Stream Channel Repair and Restoration Following Extreme Flooding Damage

Design And Implementation

26 March, 2015

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and
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Stream Channel Repair and Restoration Following Extreme Flooding Damage

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How-To Stuff

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Outline

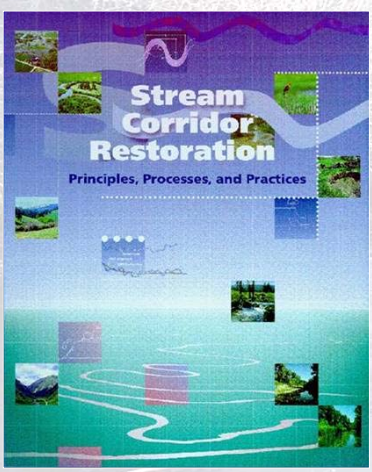
Jon
- Introduction
- Fluvial Issues
- Design Criteria
  - RipRap - Sizing
  - Scour

Ben
- Geotechnical Issues
  - Failure modes and feasibility
  - Geotechnical considerations

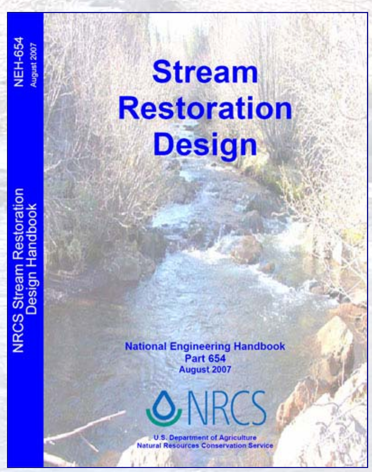
Both
- Conclusions

Focus of this webinar is on an overview of the issues and a few 'how-to' tools

Sources For Fluvial Section



USDA/NRCS NEH-653:
Basic principles, planning.



USDA/NRCS NEH-654:
Design Tools.

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Scope

- Emergency Watershed Protection (**EWP**) Program
- Administered by NRCS
- Emergencies created by natural disasters
- Caused by a storm event
- In a channel
- Storm is over
- Threat to life and property
- Need quick response

Eligibility Criteria

- Damage the result of a natural disaster?
- Recovery measures for runoff retardation or soil erosion prevention?
- Damages are a threat to life and/or property?
- Event caused a sudden impairment in the watershed?
- Imminent threat was created by this event?
- Structural repairs not repaired twice within ten years?
- Recovery measures are economically, socially, environmentally, and technically defensible?
- Are we protecting eligible property? (Cannot be land, crops, etc.)
- Is the damaged area associated with a watershed stream corridor?
- For debris, does is affect or can it be transported to the stream system?
- Is a bank or earthen slope failure caused by stream erosion or is slide material blocking a stream corridor?
- Can the Sponsor get land rights, cost share, permits, utility relocation, provide O&M? (If not, project dies)

Must answer "Yes" to all these questions!

Text modified from Alton Miller, NRCS-TN

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Responses – *A bunch of options…*

Don't just do something…

- ~~*Ready*~~
- ~~*Fire*~~
- ~~*Aim!*~~

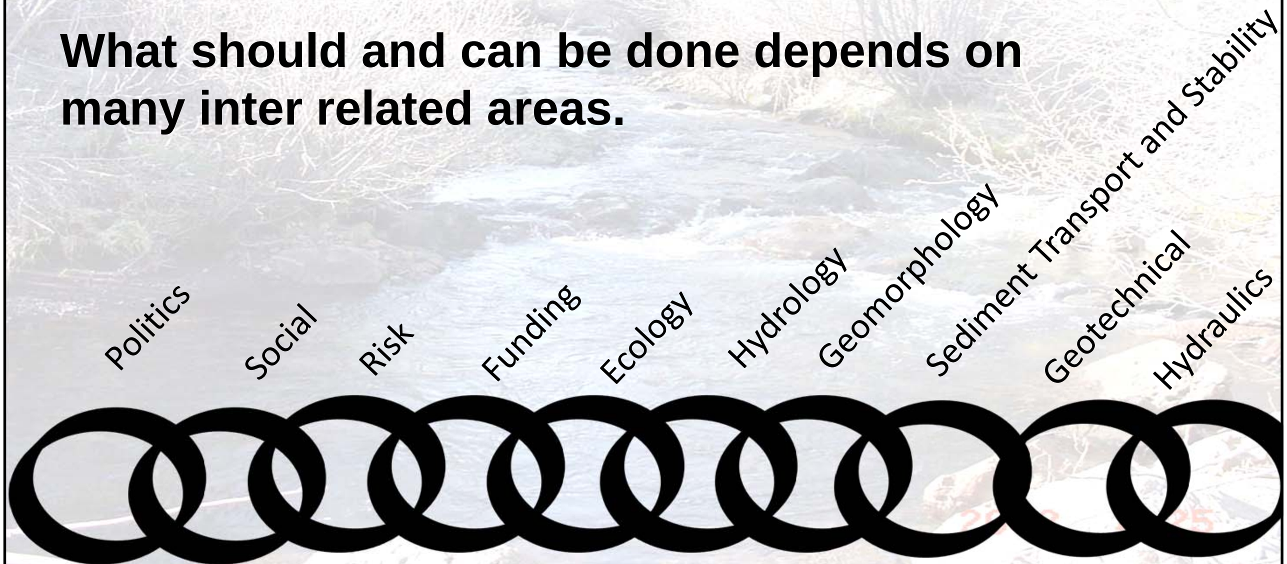
Stand there!

….and think about it

Geomorphology
Fluvial Forces
Geotechnical
etc.

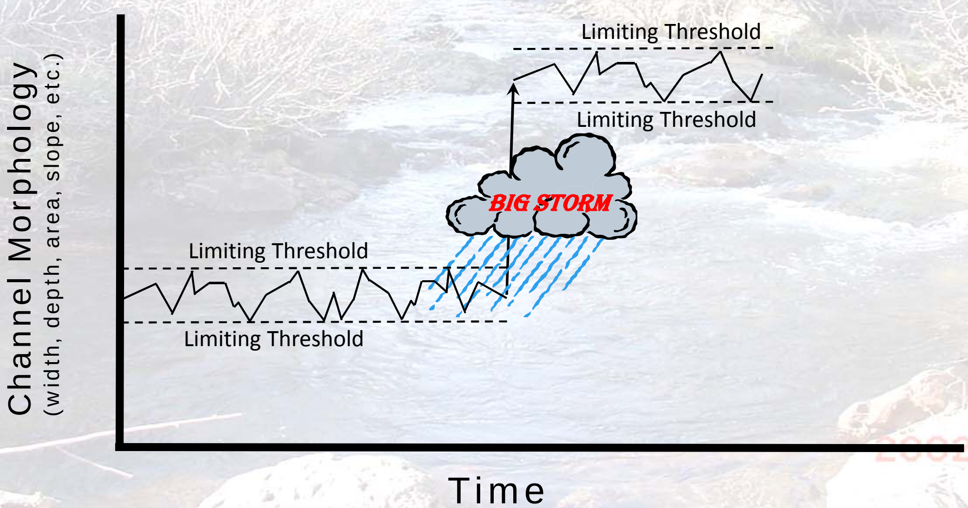
Interdisciplinary and linked

What should and can be done depends on many inter related areas.

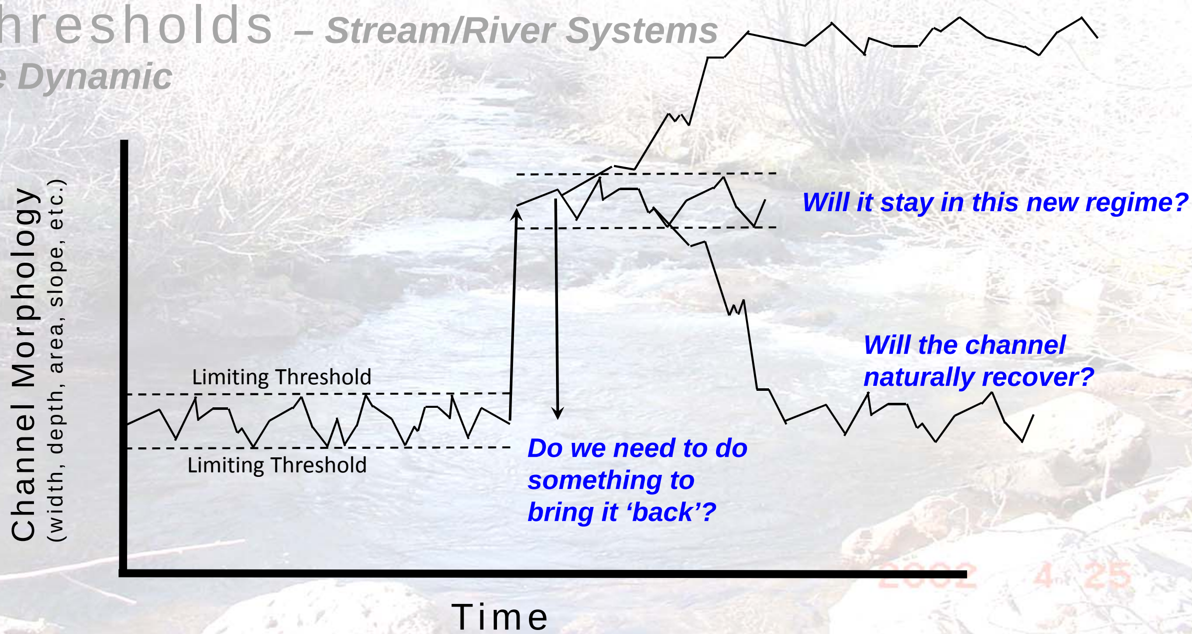


Today, we are going to overview the items on the right side of the chain

Geomorphic Limiting Thresholds *– Stream/River Systems are Dynamic*



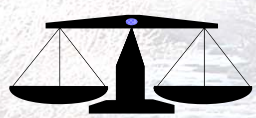
Geomorphic Limiting Thresholds *– Stream/River Systems are Dynamic*

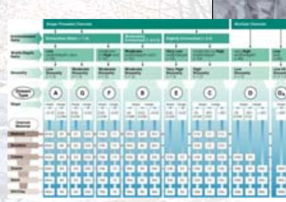


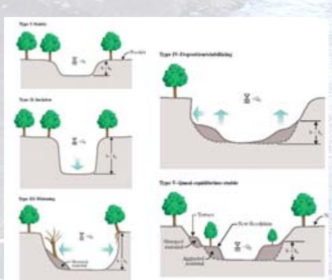
See NEH 654.3

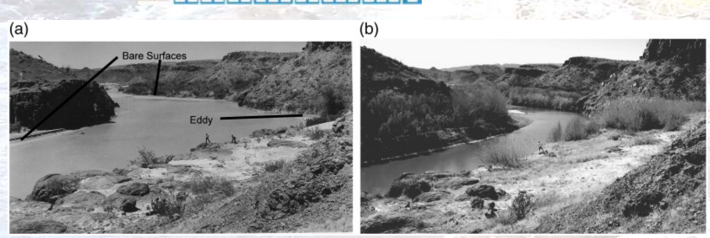
What might happen? Look at history..... Evaluate geomorphological indicators

- History
- Land use changes
- Frequent events vs infrequent events
- Are equilibrium concepts valid?
- Channel Evolution









(a) Photograph taken in 1945. (b) Photograph taken on 2/23/08.

The role of feedback mechanisms in historic channel changes of the lower Rio Grande in the Big Bend region - Geomorphology, Volume 126, Issues 3–4, 2011,David J. Dean , John C. Schmidt

See NEH 654.3 and NEH 654.13 for more information

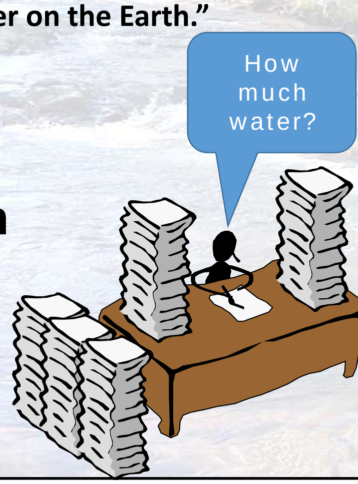
Need to consider the behavior of the stream/river but....

...often the goal is to *fix* the channel, repair the damage, and protect what is threatened

Hydrology

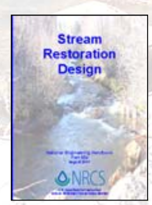
"Hydrology is the science that treats the waters of the Earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living things. The domain of hydrology embraces the full life history of water on the Earth."

U.S. National Research Council



<u>Sources of data</u>

- **Regional Regression**
- **Gage Data**
- **Models**



More info in NEH 654.5

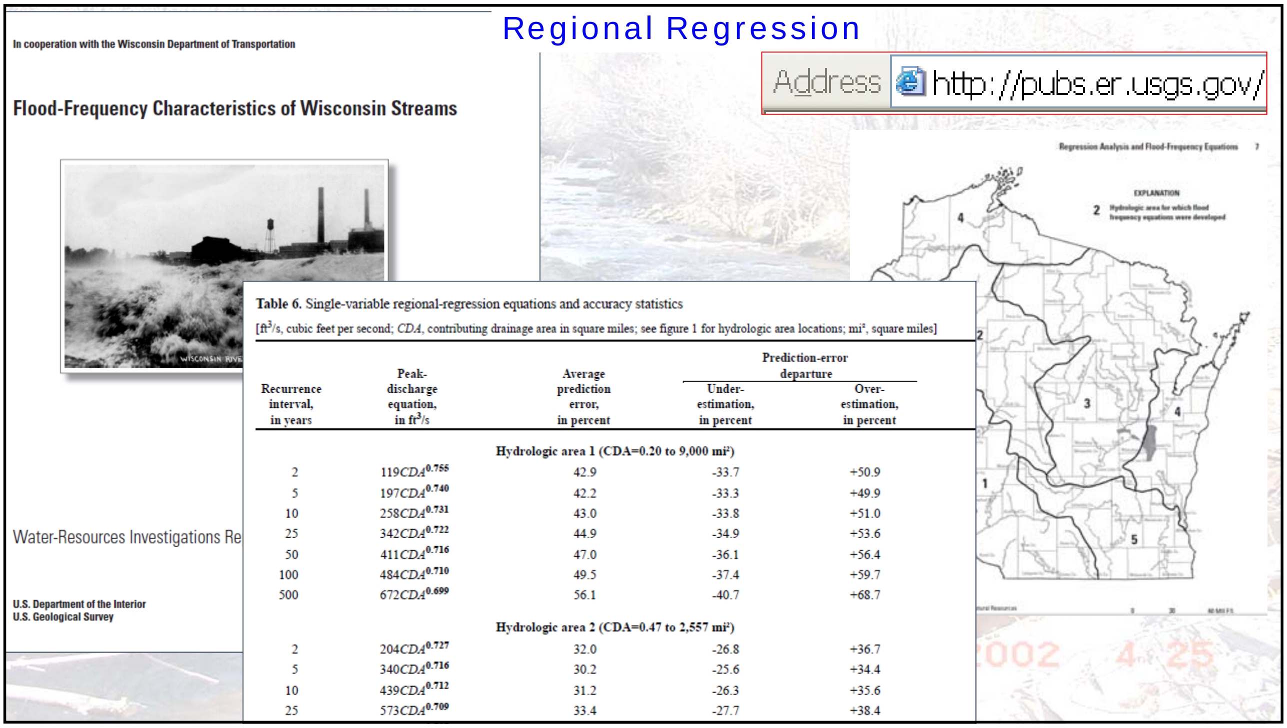
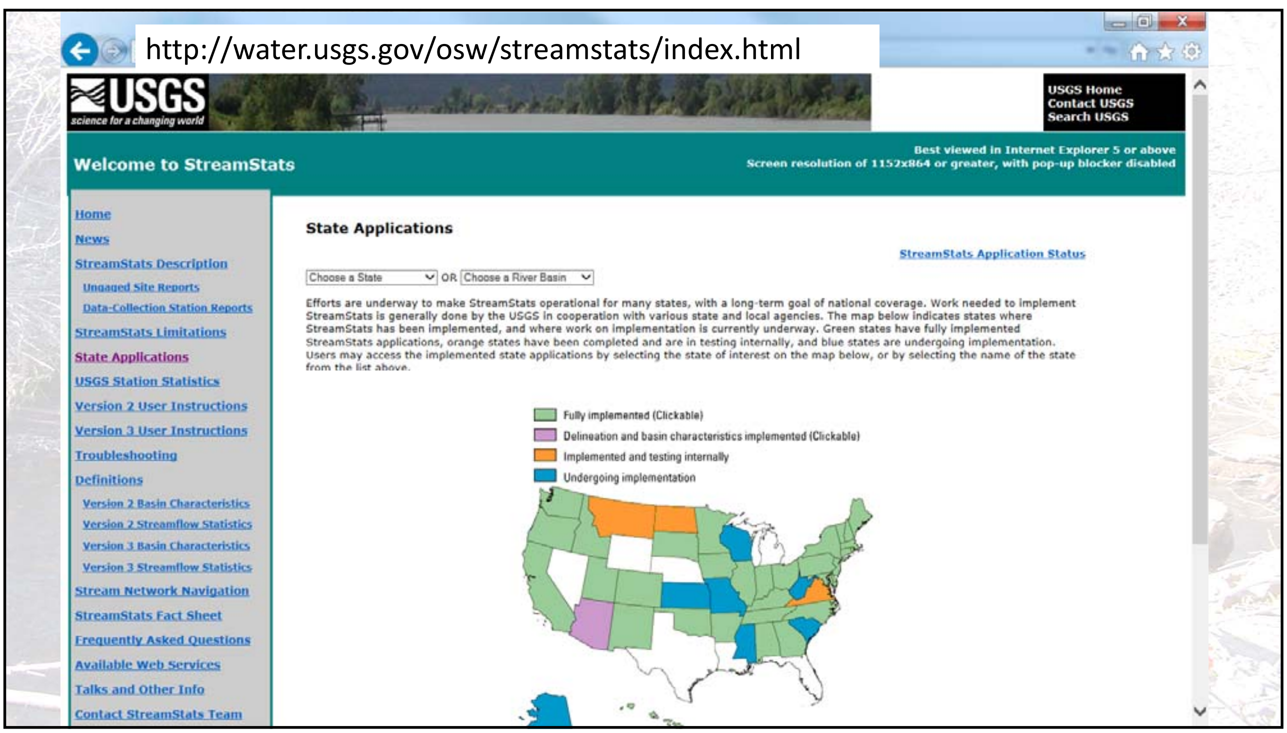
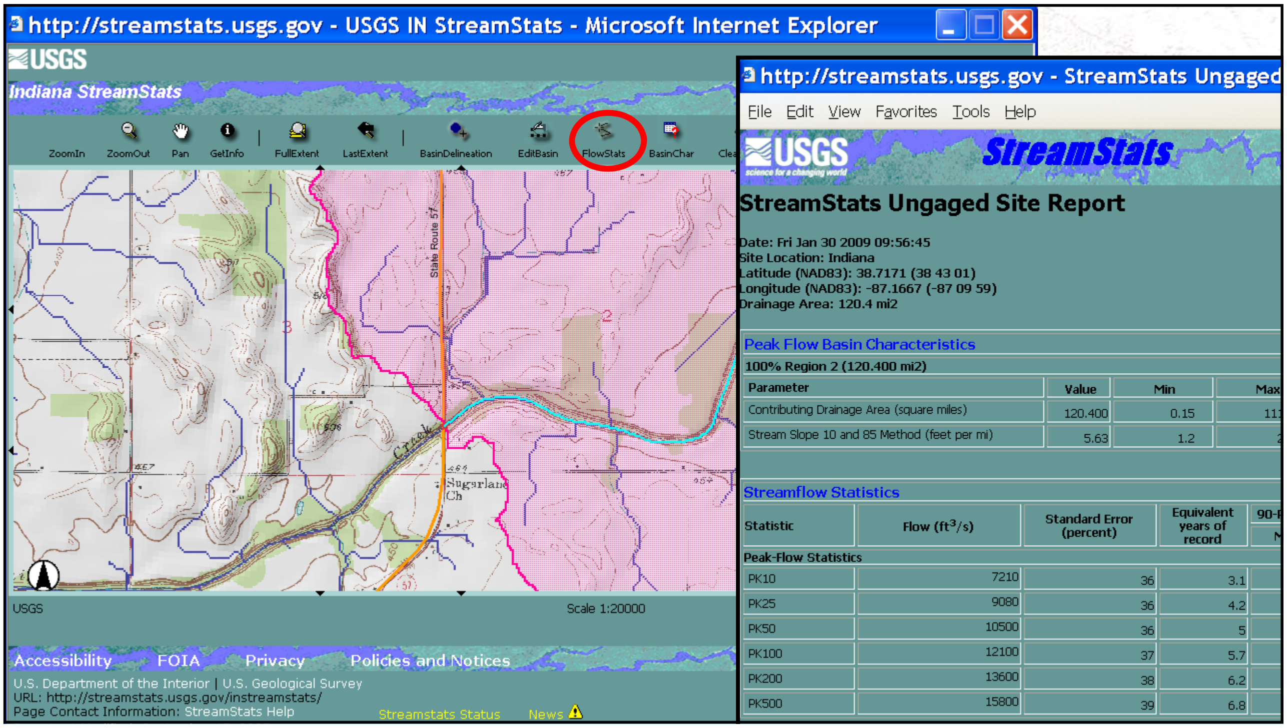


Table 6. Single-variable regional-regression equations and accuracy statistics

[ft³/s, cubic feet per second; *CDA*, contributing drainage area in square miles; see figure 1 for hydrologic area locations; mi², square miles]

Recurrence interval, in years	Peak-discharge equation, in ft³/s	Average prediction error, in percent	Prediction-error departure: Under-estimation, in percent	Prediction-error departure: Over-estimation, in percent
Hydrologic area 1 (CDA=0.20 to 9,000 mi²)				
2	$119CDA^{0.755}$	42.9	-33.7	+50.9
5	$197CDA^{0.740}$	42.2	-33.3	+49.9
10	$258CDA^{0.731}$	43.0	-33.8	+51.0
25	$342CDA^{0.722}$	44.9	-34.9	+53.6
50	$411CDA^{0.716}$	47.0	-36.1	+56.4
100	$484CDA^{0.710}$	49.5	-37.4	+59.7
500	$672CDA^{0.699}$	56.1	-40.7	+68.7
Hydrologic area 2 (CDA=0.47 to 2,557 mi²)				
2	$204CDA^{0.727}$	32.0	-26.8	+36.7
5	$340CDA^{0.716}$	30.2	-25.6	+34.4
10	$439CDA^{0.712}$	31.2	-26.3	+35.6
25	$573CDA^{0.709}$	33.4	-27.7	+38.4



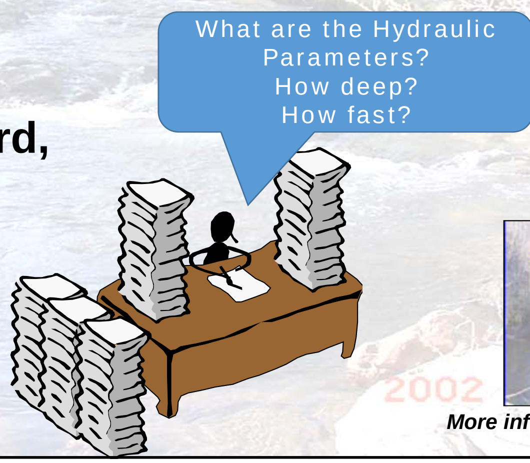


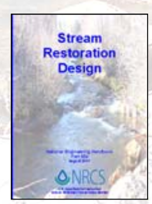
Hydraulics

The branch of physics having to do with the mechanical properties of water and other liquids in motion and the application of these properties in engineering

Sources of Data

- **Direct Measurements: hard, expensive, dangerous**
- **Analytical: predictive**





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More info in NEH 654.6

Manning's Equation

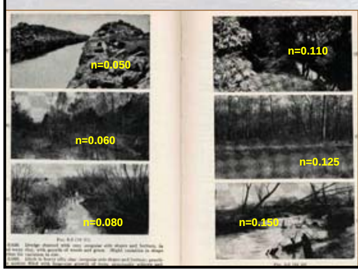
$$Q = \frac{1.49}{n} A S^{1/2} R^{2/3}$$

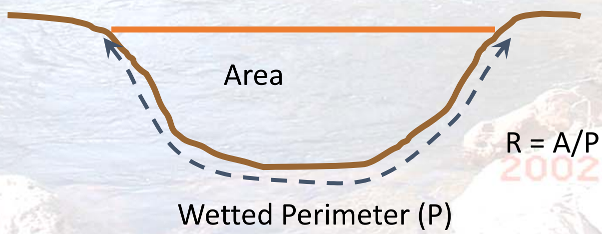
One of the most widely used to account for friction losses

$$Q = flow\,(cfs)$$

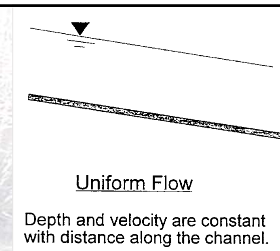
$$n = coeff\ ;\ A = area\ ;\ S = slope\ ;\ P = wetted\quad perimeter$$

$$R = A/P$$





How sensitive is the equation?

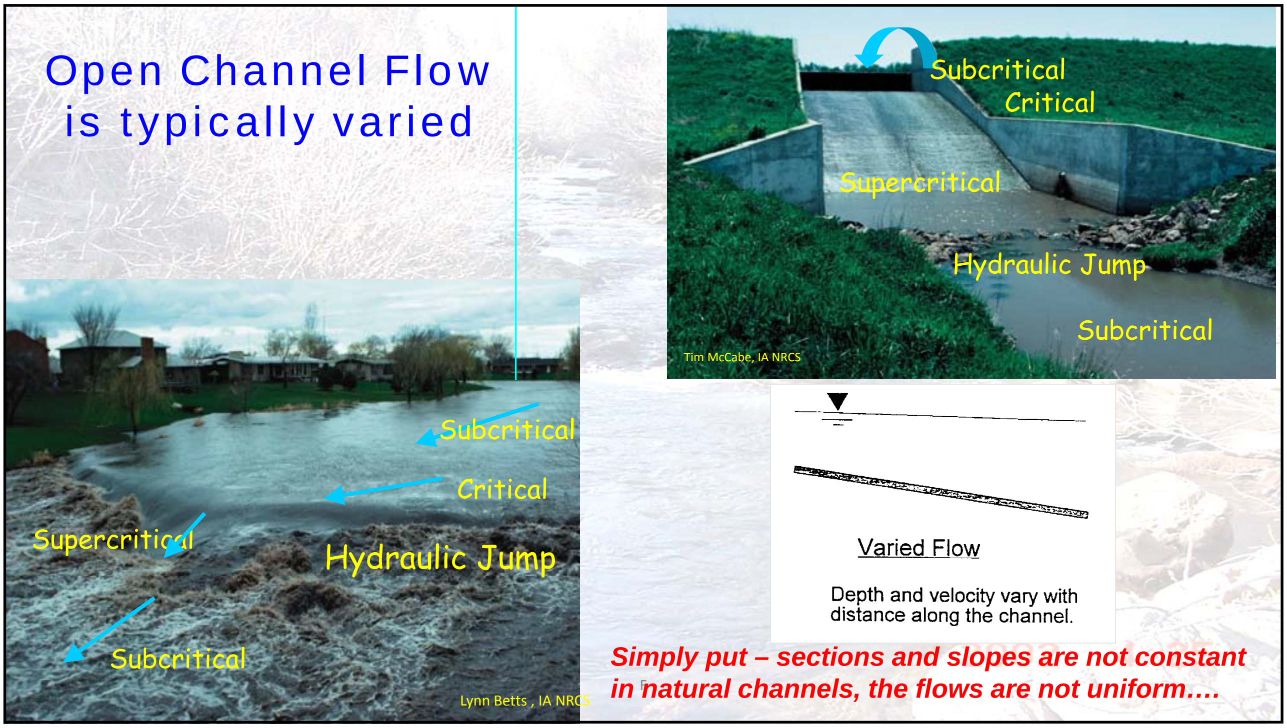


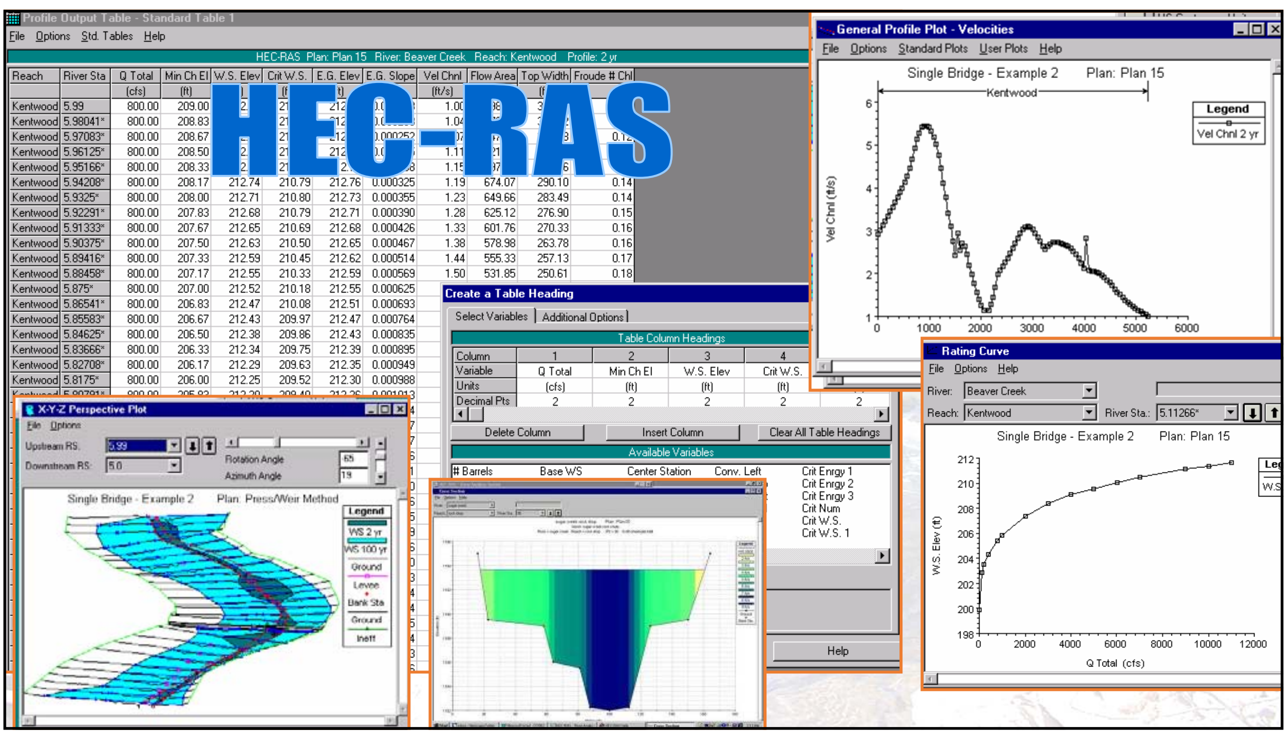
W=100'
d=5'
S=0.004
n=0.035

Q=3700 cfs

n=0.03 to 0.04	**13% to 17%**
d=4.5 to 5.5 ft	**16% to 17%**
w =90 to 110 ft	**11%**
S=0.003 to 0.005	**12% to 13%**
All	**40% to 70%**

It gets worse!


Open Channel Flow
is typically varied
Subcritical
Critical
Supercritical
Hydraulic Jump
Subcritical
Tim McCabe, IA NRCS
Subcritical
Critical
Supercritical
Hydraulic Jump
Subcritical
Lynn Betts , IA NRCS
Varied Flow
Depth and velocity vary with distance along the channel.
Simply put – sections and slopes are not constant in natural channels, the flows are not uniform….


HEC-RAS
Profile Output Table - Standard Table 1
General Profile Plot - Velocities
Single Bridge - Example 2 Plan: Plan 15
Create a Table Heading
X-Y-Z Perspective Plot
Rating Curve

Example Problem

- Given: Q (50 yr) = 10,000 cfs
- Select a stream bank soil bioengineering treatment that that should be able to withstand a 50 year design event

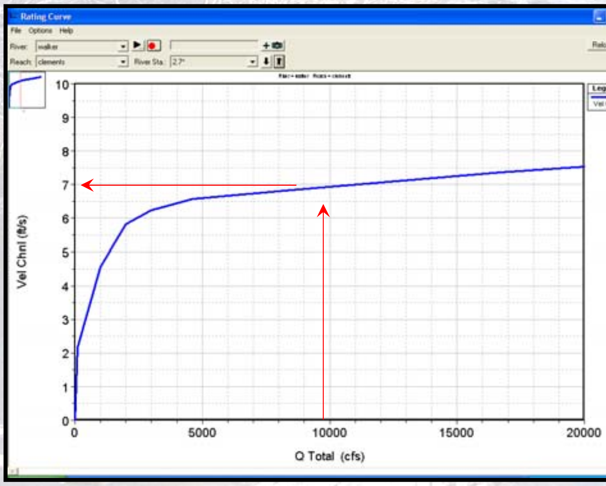
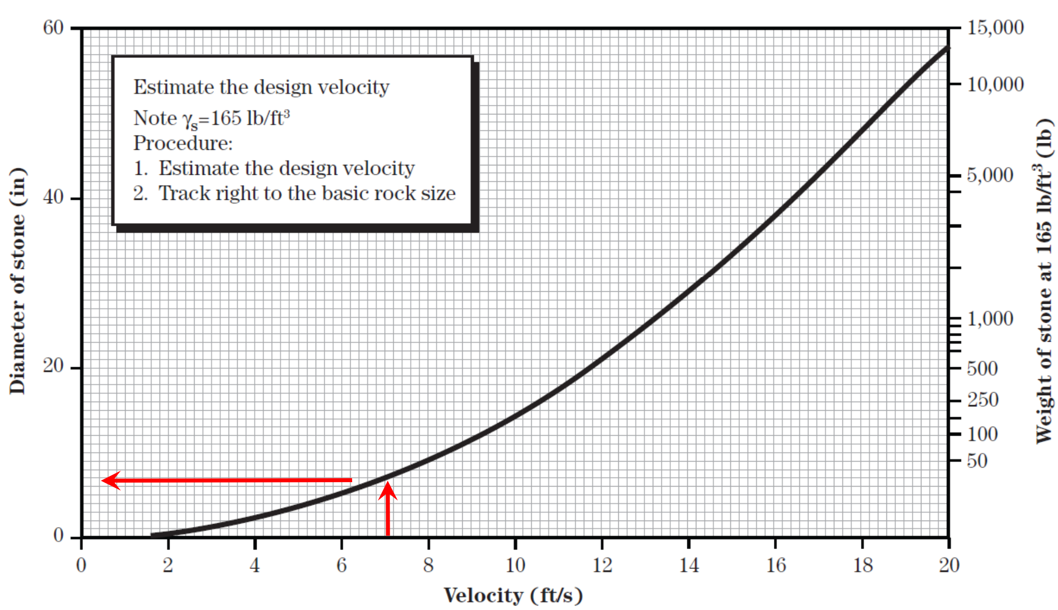


Table TS14I–4 Compiled permissible shear stress levels for streambank soil bioengineering practices

Practice	Permissible shear stress (lb/ft²)*	Permissible velocity (ft/s)*
Live poles (Depends on the length of the poles and nature of the soil)	Initial: 0.5 to 2 Established: 2 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Live poles in woven coir TRM (Depends on installation and anchoring of coir)	Initial: 2 to 2.5 Established: 3 to 5+	Initial: 3 to 5 Established: 3 to 10
Live poles in riprap (joint planting) (Depends on riprap stability)	Initial: 3+ Established: 6 to 8+	Initial: 5 to 10+ Established: 12+
Live brush sills with rock (Depends on riprap stability)	Initial: 3+ Established: 6+	Initial: 5 to 10+ Established: 12+
Brush mattress (Depends on soil conditions and anchoring)	Initial: 0.4 to 4.2 Established: 2.8 to 8+	Initial: 3 to 4 Established: 10+
Live fascine (Very dependent on anchoring)	Initial: 1.2 to 3.1 Established: 1.4 to 3+	Initial: 5 to 8 Established: 8 to 10+
Brush layer/branch packing (Depends on soil conditions)	Initial: 0.2 to 1 Established: 2.9 to 6+	Initial: 2 to 4 Established: 10+
Live cribwall (Depends on nature of the fill (rock or earth), compaction and anchoring)	Initial: 2 to 4+ Established: 5 to 6+	Initial: 3 to 6 Established: 10 to 12
Vegetated reinforced soil slopes (VRSS) (Depends on soil conditions and anchoring)	Initial: 3 to 5 Established: 7+	Initial: 4 to 9 Established: 10+
Grass turf—bermudagrass, excellent stand (Depends on vegetation type and condition)	Established: 3.2	Established: 3 to 8
Live brush wattle fence (Depends on soil conditions and depth of stakes)	Initial: 0.2 to 2 Established: 1.0 to 5+	Initial: 1 to 2.5 Established: 3 to 10
Vertical bundles (Depends on bank conditions, anchoring, and vegetation)	Initial: 1.2 to 3 Established: 1.4 to 2+	Initial: 5 to 8 Established: 6 to 10+

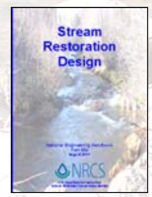
Figure TS14C–5 Rock size based on Isbash curve



Design

What implementations are going to be used to repair the site?

…assuming that a something has to be done…



More info in NEH 654.14

RipRap

- **–Appropriately sized rock used to strengthen streambanks**
- **–Stops stream bank erosion**
- **–High stress areas**
- **–Easy to construct with standard machinery**
- **–Low chance of failure if designed correctly**
- **–Good for emergency situations**
- **–Good for high risk sites**
- **–High level of confidence**
- **–Flexible**
- **–Familiar**

See NEH 654 TS 14C and 14K for more information

Photos from Don Shanklin

What do we need to know?

How Big?
What Gradation?
What Shape?
What Density?
What Quality?

If we are going to use rock – we need to do it right

Stone Sizing

Table TS14C–3 Summary of techniques

Technique	High or low energy	Slopes	Typical application(s)
Isbash	Both	Not specified	Rock revetment, stilling basins, river closures
108 Report	Both	<10%	Quick assessments for stable stone requirements
Maynord	Low	<2%	Rock revetment, bank protection, stone toe
Abt and Johnson	High	2% to 20%	Overtopping, grade protection
ARS – rock chute	High	2% to 40%	Overtopping, rock chutes, grade protection
USBR	High	Not specified	Riprap below a stilling basin
USGS Blodgett	Both	Not specified	Riprap stability
USACE Steep Slope Riprap	High	2% to 20%	Rock chutes, grade protection
USACE Habitat Boulder	High	Not specified	Instream boulders for habitat enhancement
CALTRANS RSP	Low	<2%	Rock revetment, bank protection, stone toe
Lane's (FWS)	Low	<2%	Stone bank protection, stream barbs with adjustments

See NEH 654 TS 14C

Bottom Line: ***Match the rock sizing method with the intended use.***

LANE'S Far West States Method

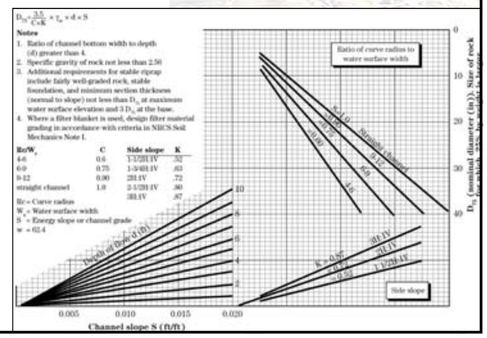
Far West states (FWS)—Lane's Method

Vito A. Vanoni worked with the Northwest E&WP Unit to develop the procedure from the ASCE paper entitled "Design of Stable Alluvial Channels" (Lane 1955a). The equation is:

$$D_{75} = \frac{3.5}{C \times K} \times \gamma_w \times D \times S_f \qquad \text{(eq. TS14C–19)}$$

where:

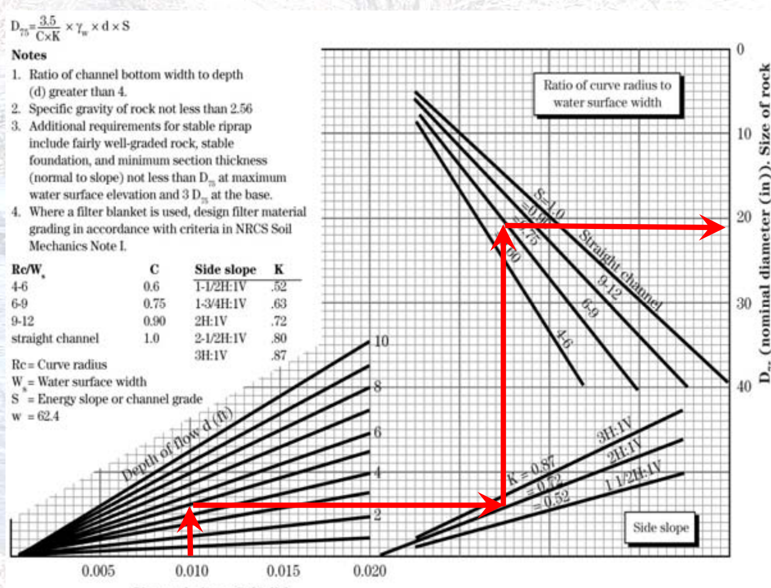
D_{75} = stone size, (in)
C = correction for channel curvature
K = correction for side slope
S_f = channel friction slope (ft/ft)
d = depth of flow (ft)
γ_w = density of water



Example Problem

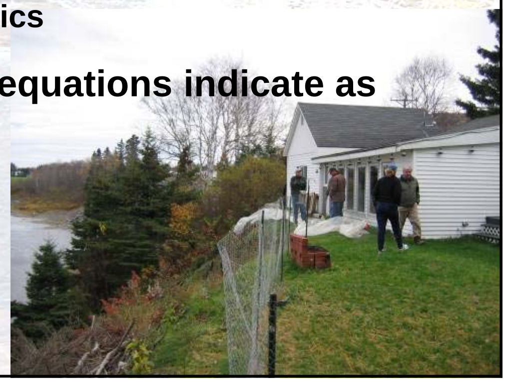
Given:
G_S = 2.6
Bend Radius = 350 ft
Channel width = 50 ft
Side slope = 2:1
Slope = 0.01 ft/ft
Depth = 5 ft

Find:
Appropriate rock size using Lane's FWS technique



Stone Sizing – Final Thoughts

- Use a rock sizing method appropriate for your application
- Use several methods and look for convergence
  - But do not expect exact convergence
- Use a factor of safety appropriate for your situation
  - Assess significant threats to life and property
  - Your uncertainty in hydrology and hydraulics
- Size may need to be larger than what the equations indicate as sufficient to resist flows
  - To resist ice and debris
  - For habitat enhancement
  - For aesthetic purposes
  - To reduce vandalism and theft
  - To account for uncertainty

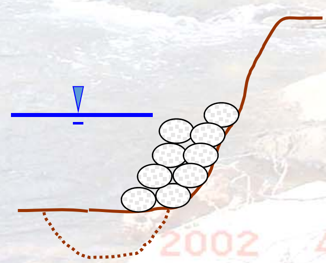


Scour – *Why Worry?*

See NEH 654 TS 14B

Answer: No matter what is designed for the bank, if the toe is undermined, it will not work well.

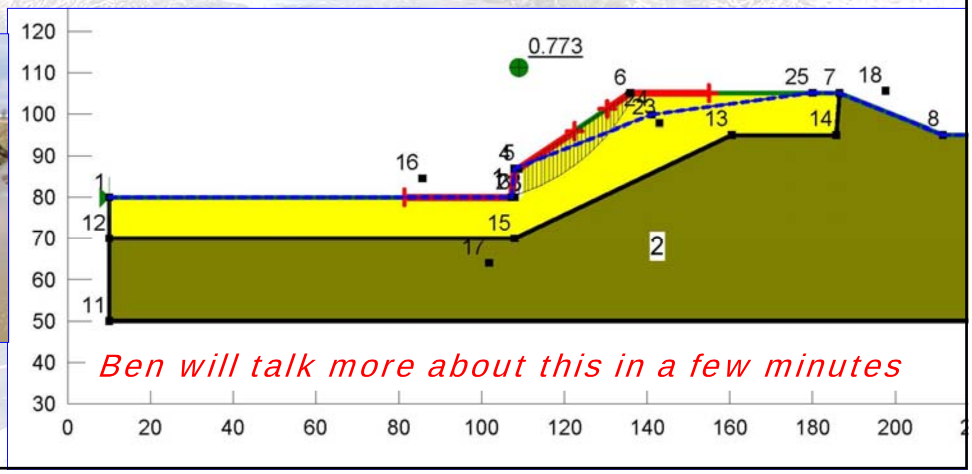
Photograph from Stephen T. Maynord



Example of local failure of riprap at toe of slope

Scour – *Why Worry?*

Answer: Scour along the toe can result in geotechnical instability on the bank.



How do you estimate total scour?

Analytical techniques vs. "Rules of thumb" for scour assessments

Bend Scour

Many formulas are available

$$z_b = y\left(\frac{y_{max}}{y} - 1\right) \qquad \text{(eq. TS14B–33)}$$

where:

y = average flow depth in the bend, ft (m)

y_{max} = maximum flow depth in the bend, ft (m)

$$\frac{y_{max}}{y} = 1.5 + 4.5\left(\frac{W_i}{Rc}\right) \qquad \text{(eq. TS14B–34)}$$

where:

W_i = channel width at bend inflection point, ft (m)

Rc = bend radius of curvature, ft (m)

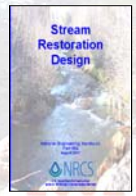
$$\frac{y_{max}}{y_c} = FS\left[1.8 - 0.051\left(\frac{Rc}{W_i}\right) + 0.0084\left(\frac{W_i}{y_c}\right)\right] \qquad \text{(eq. TS14B–36)}$$

where:

y_{max} = maximum water depth in the bend, ft (m)

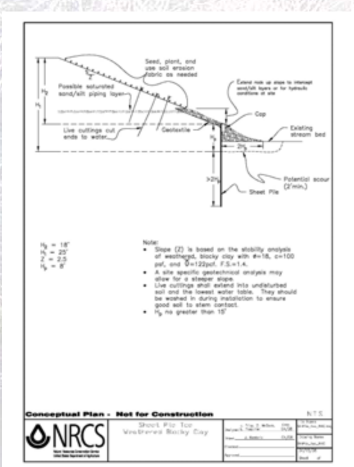
y_c = mean water depth in the crossing upstream from the bend, ft (m)

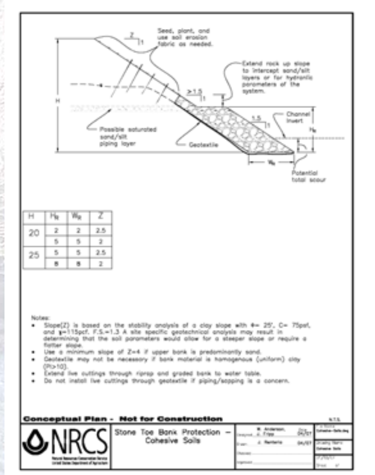
FS = a factor of safety defined below

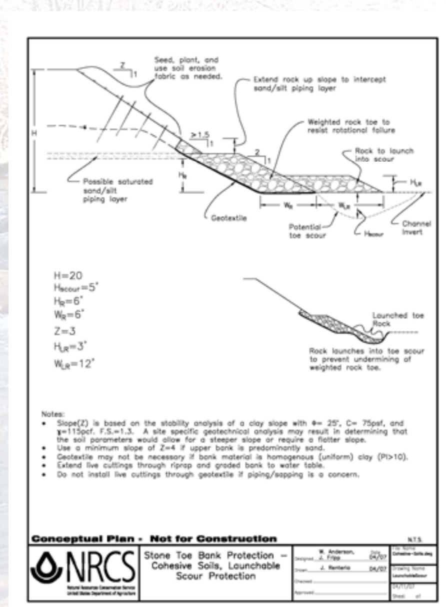


See NEH 654 TS 14B for more information

Approaches to Prevent Undermining of the Toe

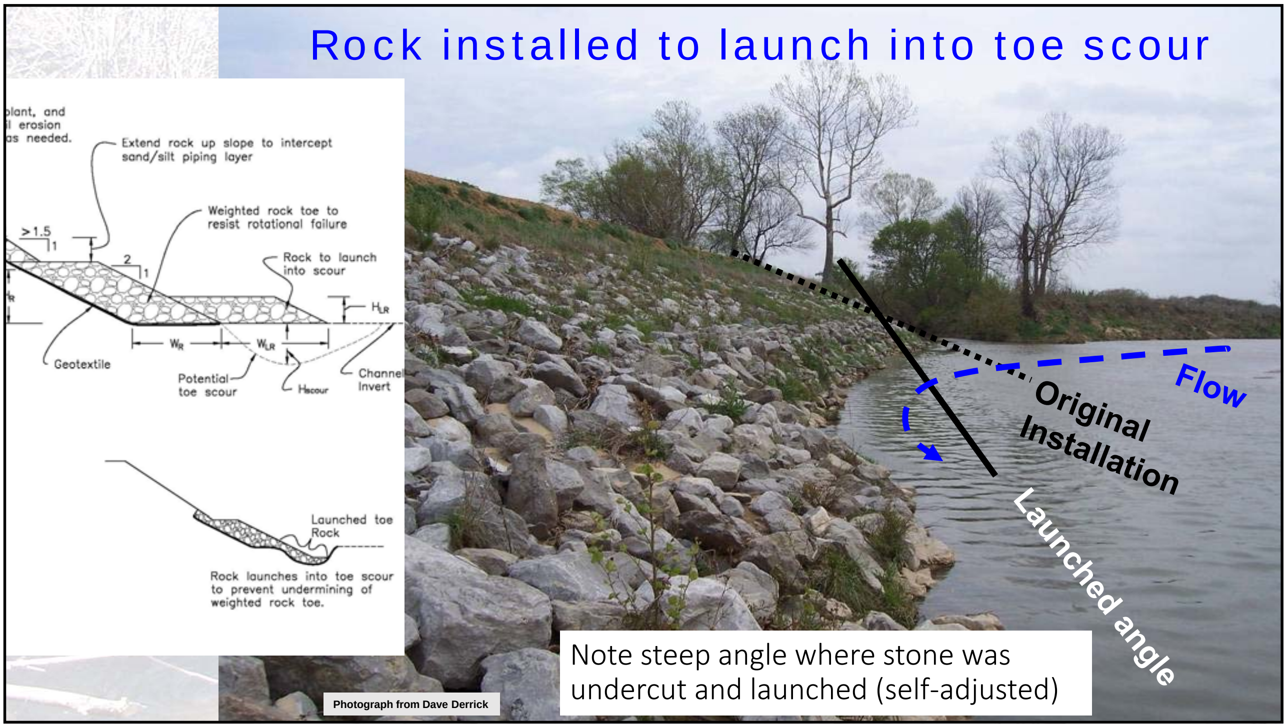






Example Options:

1. **Provide a launchable rock toe**
2. **Use sheet pile to secure toe**
3. **Excavate below anticipated scour depth and secure toe**
4. **Reduce stress**
5. **Pave stream bed**


Rock installed to launch into toe scour
Extend rock up slope to intercept sand/silt piping layer
Weighted rock toe to resist rotational failure
Rock to launch into scour
Geotextile
Potential toe scour
Channel Invert
Launched toe Rock
Rock launches into toe scour to prevent undermining of weighted rock toe.
Flow
Original Installation
Launched angle
Note steep angle where stone was undercut and launched (self-adjusted)
Photograph from Dave Derrick


Geotechnical Considerations
2002 4 25

Don't just do something...

~~•Ready~~
~~•Fire~~
~~•Aim!~~

Stand there!

….and think about it

Geomorphology
Fluvial Forces
Geotechnical
etc.

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Geotechnical Considerations for EWP

Initial Assessment

- **What is happening? Is it:**
  - **Hydraulic failure?**
  - **Geotechnical failure?**
  - **Or both?**

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Geotechnical Considerations for EWP

Initial Assessment

- What is happening? Is it:
  - Hydraulic failure?
  - Geotechnical failure?
  - Or both?
- **What is the operative failure mode?**

Geotechnical Considerations for EWP

Initial Assessment

- What is happening? Is it:
  - Hydraulic failure?
  - Geotechnical failure?
  - Or both?
- What is the operative failure mode?
- **What is the problem? → How to "fix" the problem?**

Geotechnical Considerations for EWP

Initial Assessment

- What is happening? Is it:
  - Hydraulic failure?
  - Geotechnical failure?
  - Or both?
- What is the operative failure mode?
- What is the problem? → How to "fix" the problem?
- **Is it possible/feasible to fix the problem?**

Geotechnical Considerations for EWP

Initial Assessment

- What is happening? Is it:
  - Hydraulic failure?
  - Geotechnical failure?
  - Or both?
- What is the operative failure mode?
- What is the problem? → How to "fix" the problem?
- Is it possible/feasible to fix the problem?
- **Geotechnical – high $$$**

Geotechnical Considerations for EWP

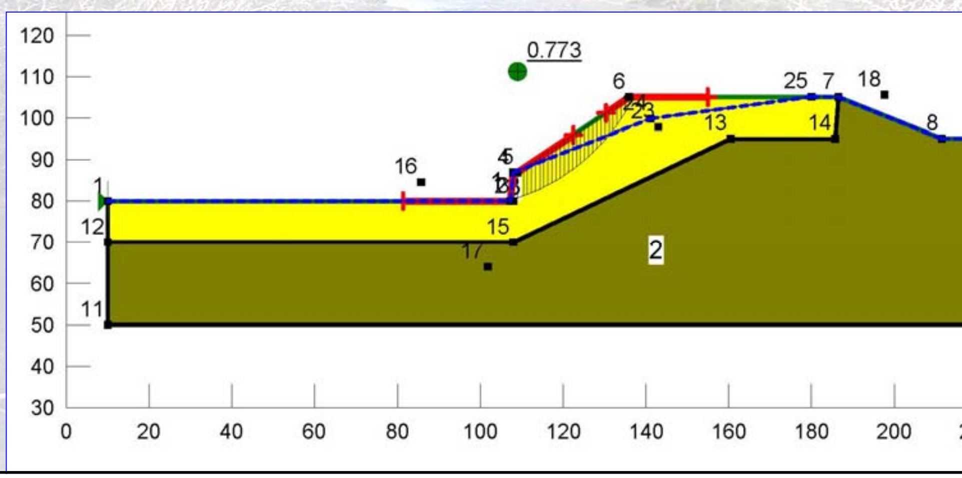
Causes of Slope Failure

- Hydraulic attack
  - Toe erosion
  - Scour
  - Head cut

Geotechnical Considerations for EWP

Causes of Slope Failure

- Toe erosion



Geotechnical Considerations for EWP

- Toe erosion

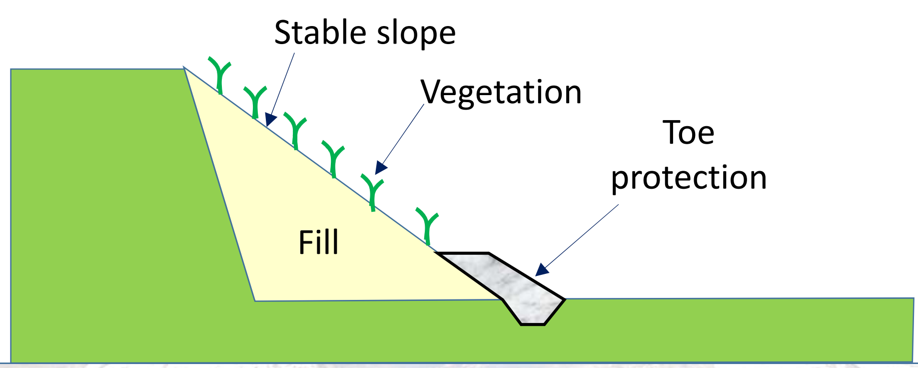
Geotechnical Considerations for EWP

- Toe erosion

Geotechnical Considerations for EWP

- Toe erosion

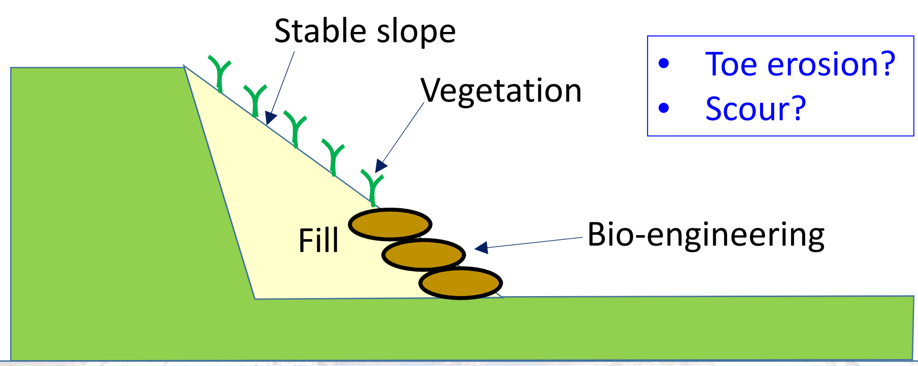
"Hard" Solution



Geotechnical Considerations for EWP

- Toe erosion

"Soft" Solution



Geotechnical Considerations for EWP

Other Hydraulic Failure Modes

- Scour
  - Key in armoring, below scour depth
  - Launching toe
- Head cut
  - Sheetpile along bank
  - Drop structure in channel

Geotechnical Considerations for EWP

Causes of Slope Failure

- Hydraulic attack
  - Toe erosion
  - Scour
  - Head cut
- Geotechnical slope failure
  - Saturation
  - Rapid drawdown
  - Groundwater seepage

Geotechnical Considerations for EWP

Causes of Slope Failure

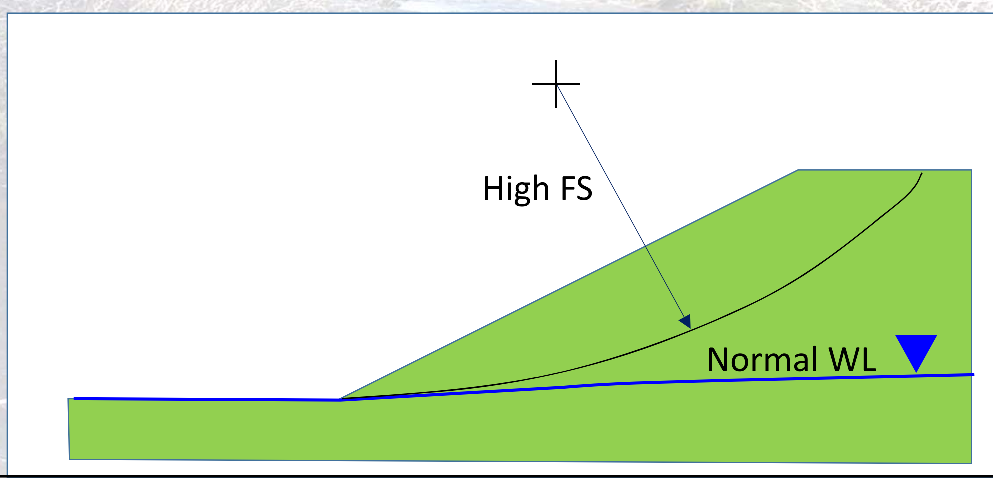
- Hydraulic attack
  - Toe erosion
  - Scour
  - Head cut
- **Geotechnical slope failure**
  - **Saturation**
  - **Rapid drawdown**
  - **Groundwater seepage**

Water reduces shear strength, stability

Geotechnical Considerations for EWP

Causes of Slope Failure

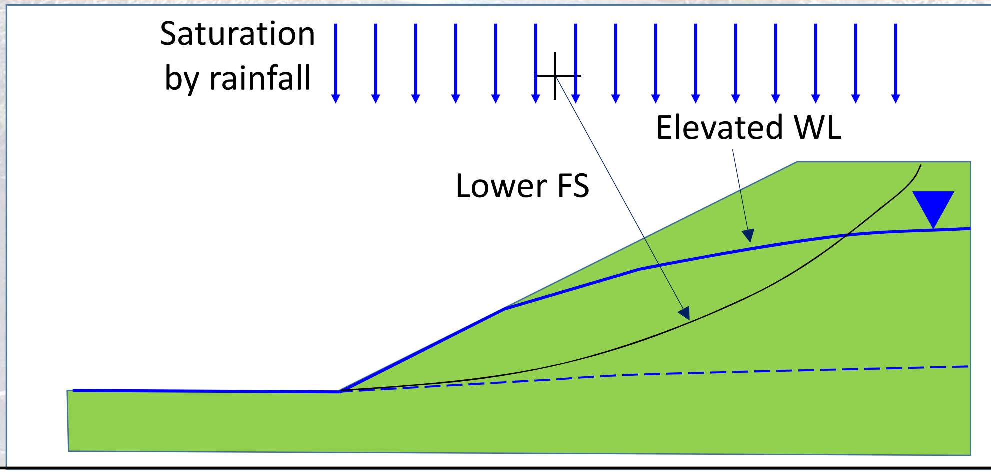
- **Saturation**



Geotechnical Considerations for EWP

Causes of Slope Failure

- Saturation



Geotechnical Considerations for EWP

Causes of Slope Failure

- Saturation

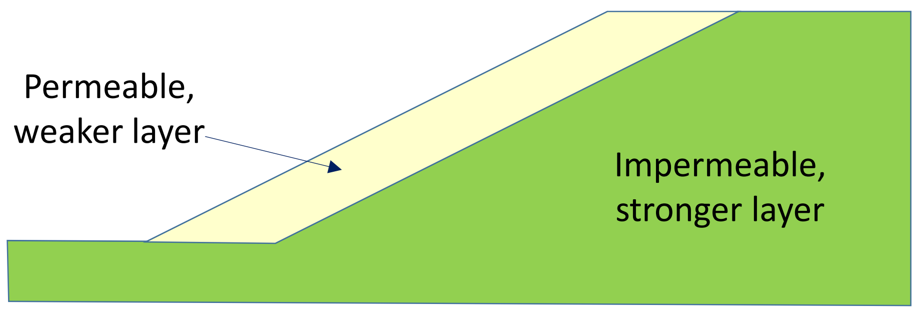
Shallow slide

- Rain on snow

Geotechnical Considerations for EWP

Causes of Slope Failure

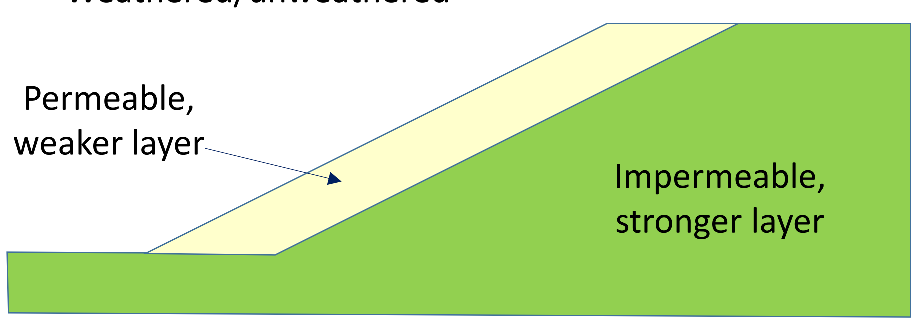
- **Saturation**



Geotechnical Considerations for EWP

Causes of Slope Failure

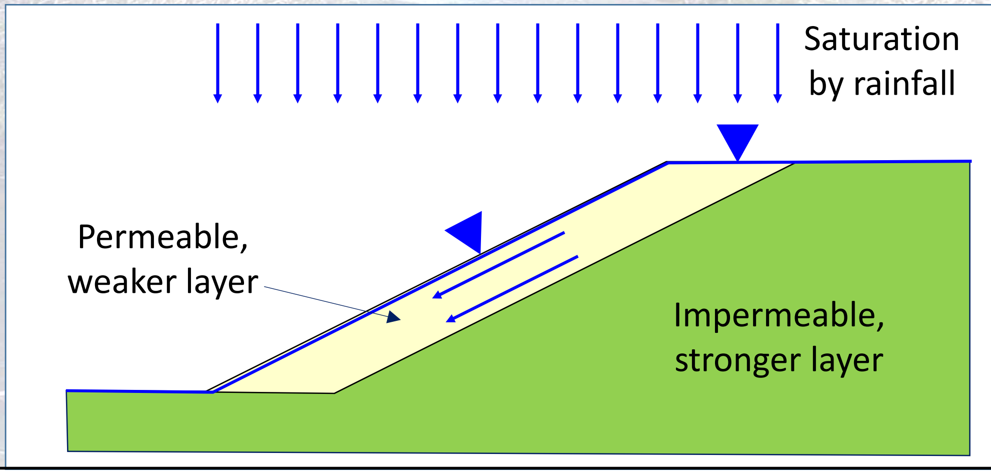
- **Saturation**
  - Sand/clay
  - Soil/rock
  - Weathered/unweathered



Geotechnical Considerations for EWP

Causes of Slope Failure

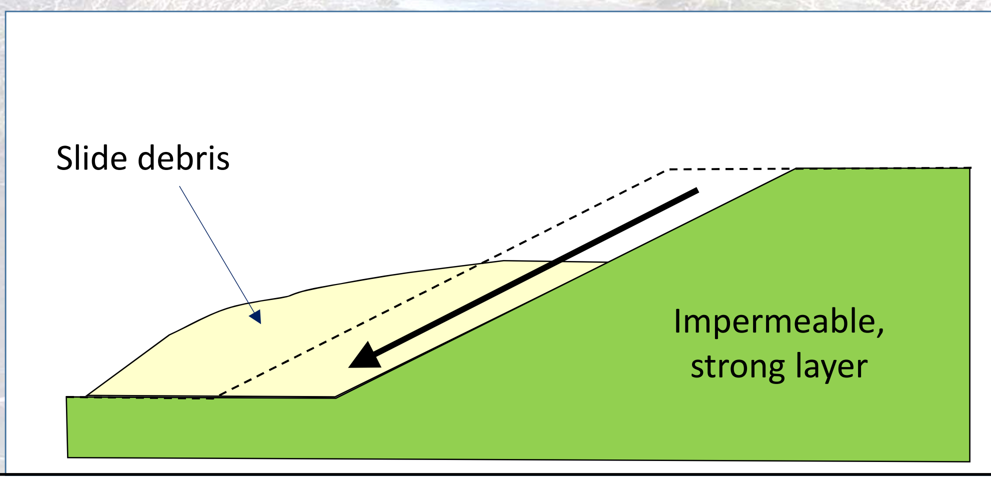
- **Saturation**



Geotechnical Considerations for EWP

Causes of Slope Failure

- **Saturation**



Geotechnical Considerations for EWP

- **Saturation**

Block slide

- **Soil over bedrock**

Geotechnical Considerations for EWP

- **Saturation**

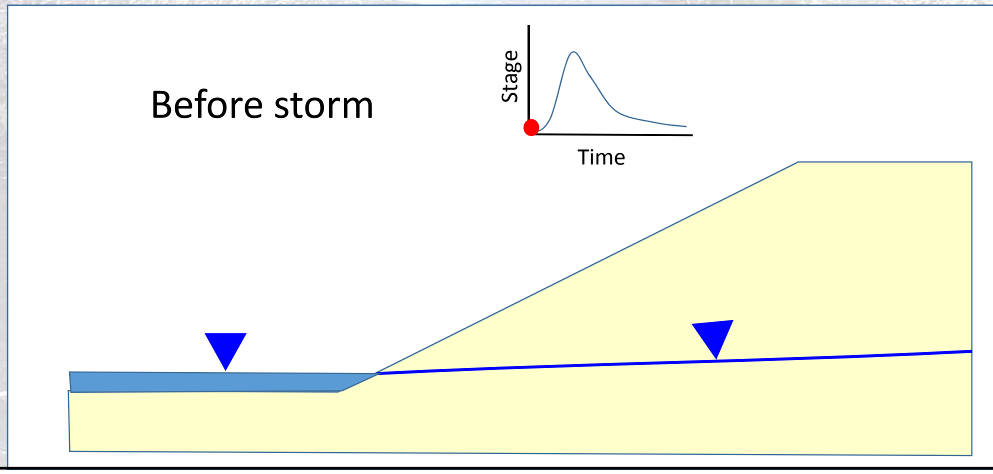
Shallow slide

- **Shrink/swell weathering**

Geotechnical Considerations for EWP

Causes of Slope Failure

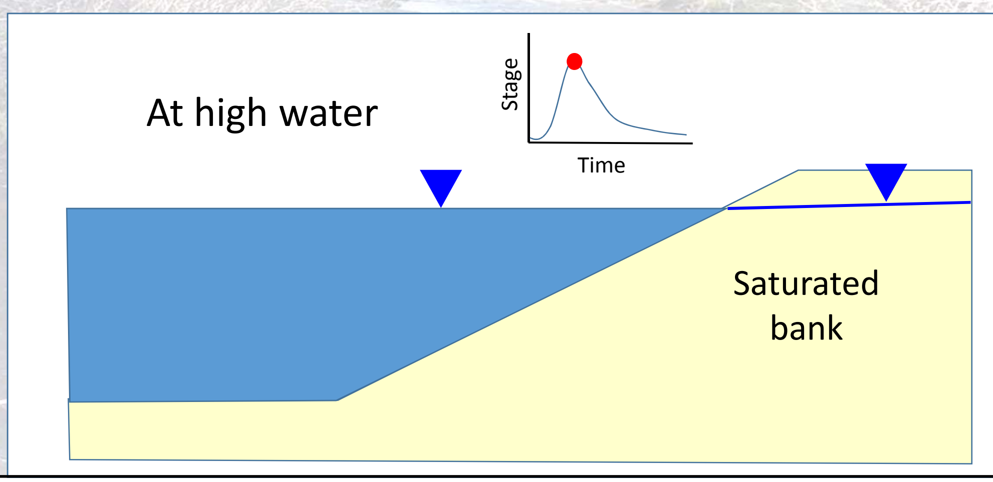
- **Rapid drawdown**



Geotechnical Considerations for EWP

Causes of Slope Failure

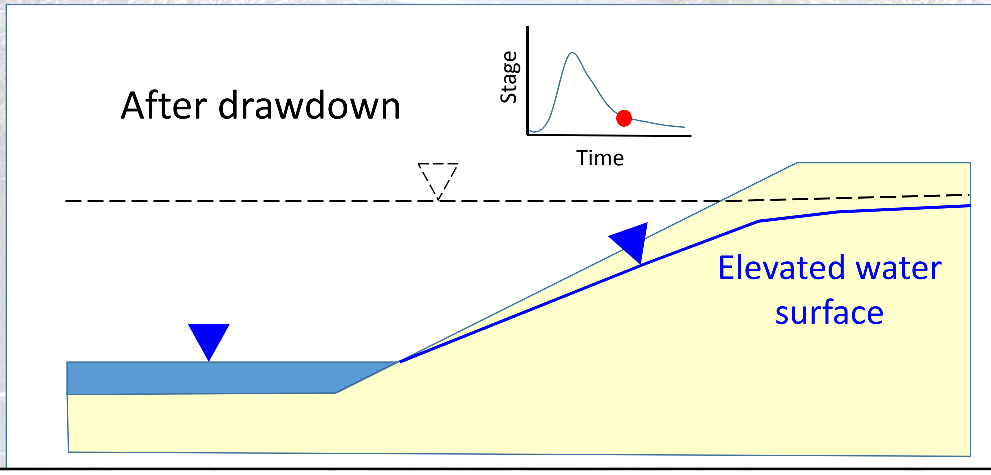
- **Rapid drawdown**



Geotechnical Considerations for EWP

Causes of Slope Failure

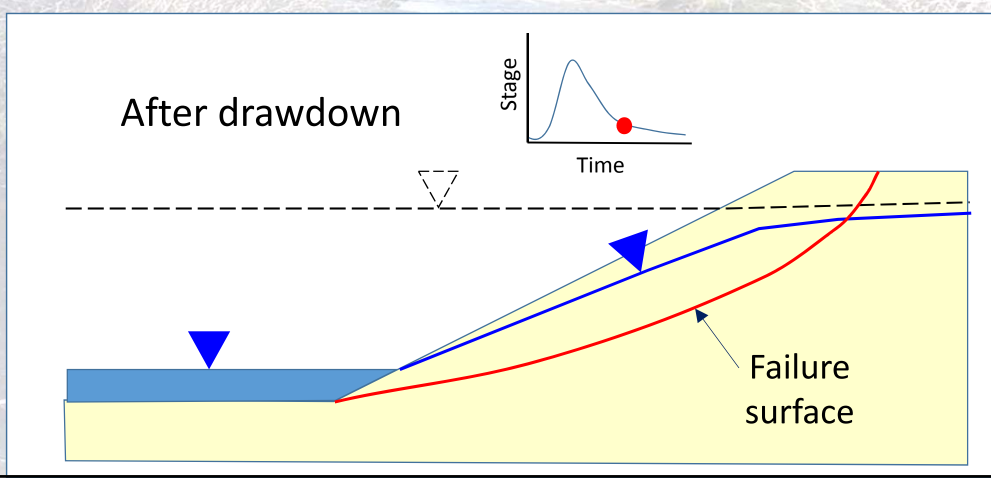
- **Rapid drawdown**



Geotechnical Considerations for EWP

Causes of Slope Failure

- **Rapid drawdown**



Geotechnical Considerations for EWP

Causes of Slope Failure

- Rapid drawdown

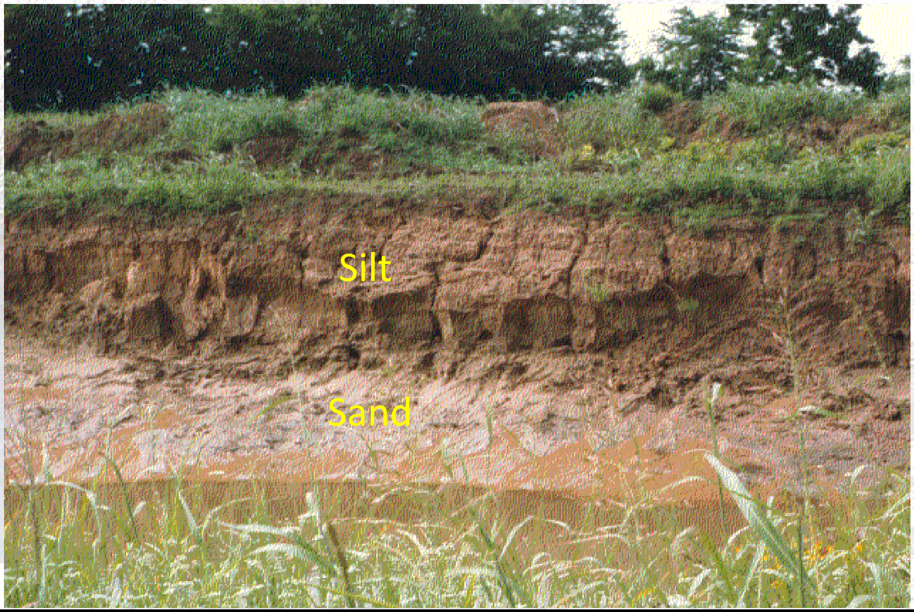
Geotechnical Considerations for EWP

Repair Approaches

- Stabilize failed slope
  - Remove slide debris
  - Flatten slope
  - Provide drainage
  - Buttress toe
  - Reinforce soil
- $$$

Geotechnical Considerations for EWP

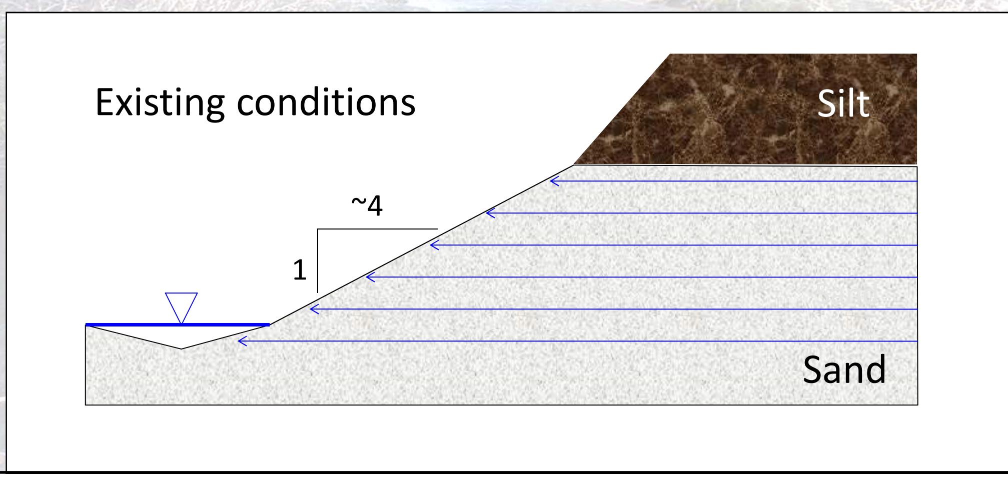
Groundwater Seepage



Geotechnical Considerations for EWP

Causes of Slope Failure

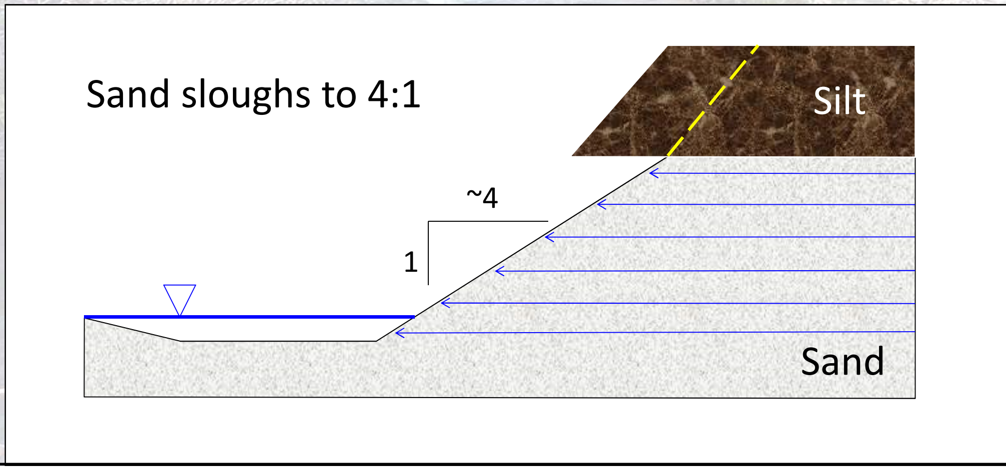
- **Groundwater seepage**



Geotechnical Considerations for EWP

Causes of Slope Failure

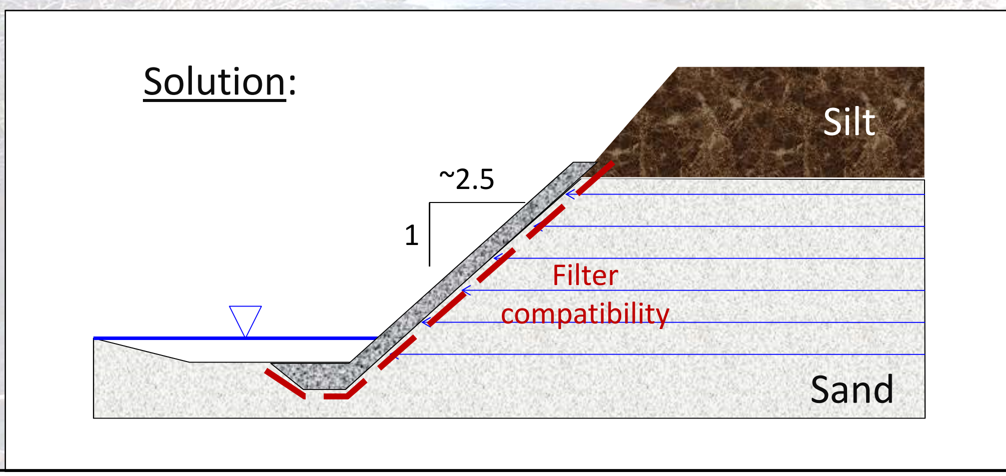
- **Groundwater seepage**



Geotechnical Considerations for EWP

Causes of Slope Failure

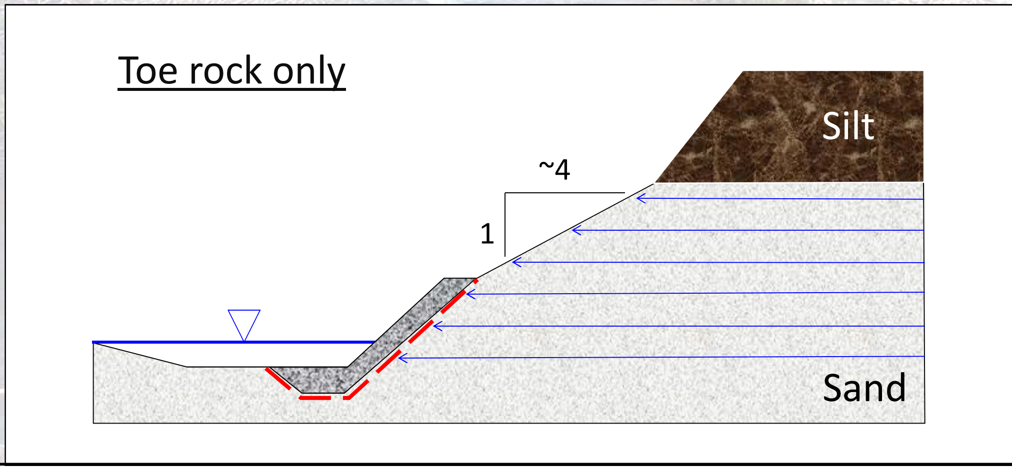
- **Groundwater seepage**



Geotechnical Considerations for EWP

Causes of Slope Failure

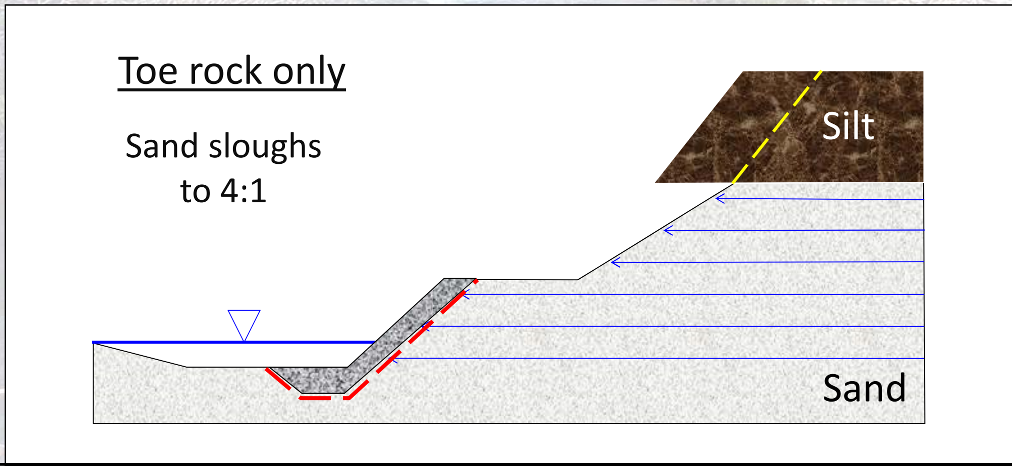
- **Groundwater seepage**



Geotechnical Considerations for EWP

Causes of Slope Failure

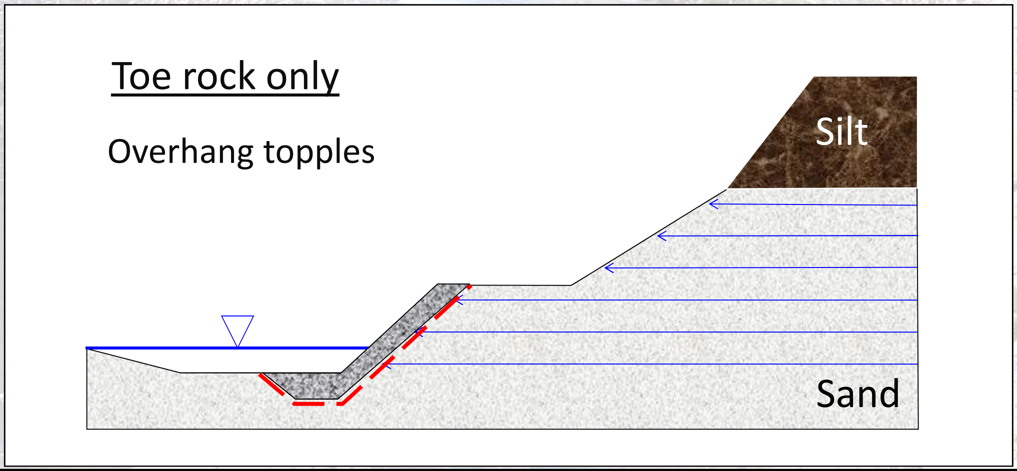
- **Groundwater seepage**



Geotechnical Considerations for EWP

Causes of Slope Failure

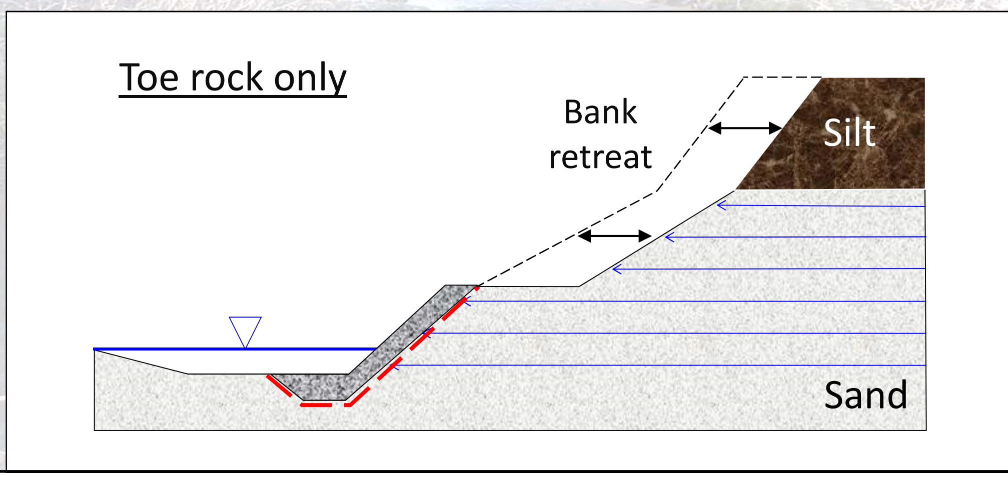
- **Groundwater seepage**



Geotechnical Considerations for EWP

Causes of Slope Failure

- **Groundwater seepage**



Geotechnical Considerations for EWP

Other Considerations

- **Sloping back is not feasible.**
  - **Steepen slope**
  - **Support structure**
- **Construction considerations.**
  - **Top-down excavation**
  - **Key trench construction**

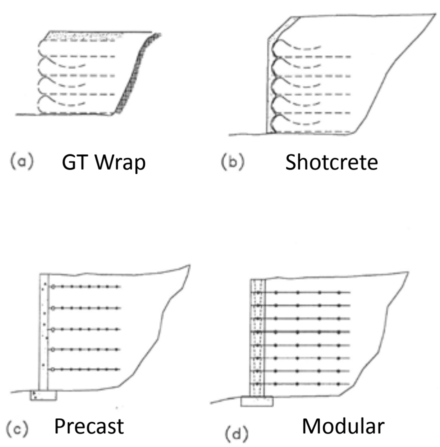
Geotechnical Considerations for EWP

Sloping back is not feasible.

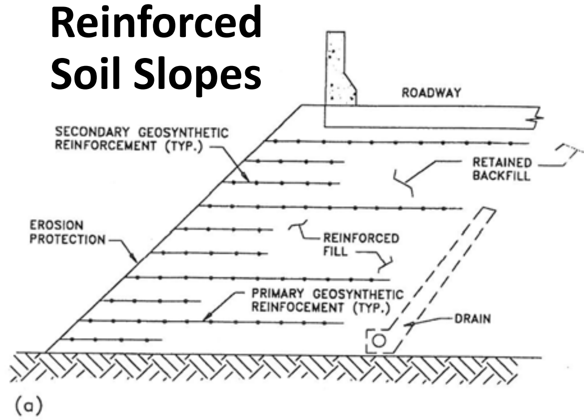
Geotechnical Considerations for EWP

<u>Sloping back is not feasible</u> – steepen slope.

MSE Walls



Reinforced Soil Slopes



Geotechnical Considerations for EWP

<u>Sloping back is not feasible</u> – steepen slope.

- **MSE walls**
  - **GG-reinforced**
  - **Rebar facing**

Geotechnical Considerations for EWP

Sloping back is not feasible.

- **MSE walls**
  - **GG-reinforced**
  - **Precast block facing**

Geotechnical Considerations for EWP

Sloping back is not feasible.

- **MSE Walls**
  - **Stacked rock wall**

Geotechnical Considerations for EWP

<u>Sloping back is not feasible</u>.

- Reinforced slope
  - First lift

Geotechnical Considerations for EWP

<u>Sloping back is not feasible</u>.

- Reinforced slope
  - Coir/GG-reinf.
  - Willows

Geotechnical Considerations for EWP

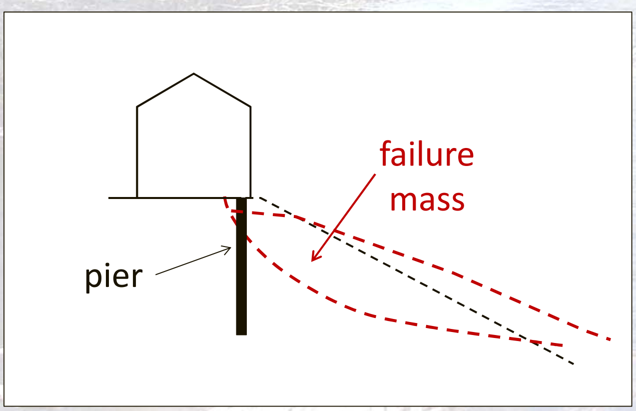
Sloping back is not feasible.

- **Reinforced slope**
  - **Finished project**

Geotechnical Considerations for EWP

Sloping back is not feasible – support structure.

- **Piers**



Geotechnical Considerations for EWP

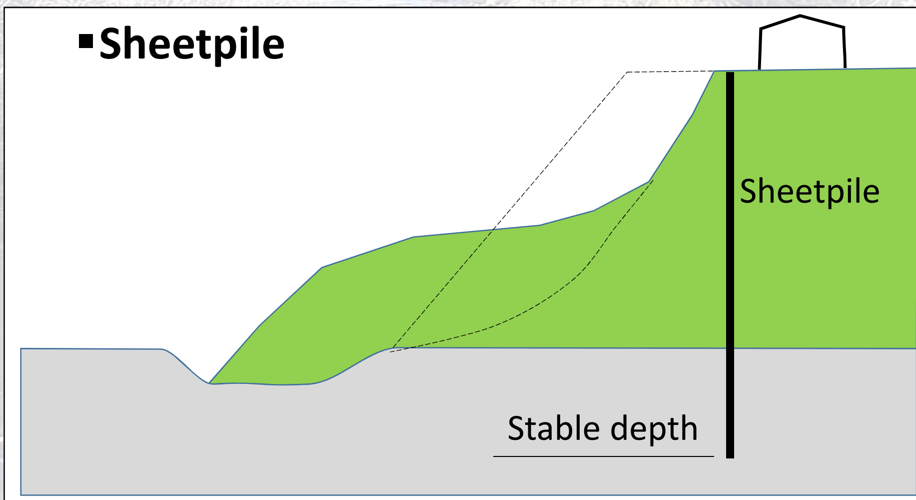
<u>Sloping back is not feasible</u> – support structure.

- **Piers**

Geotechnical Considerations for EWP

<u>Sloping back is not feasible</u>.

- **Sheetpile**



Geotechnical Considerations for EWP

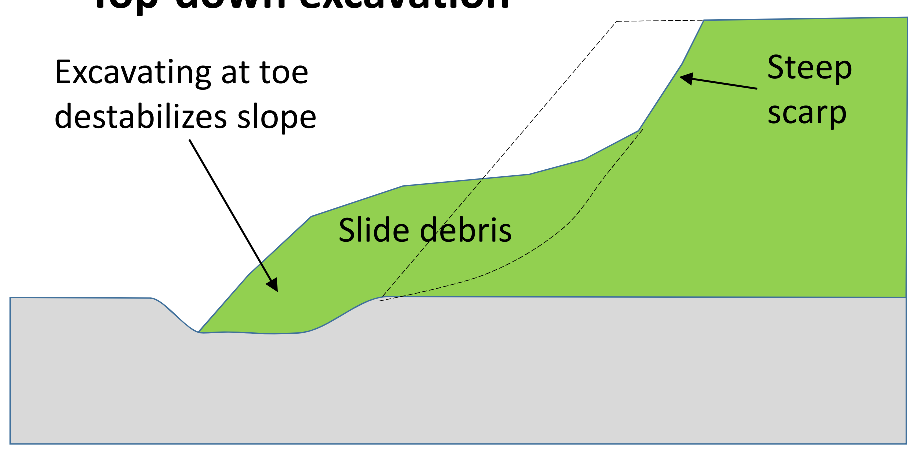
Sloping back is not feasible.

- **Sheetpile**

Geotechnical Considerations for EWP

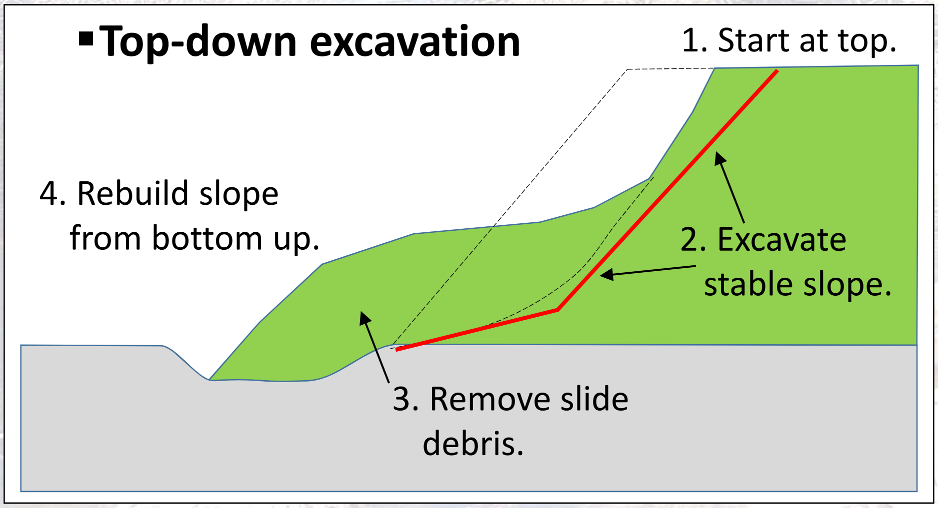
- **Construction considerations.**

  - **Top-down excavation**



Geotechnical Considerations for EWP

- **Construction considerations.**



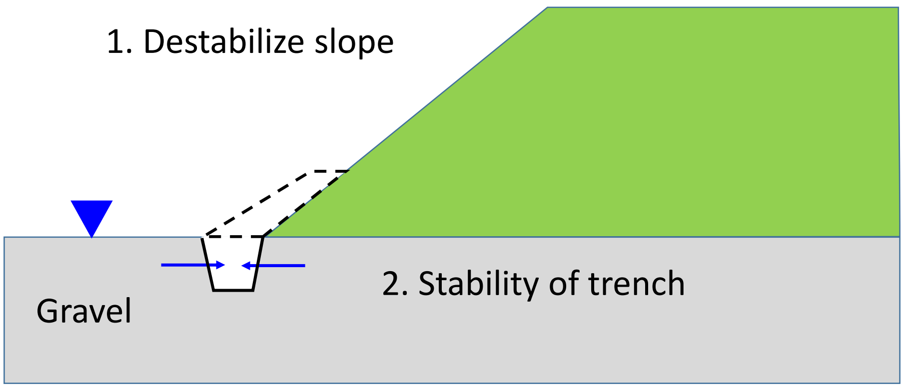
Geotechnical Considerations for EWP

- **Construction considerations.**
  - **Top-down excavation**

Geotechnical Considerations for EWP

- **Construction considerations.**

▪Key trench construction



Don't just do something…

Stand there!

….and think about it

- **Geomorphology**
- **Fluvial Forces**
- **Geotechnical**
- **etc.**

Stream Channel Repair and Restoration Following Extreme Flooding Damage

~

How-To Stuff

~

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