Fluvial Processes and Crossing Structures

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Vermont River Management Program

- State Floodplain Management, Federal NFIP
- Stream Alterations Permitting
- Fluvial Erosion Hazard Management
- River Assessment, Restoration and Protection

70+ years of observing interactions between rivers and human investments

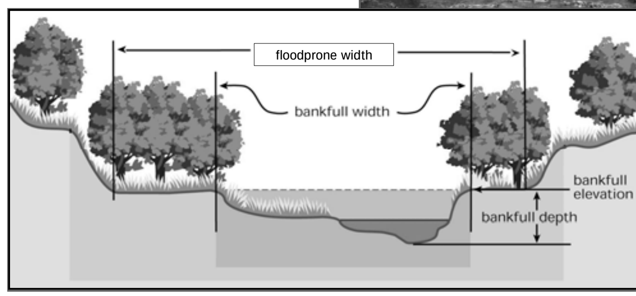
How do we understand river behavior? Fluvial Geomorphology: The study of landforms created by flowing water

- Fluvial Geomorphology (key concepts and principles)
  - Channel Classification/inherent sensitivity/Bedload
  - Most probable form/equilibrium/geomorphic stability
  - Channel evolution
  - Bankful, Alluvial and Threshold Channels
  - Culvert Sizing for Sediment Transport Continuity

Most Probable Form

Given consistent controlling factors (sediment and hydrologic regimes boundary condition and valley slope), every river has a most probable form (reference or equilibrium condition) toward which it is constantly working (Leopold, 1994).

Most Probable Dimensions



A Most Probable Planform

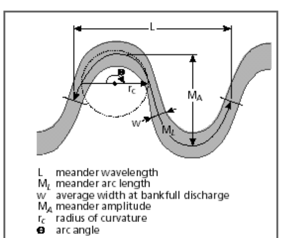
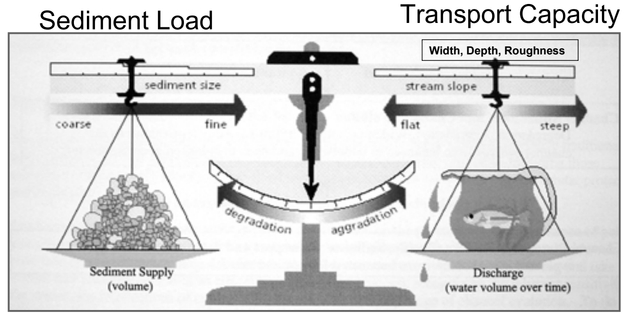


Figure 7.21: Meander geometry variables.
Adapted from Williams 1986.

Channel Equilibrium

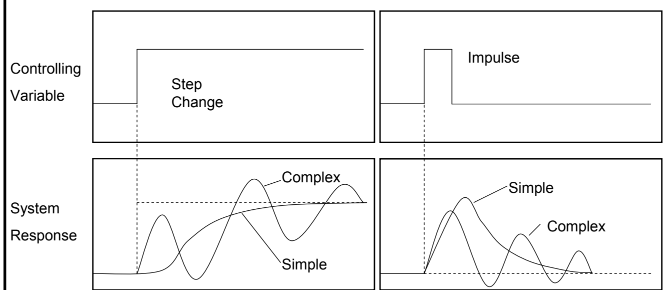
Sediment Load

Transport Capacity



Lane (1955)

The affect of changes in controlling variables



From Thorne, Hey and Newson (1997)

When a river reaches its most probable form or equilibrium condition the rate of work (erosion, deposition and migration) is minimized. The channel is geomorphically stable.

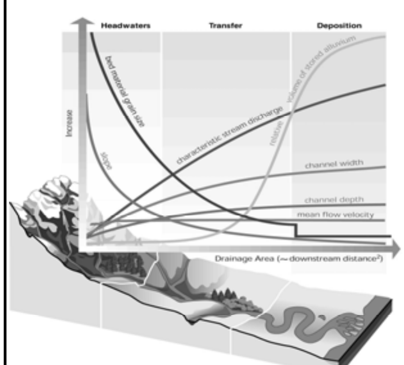
Designing structures that minimize change to the river results in a more stable built environment and increased structure longevity.

Channels are classified by how they look with the expectation that there is a correlation between appearance and behavior

<u>Relevancy to crossing structure design</u>

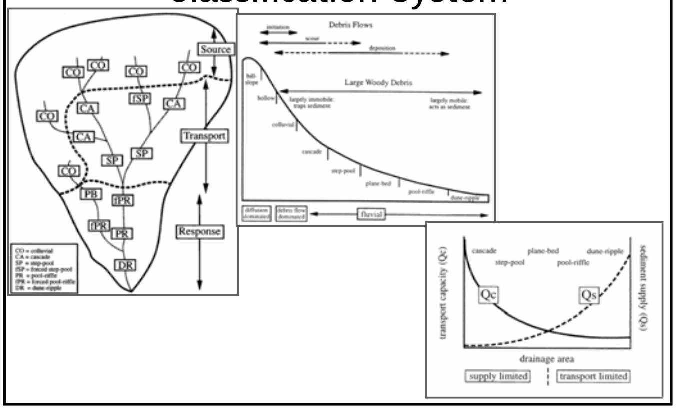
- Explain how sensitive will the channel be to a change in hydraulics and the boundary condition.
- Predict the disequilibrium channel processes.
- Describe the hydraulic geometry of the equilibrium channel.
- Describe the relation between sediment supply and transport capacity.
- Describe the important characteristics of the natural channel bed?

Watershed Zone Classification

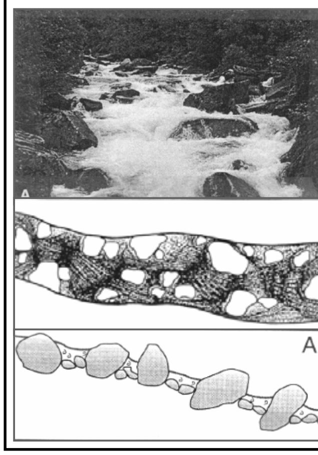


From the Stream Corridor Restoration Manual, Federal Interagency Stream Restoration Working Group, 1998.

Montgomery and Buffington Stream Classification System



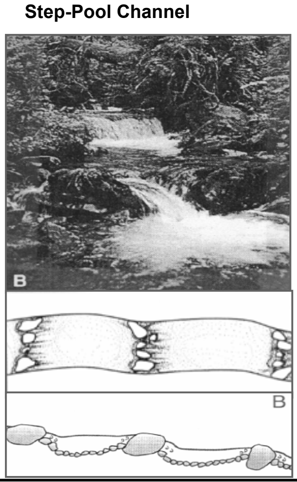
Cascade Channel



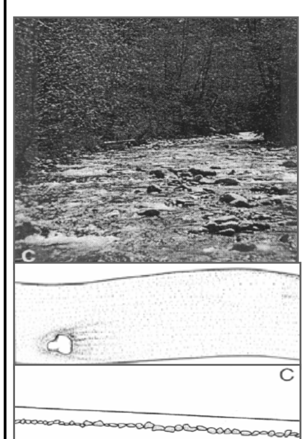
- Disorganized bed
- Continuous supercritical flow (Fr ≥ 1)
- Typically boulder bedded
- Thalweg hard to identify
- “Pool” frequency < 1 channel width
- **Transport capacity >>sediment supply**

Step-Pool Channel

- Sediment organized into channel-spanning steps
- Flow alternates between supercritical and subcritical flow
- Typically gravel to boulder bedded
- Pools 1-4 channel widths apart
- Gravel in pool is annually mobile; steps mobile during multi-decade flows
- **Transport capacity > sediment supply**



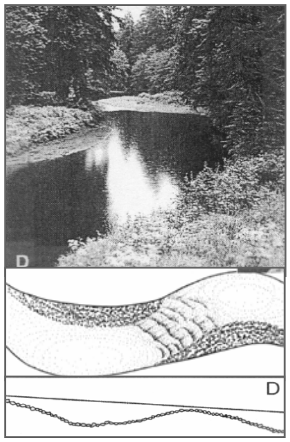
Plan Bed Channel



- Flume-like
- No organization to bed, but not chaotic
- Relatively uniform grain size, typically cobble and gravel
- Pools are infrequent, around isolated boulders or logs
- **Transport capacity ≈ sediment supply**
- Grain size can adjust to accommodate changing sediment supply

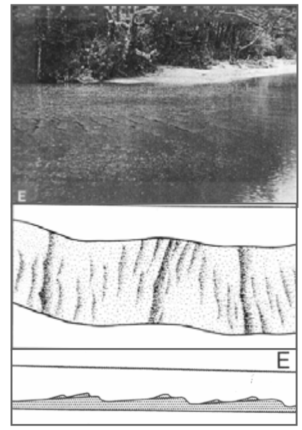
Riffle Pool Channel

- The “classic” fluvial channel
- Alternate bars, meander bends, floodplains
- Gravel bedded
- Pools typically 5-7 channel widths apart
- **Transport capacity << sediment supply**

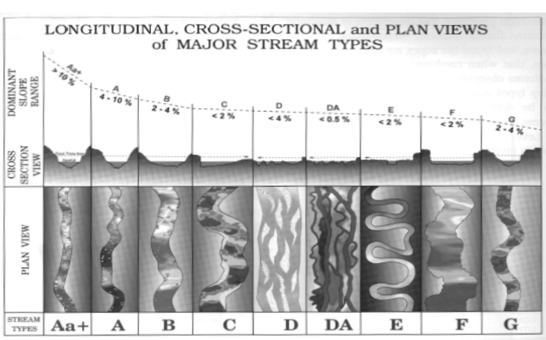


Ripple Dune Channel

- Multiple-scale bedforms
- Sediment mobile at low flows
- Typically sand bedded
- Pools occur where forced by channel pattern
- **Transport capacity << sediment supply**



Rosgen Classification System



Rosgen (1996)

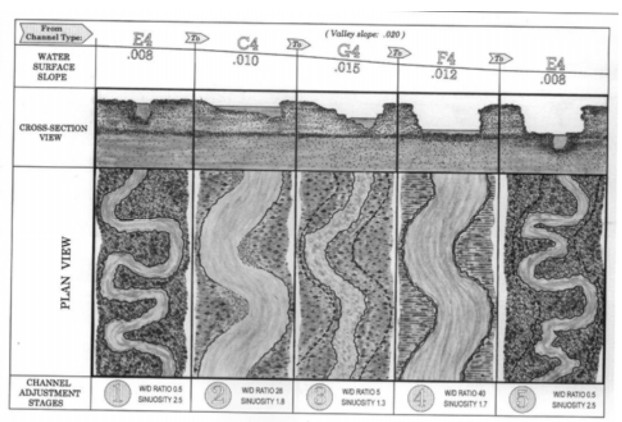
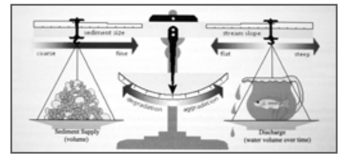


FIGURE 6-8e. Example of a E5 streamtype evolved from a G5-F5-C5 type conversion.

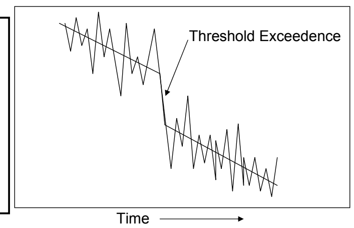
FIGURE 6-8f. Example of G5 stream type 150 feet downstream of (6-8e) due to culvert crossing. An important comparison of adjustment, reverting back to a G5 from an E5 streamtype.

Channel Evolution

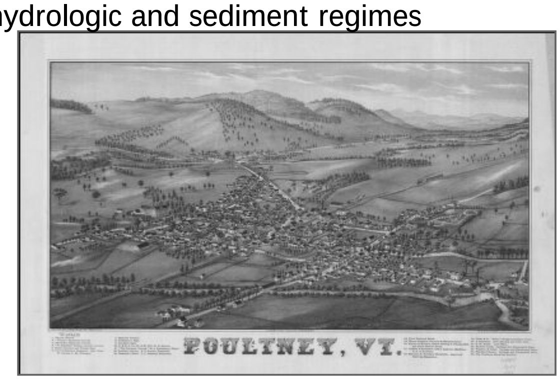
The sequence of adjustments processes that a channel goes through when changes to controlling factors exceed a "geomorphic threshold".



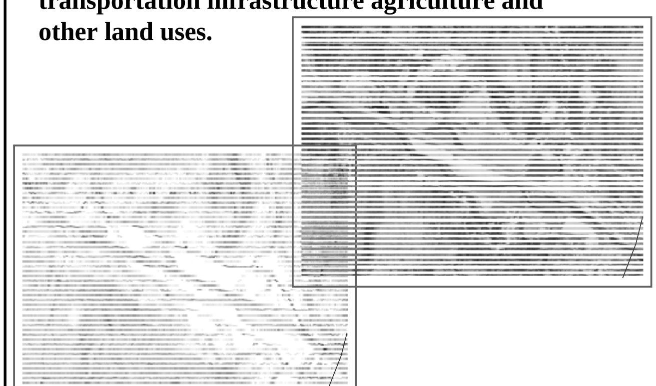
Controlling Factors
- Flow regime
- Sediment regime
- Slope
- Cross section
- Boundary condition
- Channel Roughness



Throughout Vermont changes in land cover and land use have resulted in changing hydrologic and sediment regimes



Channel slope and dimension have been significantly altered to accommodate transportation infrastructure agriculture and other land uses.



Post flood recovery works have altered channel dimension and boundary condition.

Timescale of Geomorphic Response (relaxation period)

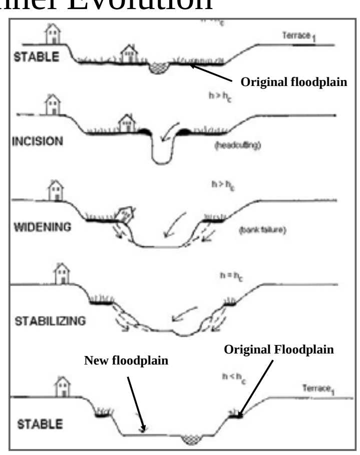
Micro-scale changes (bedforms): 1-10 yrs.

Meso-scale changes (cross section dimensions) 10-100 yrs.

Macro-scale changes (meander geometry and floodplain) 100+ yrs.

Rivers today are likely still adjusting to changes going back to the 1800's deforestation

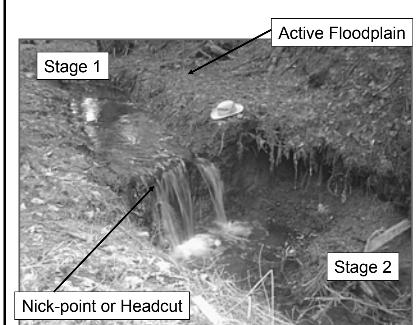
Channel Evolution

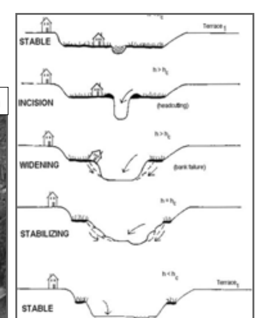


When destabilized a river will begin working back toward the equilibrium condition through a fairly predictable channel evolution process.

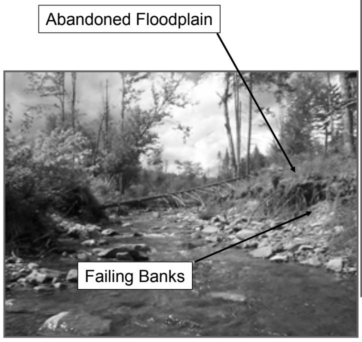
Schumm Channel Evolution Model

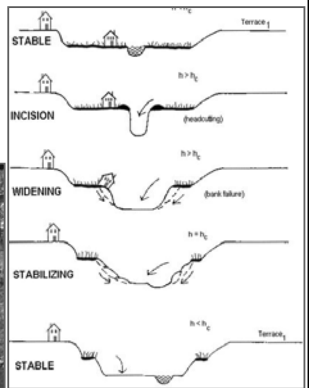
Stages 1 and 2: Equilibrium to Incision



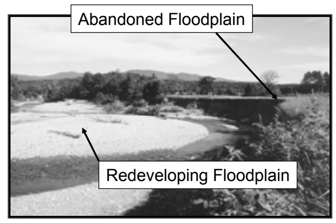


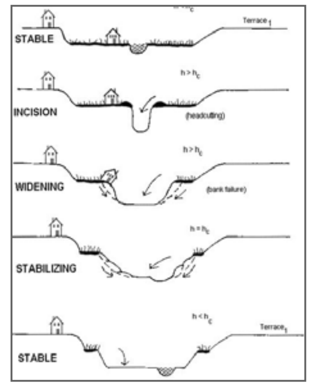
Stage 3: Widening



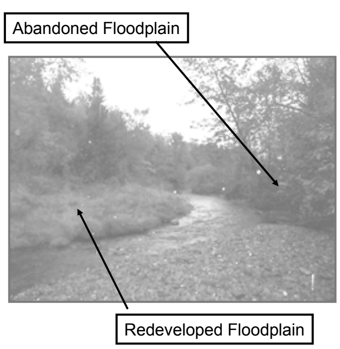


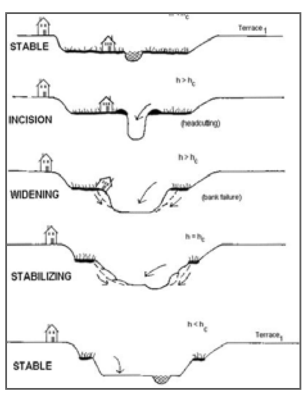
Stage 4: Continued widening and floodplain development



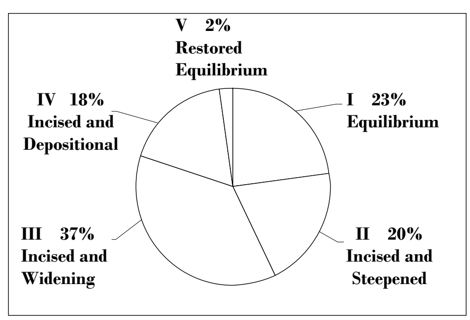


Stage 5: Return to Equilibrium





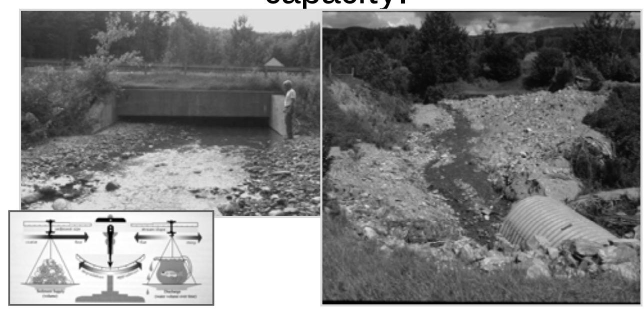
Approx. 900 Miles Assessed



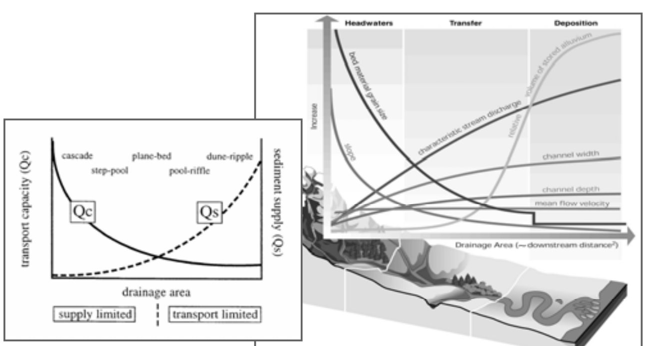
Considering River Processes in Structure Design

- Selecting Most Stable Location
  - Sensitivity
  - Alluvial Fans
  - Channel Evolution
- Sizing
  - Bankfull Channel Width
  - Sensitivity (sediment supply:transport capacity)

The most common problem created by crossing structures is a sudden decrease in sediment transport capacity.



Structure Location, Consider Valley Setting, Stream and Valley Morphology and Inherent Stability



From the Stream Corridor Restoration Manual, Federal Interagency Stream Restoration Working Group, 1998.

Alluvial Fans

- Sediment naturally deposits at locations of significant decrease in valley slope.
- These highly depositional zones may form "alluvial fans".

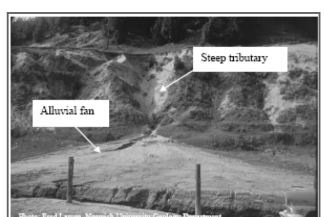
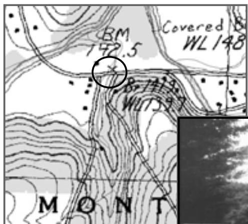


Figure 1.1 A small alluvial fan deposited from a steep tributary due to a change in slope.

Fans aren't good crossing structure locations



Structures placed at the toe of the valley wall often require repetitive maintenance.

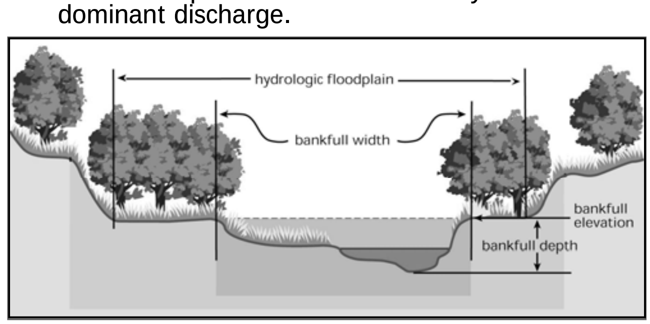
Through headcutting and transport of sediment waves the effects of channel evolution travel up and downstream

Sizing the Structure to Maintain Sediment Transport Continuity

- Start by Maintaining hydraulic characteristics of the channel by sizing to the bankfull width.
- Adjust size according to stream sensitivity or the relation between sediment load and transport capacity.

Bankfull Width

- The stream channel that is bounded by the active floodplain. It is maintained by the dominant discharge.



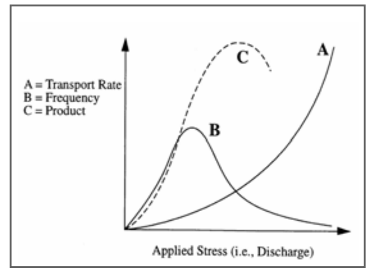
Bankfull or Dominant Discharge

- The discharge that has the right combination of frequency and magnitude to transport the greatest volume of sediment over time.
- It is the flow that maintains the channel.
- In humid environments such as Vermont's it has been shown to have a recurrence interval of 1.5 – 2 yrs.

Sizing the Structure to Maintain Sediment Transport Continuity Design for the Bankfull Flow A.K.A. Dominant or Effective Discharge

The discharge that is large enough yet occurs frequently enough to move the most sediment over time.

Recurrence Interval = 1.5 yrs
Exceedence Probability = 66%



Threshold Channel Concept

•Streams where the boundary materials are remnants of processes no longer active in the stream system may be threshold streams. Streams formed by post-glacial hydrology or running through colluvial deposits.

•Threshold shear is just equaled at the maximum sustained discharge of record.

•At flows < Qm.s. the channel boundary is immobile.

•At flows > Qm.s. the channel perimeter mobilizes and the channel enlarges until the boundary shear is reduced to the threshold value.

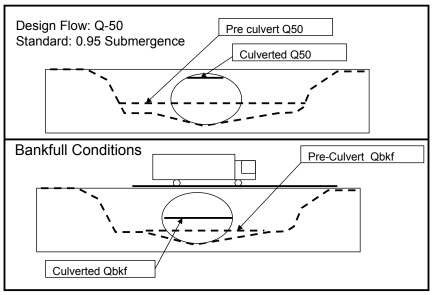
•An implicit assumption is that supply of coarse material to channel is negligible. Otherwise, the channel would aggrade at flows less than Qm.s. and would not necessarily degrade at flows > threshold.

What about using hydraulic criteria?

Vermont Hydraulic Criteria:

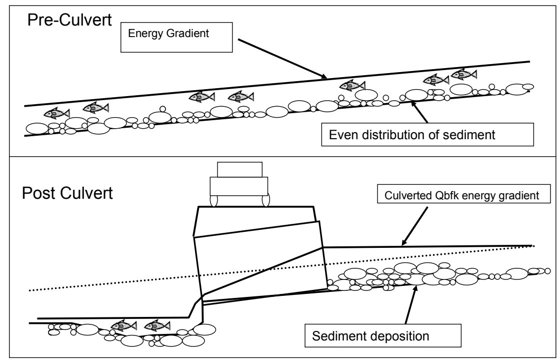
- Interstate highways: Q100
- State highways: Q50
- Town Roads: Q25
- 95% Max Submergence

Hydraulic or flow criterion based design (i.e., pass design flow with max. specified submergence) results in decreased flow width and increased flow depth. Even at flows as low as Q2

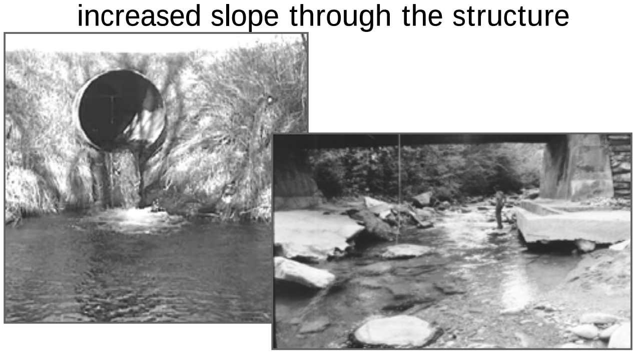


The flattened water surface upstream of the culvert results in sediment deposition.

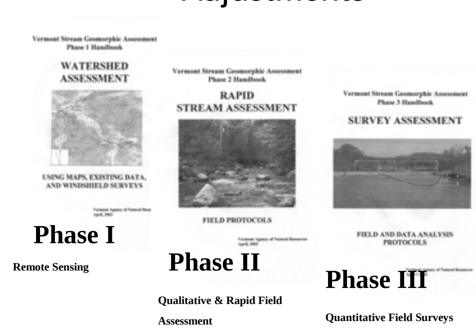
The elevated water surface in the structure results in increased velocities and scour at the culvert outlet which can create a barrier to fish movement.



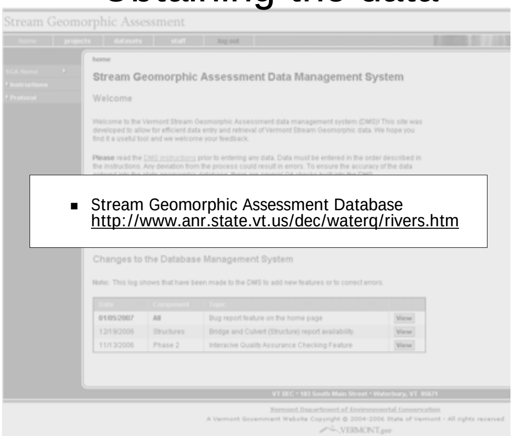
A reduced water surface (energy gradient) upstream of structure usually means an increased slope through the structure



Geomorphic Assessment to Understand Stream Type, Sensitivity and Ongoing Adjustments



Obtaining the data



- Stream Geomorphic Assessment Database
  http://www.anr.state.vt.us/dec/waterq/rivers.htm

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