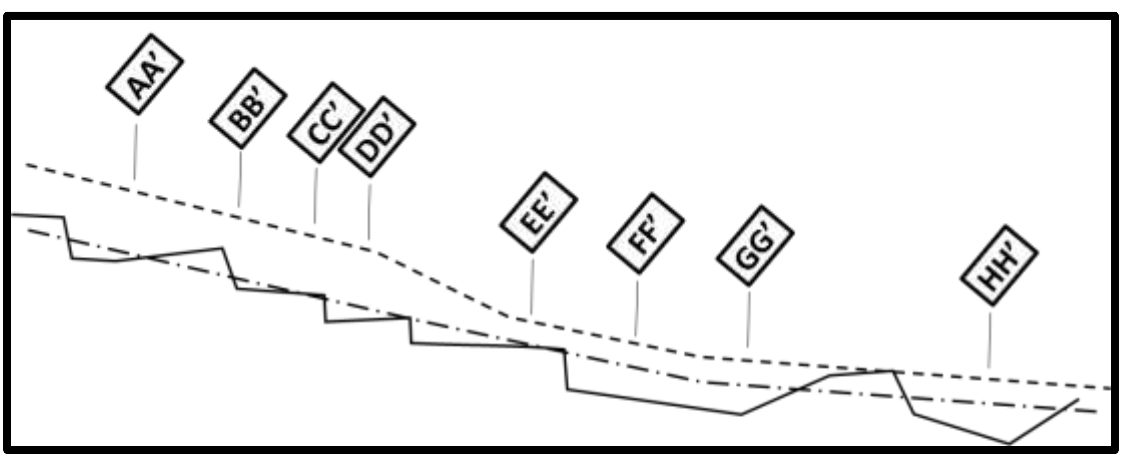
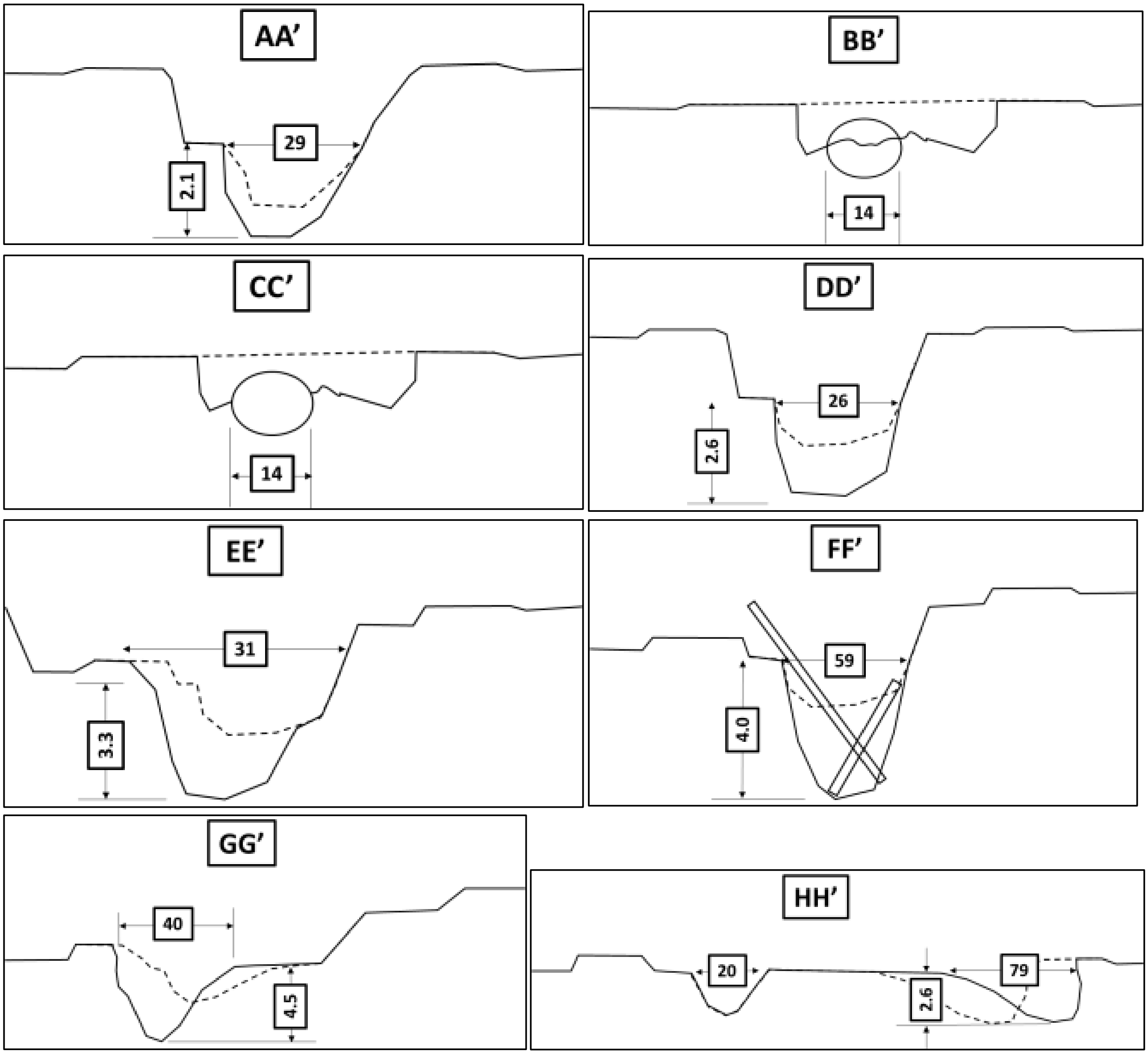


Figure 3. Profile view of the flood damaged river. Dash line represents top of bank. Dash-dot line represents equilibrium bed profile.

Pre and Post Flood Cross Sections



River Model Photographs

Figure 1. General valley and channel morphology set-up.

Figure 2. Participant constructed flood recovery.

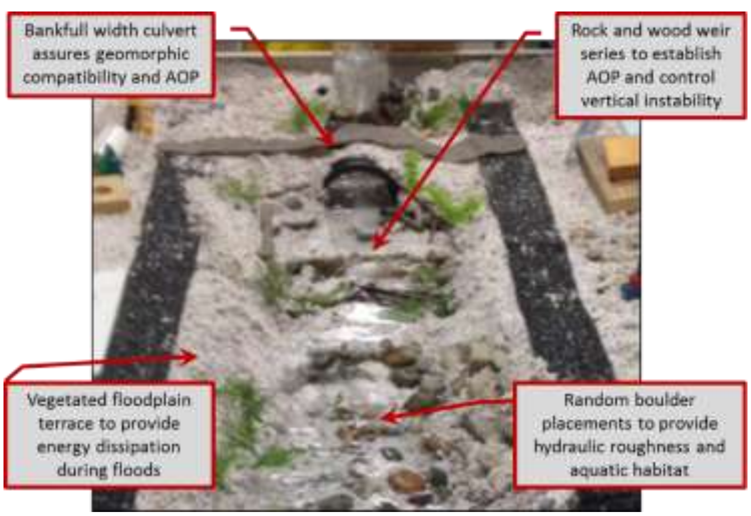


Figure 3. Example of a completed flood recovery exercise.

Appendix B: Channel and Valley Section and Scenario Feature Descriptions

AA': This section lies in a narrow and steep valley. The natural entrenchment is increased by the roadway fills on both banks. The section downcut during the flood (D = 2.1 ft.) and is slightly wider than predicted (W = 29 ft.). Failure of the downstream step feature indicates that the incision was initiated at or below the step and migrated through this section. A nickpoint is present upstream of this section and threatens the energy dissipater.

BB': This section lies in a narrow and steep valley and at the inlet of a culvert. The natural entrenchment is increased by the approach fills on both banks. The section has completely filled with culvert induced deposition. The deposits likely originated from the upstream incised reach. Channel flow has been re-routed into the toe of the roadway on river-right.

CC': This section lies in a narrow and steep valley at the midpoint of the culvert. The natural entrenchment has been increased by the approach fills on both banks. The culvert has a diameter of (14 ft.) Severe deposition at the culvert inlet has resulted roadway overtopping and structure outflanking.

DD': This section lies in a narrow and steep valley at the midpoint of the culvert. The natural entrenchment is increased by the approach fills on both banks. The section downcut during the flood and is moderately incised (D = 5 ft.).

EE': This section lies in a moderately broad valley that is narrowed by the roadway on river-left. The river has historically downcut as evidenced by an abandoned terrace on river right. The active floodplain is several feet lower than abandoned terrace. The channel is severely incised (D = 3.3 ft.) and has widened into the roadway on river-left (W = 31 ft.).

FF: This section sits in a broad valley that is narrowed by the roadway on river-left. The river has historically downcut as evidenced by an abandoned terrace on river right. Current floodplain is several feet lower than abandoned terrace. The channel is severely incised with an average bankfull depth of 8.0 ft. Flood adjustments include incision and lateral migration into the road embankment.

GG': This section sits in a broad low gradient valley which has been greatly narrowed by the roadway on river-left. Aggradation initiated by the downstream woody debris jam caused lateral migration and channel incision during the flood.

HH': This section sits in a broad low gradient valley which is only minimally constricted by the roadways. The section crosses the main channel and the flood shoot.

Scenario Feature Descriptions

The 12 primary features included in the scenario are presented in figure XX. These features represent infrastructure failures and channel adjustments that must be addressed in the recovery design. These features may also provide diagnostic information that supports river process analysis and recovery design. Each feature and its construction are described below and possible solutions for addressing them are presented.

1: Energy Dissipater: The purpose of the energy dissipater is to prevent outfall scour and maintain the upstream grade of the channel and prevent flow from going sub-surface. It is constructed by digging a basin that is approximately 4 inches in diameter and 2 inches deep, lining it with geotextile and covering with ¼ to ½ inch stone.

2: Partially Failed Step Feature: The step feature is intended to indicate that the reach within the upper third of the flume is a step-pool Bedform. Participants should use the presence of the step-pool feature to support their selection of recovery practices (i.e. rock weir grade control. The step should be identified as a feature to be restored and may be used as an indication of appropriate excavation depth. Setup of the step feature is straight forward. Use a size stone that allows for 5 – 6 stones to span the bankfull channel. The step feature should be partially buried by flood deposits during setup to provide a reminder to participants that deposition excavation should be done carefully so as not to disturb boundary features that remained intact through the flood.

3: Aggraded bedload and woody debris clogging culvert: Participants will recognize that the deposited bedload and woody debris should be removed during the recovery operation. Discuss the appropriate width and depth to which the channel should be dredged before the material is excavated. A bankfull bench at this section provides a benchmark for measuring appropriate channel dimensions.

4: Undersized Culvert: The culvert is constructed using 2-inch tubing placed level along the profile (not on channel grade). The scenario envisions that the culvert and roadway have been overtopped through the flood and the roadway scoured to an elevation of the invert of the culvert. Upstream and downstream headwalls (if any) have been failed. The culvert is perched at the outlet. The intent here is to have participants recognize that the structure is undersized and not on channel grade and replace it with an appropriately sized structure that meets standards.

5: Headcut: This headcut threatens the upstream culvert and banks. Participants may use a number of techniques to stabilize it.

6: Incision triggered embankment failure: This embankment failure is the result of channel incision which is marked on the upstream end by the upstream headcut. The incision has resulted in an embankment that is higher than pre-flood embankment and participants will have to select a practice that minimizes encroachment on the river channel.

7: Nickpoint and wood debris accumulation: This headcut represents the upstream end of an incision process that extends downstream to section GG'. Woody debris has accumulated and lodged immediately downstream of the nickpoint.

8: Incision triggered embankment failure: This embankment failure was caused by the channel incision process that extended upstream to the upstream nickpoint. The challenge for participants is to rebuild an embankment that is stable but doesn't encroach into the bankfull channel.

9: Channel avulsion: This channel avulsion developed during the flood event. Participants should be encouraged to evaluate the stability of the avulsion channel and associated risks and benefits when determining how to manage it.

10: Channel spanning woody debris jam and upstream channel filling aggradation: This severe debris jam was likely initiated by the shallow channel that resulted from deposition related to the upstream incision and embankment failure. The deposition and jam appear to be responsible for diverting flow into the outside bank and causing the bank failure.

11: Lateral channel migration: This bank failure was likely the result of flows being diverted from the upstream woody debris jam into the bank. Participants should understand that the bank failure is the result of only lateral channel movement and not vertical instability. The selected management option should consider this.

12: Minor woody debris jam: This woody debris jam is not channel spanning and doesn't represent significant risk to infrastructure. Participants should be encouraged to give consideration to leaving the jam in place and potentially enhancing its value as a habitat feature.

Appendix C: Possible Restoration Options

AA: The section could be reconstructed to elevate bed to restore bankfull depth and protect energy dissipater. The downstream step feature could be restored or rebuilt.

BB: The woody debris at the culvert inlet will need to be at least partially removed. Design considerations must include floodplain morphology, bankfull channel dimensions, boundary condition and continuity with the crossing structure dimensions.

CC: The appropriate reconstruction of this section involves culvert replacement with a bankfull width structure that is on vertical and horizontal alignment, is appropriately embedded, and reconstruction of headwalls and roadway approaches. Determination of the correct vertical alignment is complicated by the fact that the channel downstream of the culvert has incised. Participants will need to determine which vertical profile (pre or post flood) to match.

DD: Reconstruction of this section should focus on raising the bed elevation to return connectivity to adjacent floodplain benches and address the nickpoints that developed during the flood. AOP must be considered in the bed elevation design. The river-right terrace could be lowered to the bankfull elevation to provide additional flood relief. However, the risk associated with increasing the frequency with which the road embankment is exposed to flood flows must be considered.

EE: This roadway must be reconstructed on the pre-flood alignment. There are several possible alternatives for the embankment design ranging from a 2:1 rip-rap embankment that does not re-establish a bankfull bench, to a stacked wall which provides enough horizontal room for creation of a floodplain bench. Reconstruction may also include lowering of the terrace on river-right to provide greater flood refief.

FF: The section could be reconstructed to include placed rip-rap wall, slight bed armoring to elevate thalweg and excavation of point bar to slide channel back to river right. Additionally the abandoned terrace could be excavated to provide flood relief. This section would ideally have much more floodplain width so the placed wall and floodplain cut are important.

GG: This section could be reconstructed by moving river-left roadway away from the river to provide overbank area. The channel avulsion could be stabilized and retained as a flood chute. The debris jams should be removed to the extent necessary to provide bankfull flow conveyance. The roadway could be restored by rebuilding the embankment at 1.5:1 and the point bar excavated to move the channel away from the roadway and re-establish a stable bankfull width.

HH': This section includes the mainstem which has migrated laterally during the flood and an avulsion chute which developed during the flood. The reconstruction could consist of rebuilding the road embankment on river left. Consideration should be given to whether the avulsion should be maintained as a flood chute or filled in.