

# Development of the Bank-Stability and Toe-Erosion Model (BSTEM Version 5.4)

Andrew Simon, Robert Thomas, Andrea  
Curini and Natasha Bankhead

USDA-ARS National Sedimentation Laboratory,  
Oxford, MS

[andrew.simon@ars.usda.gov](mailto:andrew.simon@ars.usda.gov)



National Sedimentation Laboratory

# Bank Stability/Instability

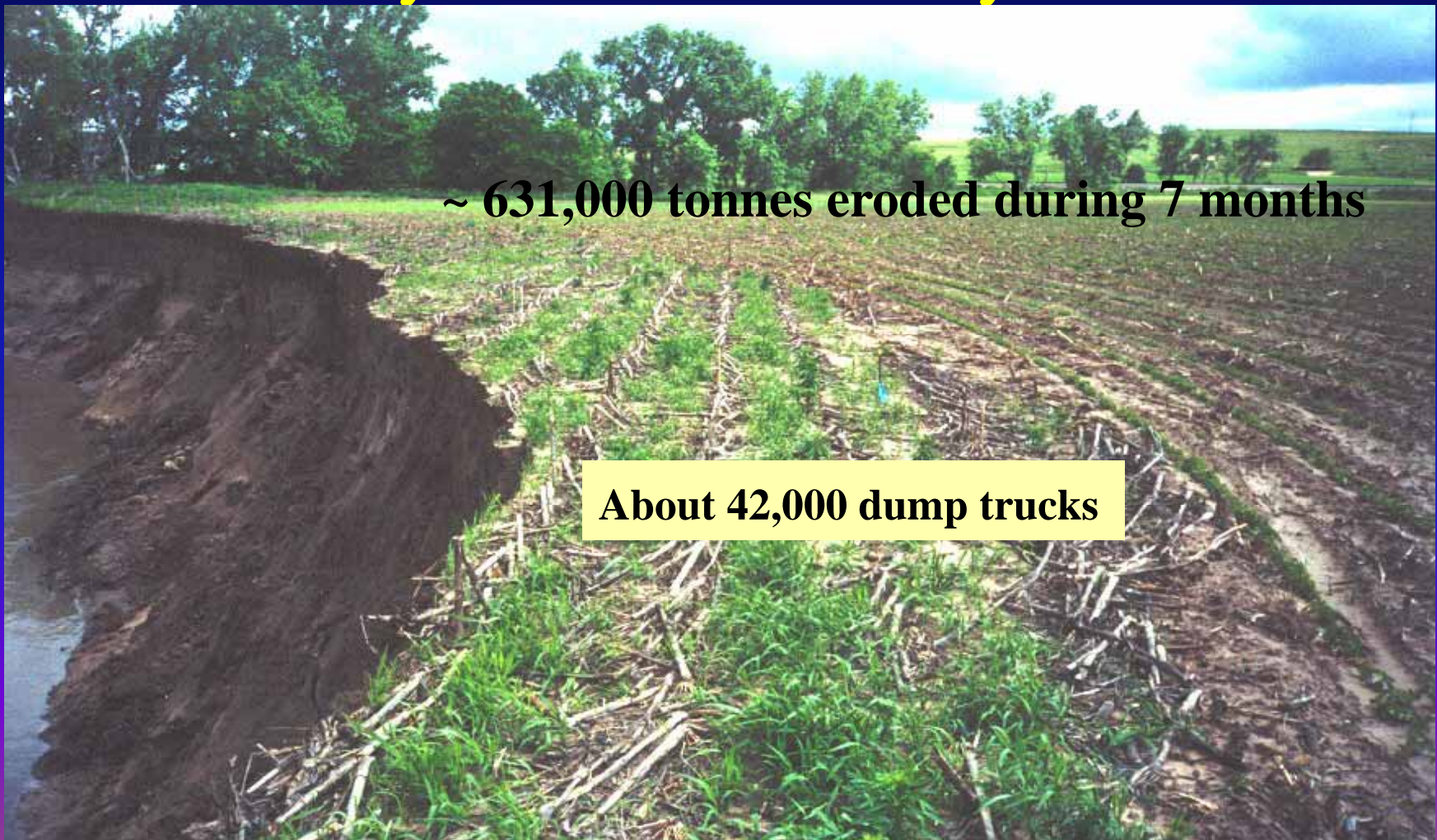
- Bank instability is a form of channel adjustment
- Bank instability is a combination of hydraulic and geotechnical processes.

# Erosion of Streambanks

- Electro-chemical bonding makes prediction of entrainment difficult
- Bank failures occur by gravity, requiring evaluation of geotechnical variables
- **70-90% of sediment comes from banks**
- Problems of bridge failure and loss of agricultural land
- Downstream problems from sedimentation, flooding and habitat loss
- TMDL Issues: Sediment and temperature



There is a growing body of evidence that channel systems, particularly streambanks, are now the dominant source of sediment in many/most disturbed systems



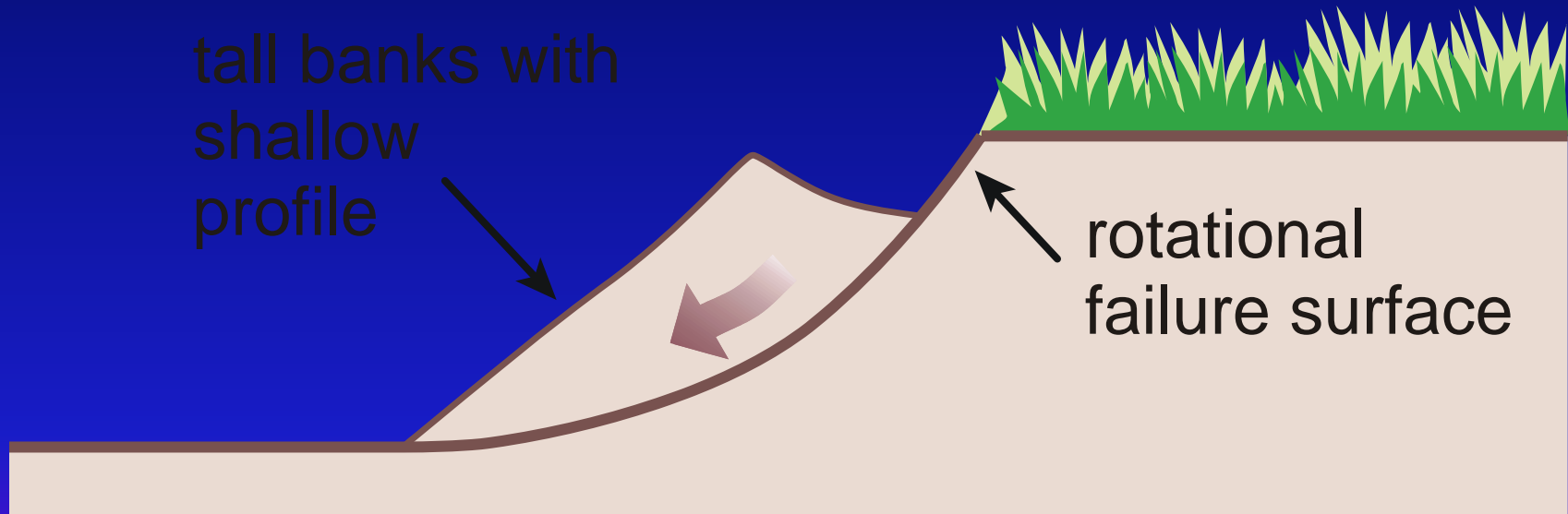
**~ 631,000 tonnes eroded during 7 months**

**About 42,000 dump trucks**

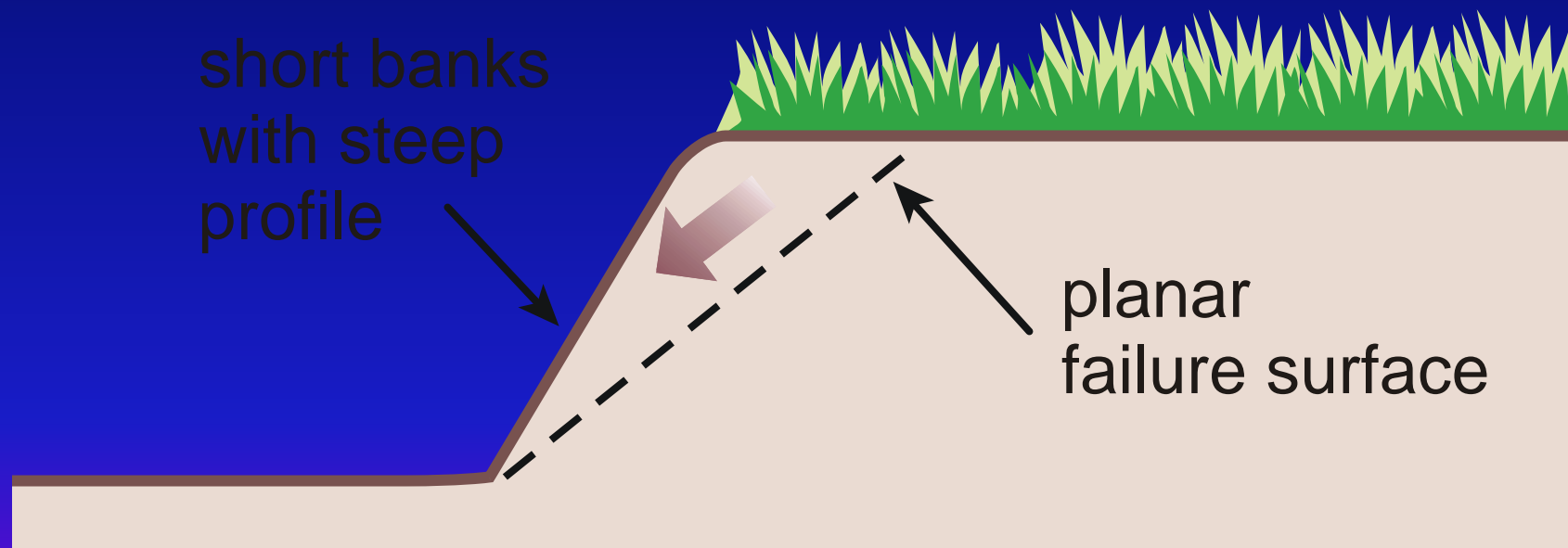
# How Do Banks Become Unstable ?



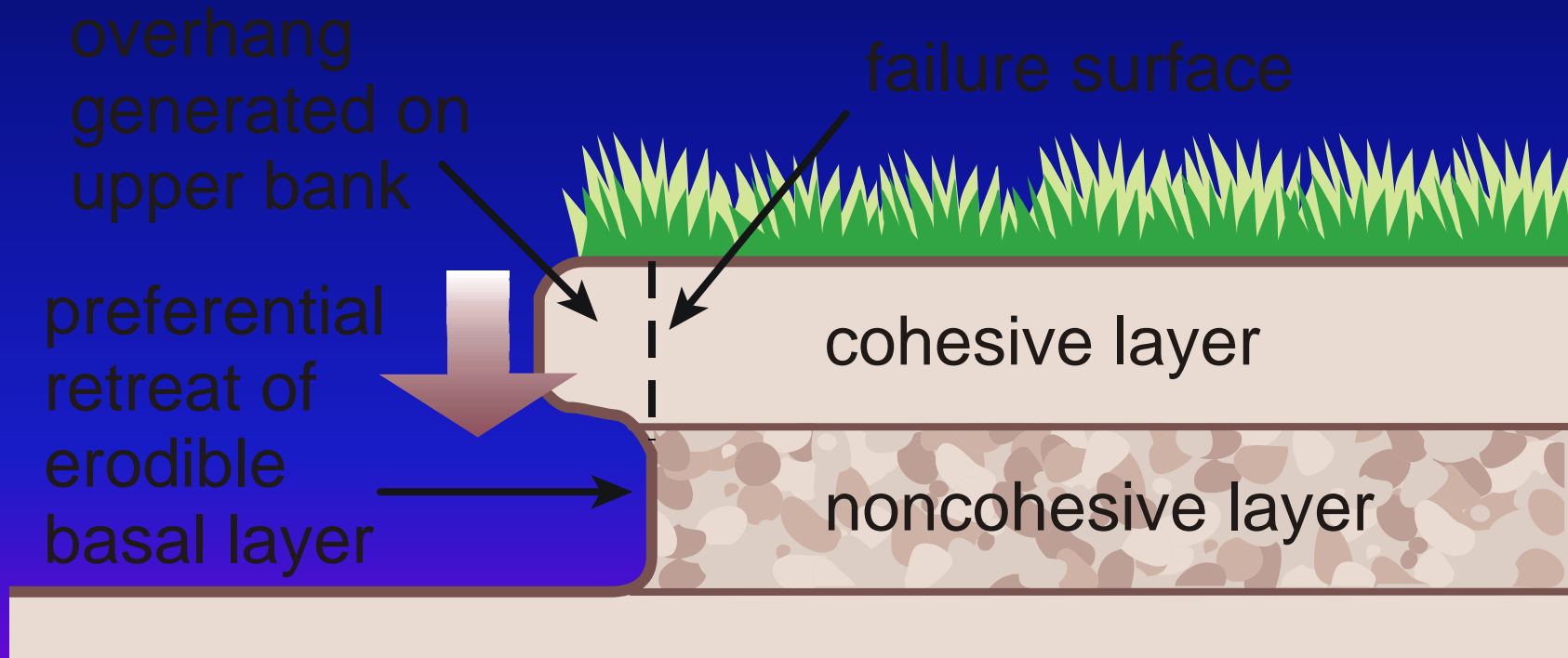
# Streambank Erosion – Rotational Streambank Failure



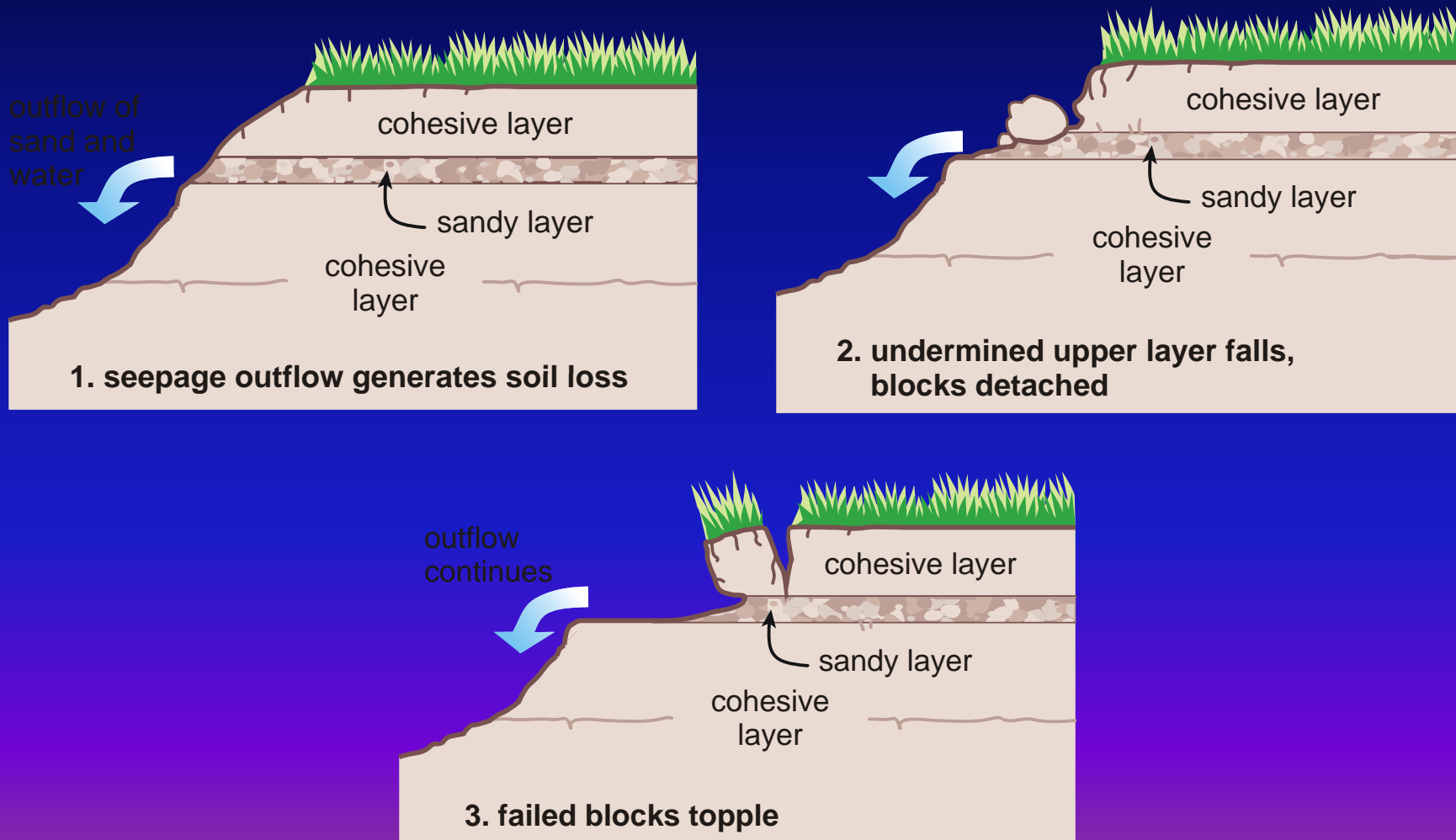
# Streambank Erosion – Planar Streambank Failure



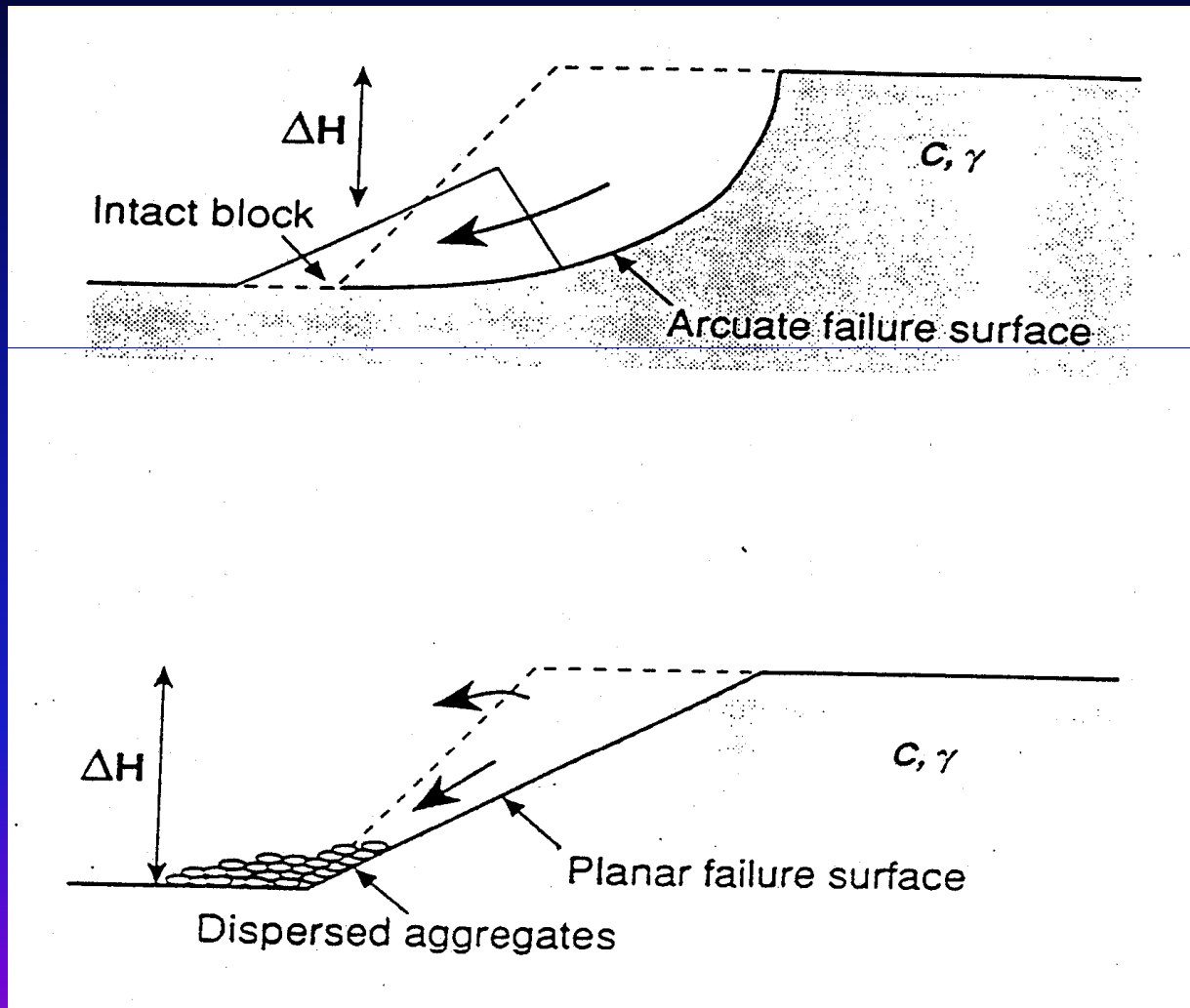
# Streambank Erosion – Cantilever Streambank Failure



# Streambank Erosion – Piping Streambank Failure



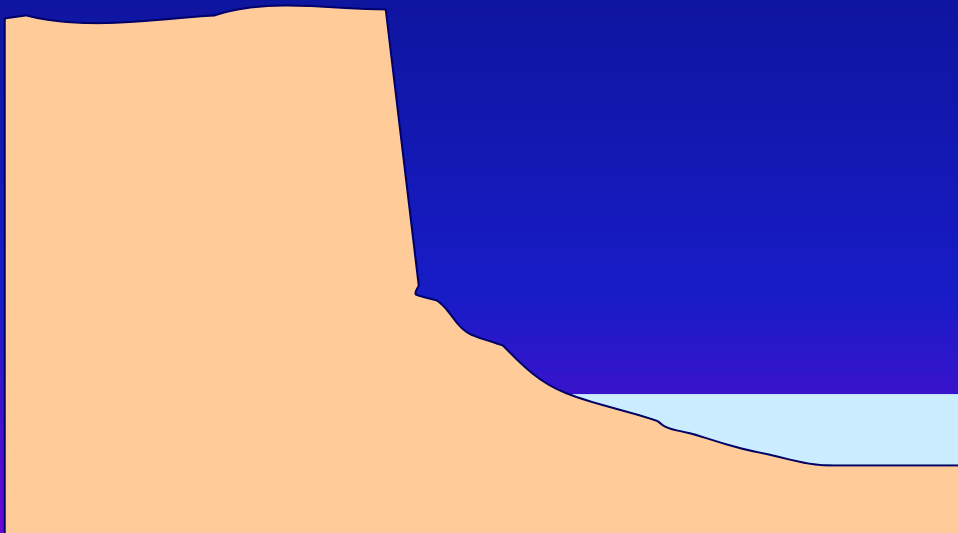
# Disposition of Failed Materials



# **Bank Stability Processes**

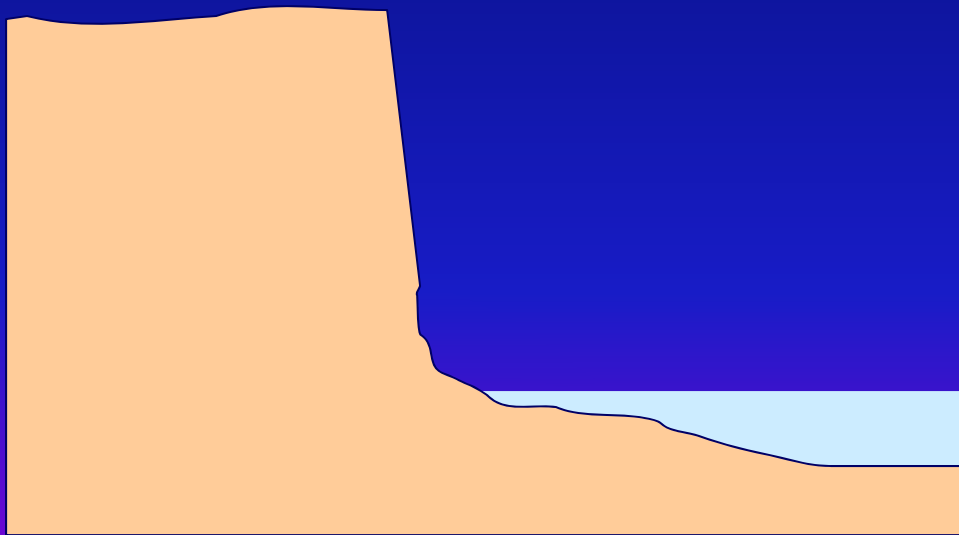
# Bank Retreat Processes

Vertical face



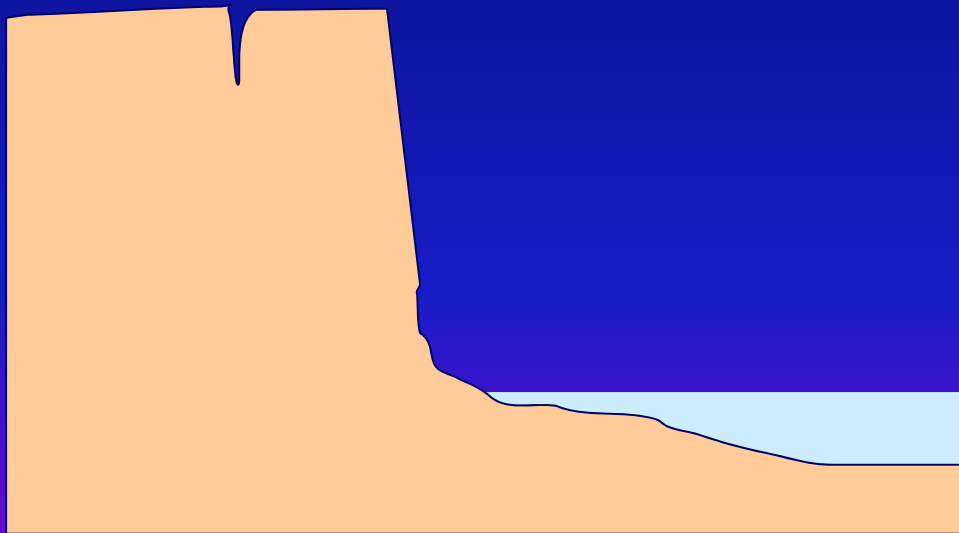
# Bank Retreat Processes

Toe erosion  
steepens bank



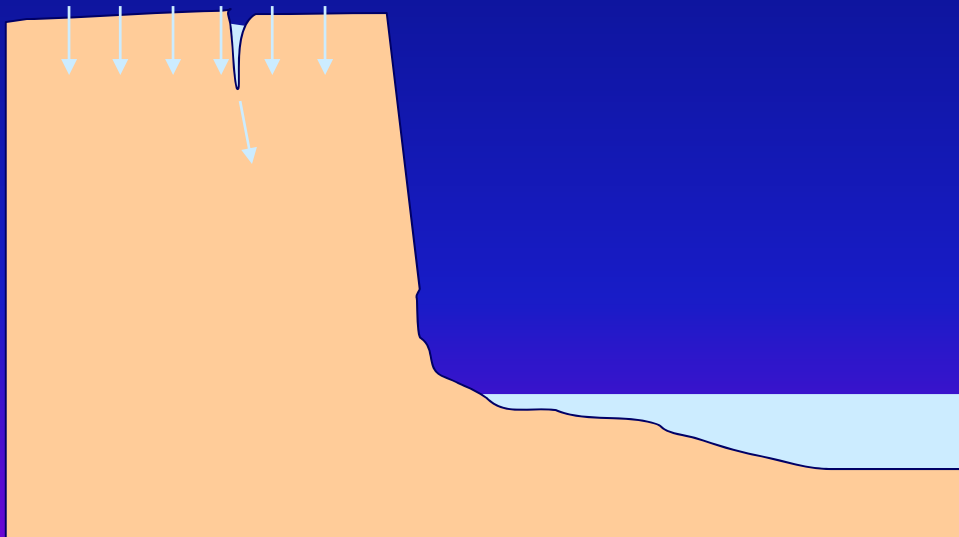
# Bank Retreat Processes

Tension crack  
develops



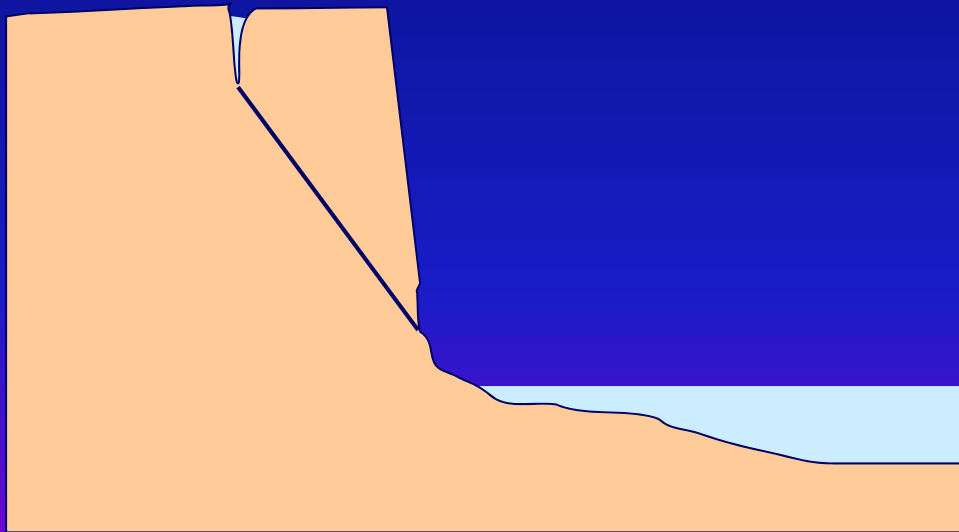
# Bank Retreat Processes

Infiltration raises pore-  
water pressure



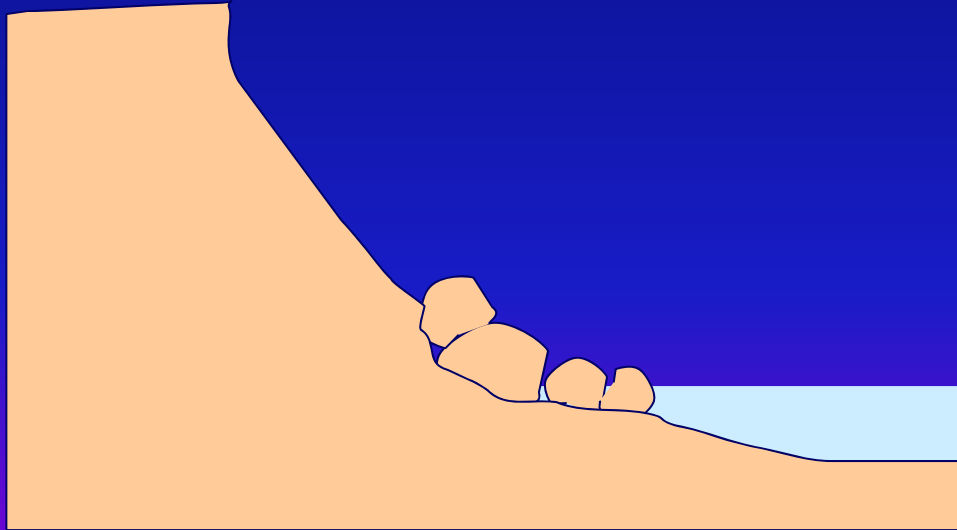
# Bank Retreat Processes

Shearing starts



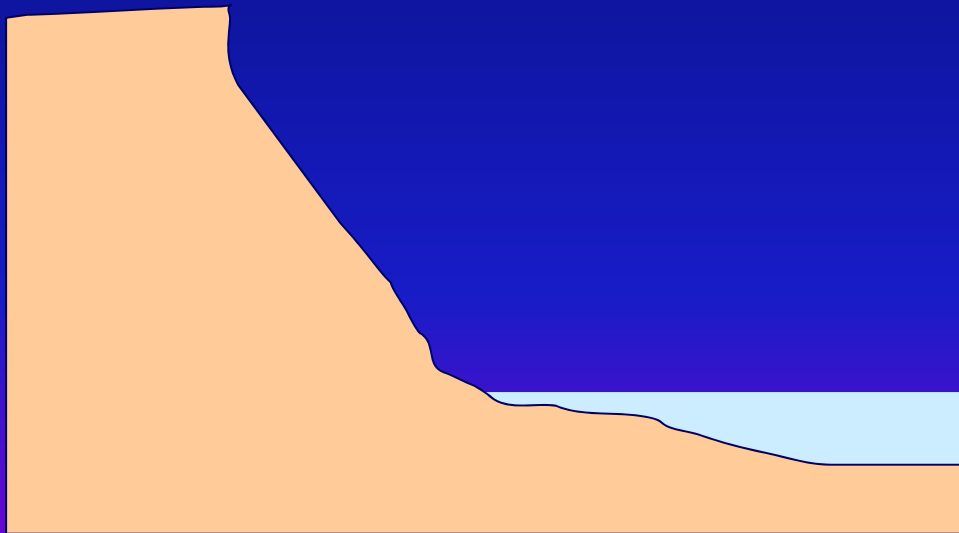
# Bank Retreat Processes

Bank failure  
occurs



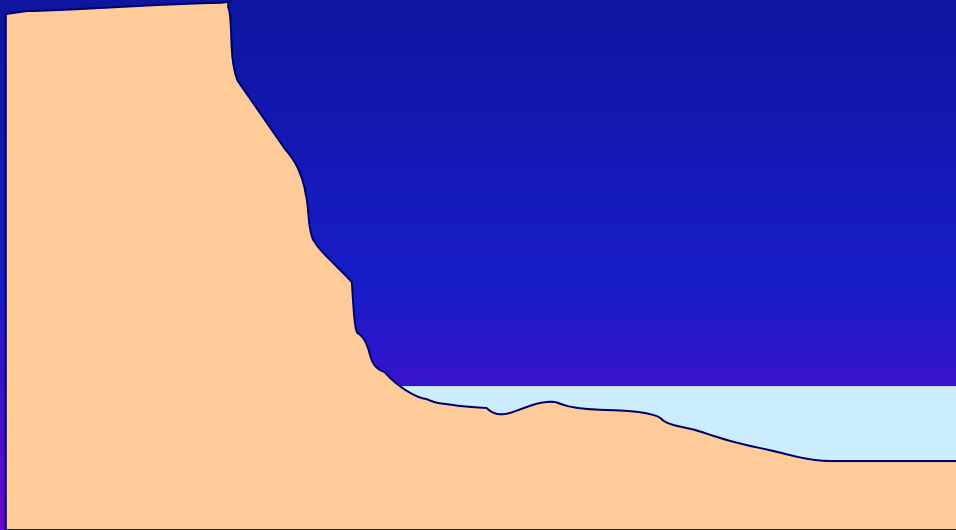
# Bank Retreat Processes

Erosion removes  
the failed debris



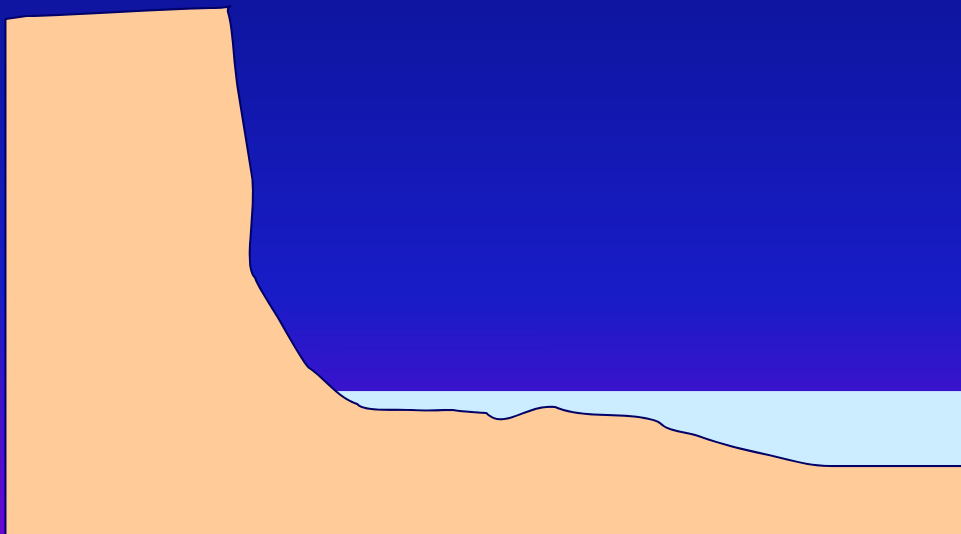
# Bank Retreat Processes

Bank steepening  
starts again

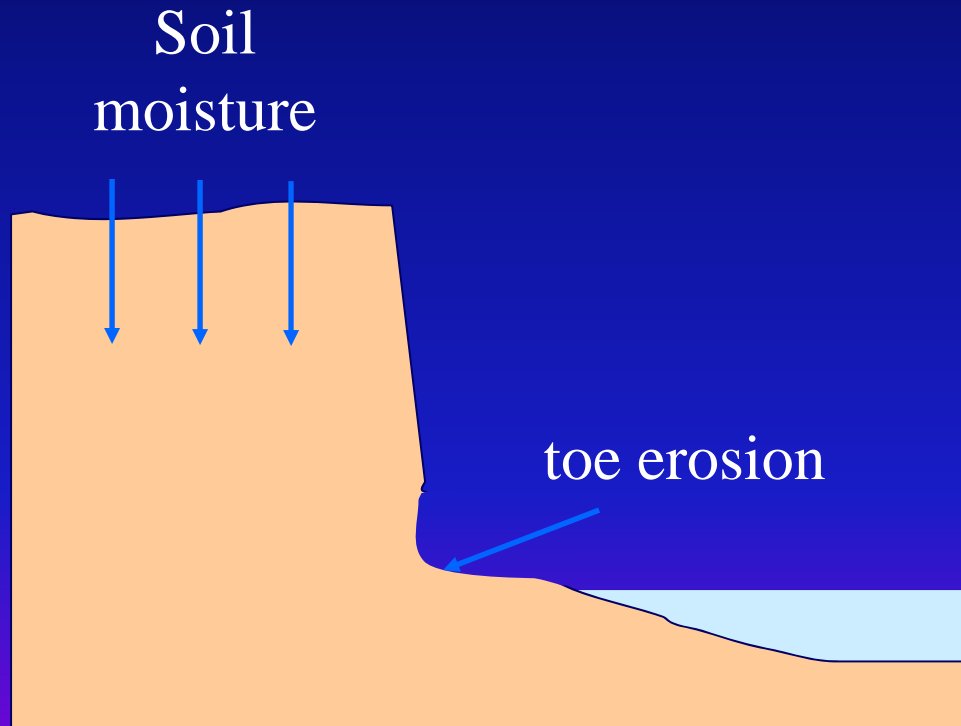


# Bank Retreat Processes

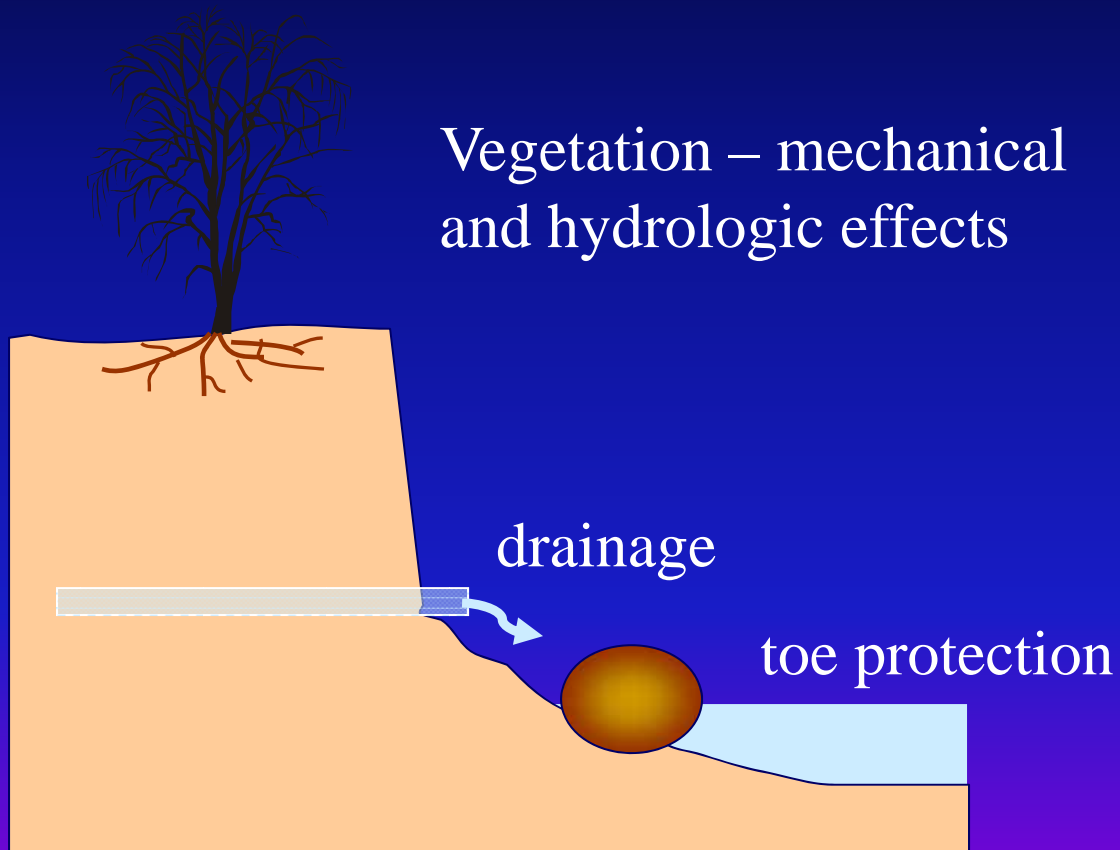
Vertical face



# Bank stability is decreased by....



# Bank stability is increased by....

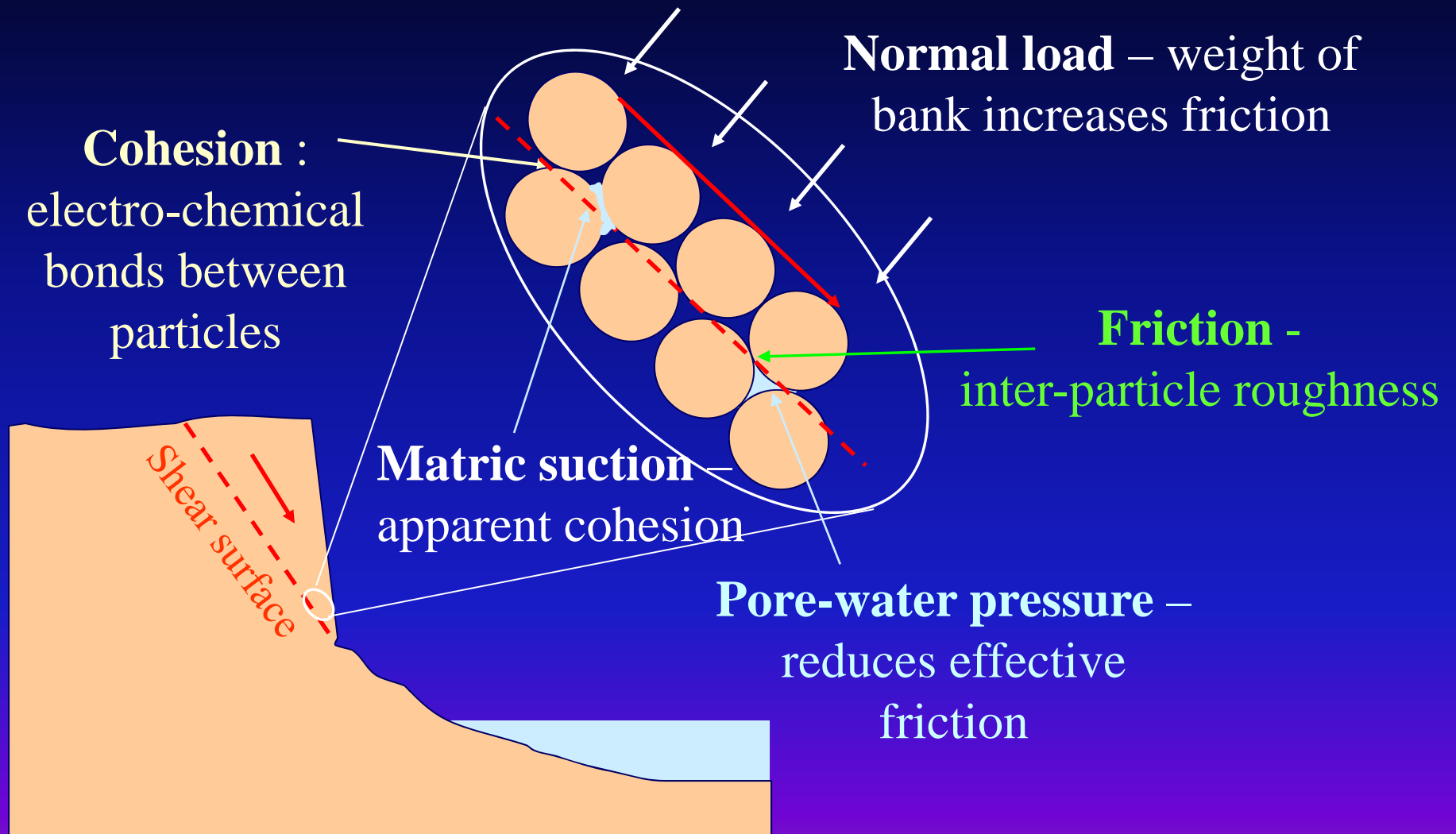


# Fundamental Processes Behind Bank Stability

If we want to predict bank stability we need to quantify the underlying processes controlled by force and resistance to mass failure and hydraulic shear:

- **Bank shear strength** (resistance to mass failure)  
vs. **Gravitational forces**
- **Bank-toe erodibility** (resistance to hydraulic erosion)  
vs. **Boundary shear stress**

# Forces Affecting Soil Shear Strength



# Some “Ball Park” Figures (based on more than 800 tests)

Soil Type	Statistic	$c_a$ (kPa)	$c'$ (kPa)	$\phi'$ (degrees)	$\gamma_{sat}$ (kN/m <sup>3</sup> )
<b>Gravel*</b>		-	<b>0.0</b>	36.0	20.0
<b>Sand</b>	75th percentile	5.8	1.0	32.3	19.1
	<b>Median</b>	2.9	<b>0.4</b>	<b>30.3</b>	<b>18.5</b>
	25th percentile	1.3	0.0	25.7	17.9
<b>Loam</b>	75th percentile	11.9	8.3	29.9	19.2
	<b>Median</b>	8.4	<b>4.3</b>	<b>26.6</b>	<b>18.0</b>
	25th percentile	4.6	2.2	16.7	17.4
<b>Clay</b>	75th percentile	18.0	12.6	26.4	18.3
	<b>Median</b>	11.0	<b>8.2</b>	<b>21.1</b>	<b>17.7</b>
	25th percentile	7.2	3.7	11.4	16.9

\* From Selby (1982)

# Effects of Pore-Water Pressure (*saturated soils*)

- Pore-water pressure reduces effective normal stress – weakens the soil by:

$$\tau_f = c' + (\sigma - \mu_w) \tan \phi'$$

- Increases weight of bank
- However, negative pore-water pressure (matric suction) increases bank strength
- Converting positive to negative pressure (lowering water table) increases overall bank strength

# Incorporating Matric Suction - The Fredlund Approach

*(un-saturated soils)*

$$\tau_f = c' + (\sigma - \mu_a) \tan \phi' - \mu_w \tan \phi^b$$

where

$(\sigma - \mu_a)$  = net normal stress on the failure plane

$\mu_a$  = pore-air pressure on the failure plane

$\phi^b$  = angle representing the relation  
between the shear strength and  
matric suction

# Incorporating Matric Suction as Apparent (total) Cohesion

$$c_a = c' - (\mu_a - \mu_w) \tan \phi^b$$

Where:

$c_a$	=	apparent (total) cohesion
$c'$	=	effective cohesion
$(\mu_a - \mu_w)$	=	suction on the failure plane
$\phi^b$	=	angle representing the relation between the shear strength and the matric suction

# What a Model Needs to Incorporate

If we want to model and control bank erosion we need to quantify and simulate the underlying processes. These are:

- **Bank shear strength** (resistance to bank failure: geotechnical processes)
- **Bank-toe erodibility** (resistance to toe erosion and steepening: hydraulic processes)
- The effects of stabilization measures on these processes (roughness, root reinforcement, transpiration)

# Bank Stability – The Factor of Safety

$$\text{Factor of Safety (F}_s\text{)} = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

If  $F_s$  is greater than 1, bank is stable. If  $F_s$  is less than 1, bank will fail. (We usually add a safety margin:  $F_s > 1.3$  is stable.)

## Resisting Forces

soil strength

vegetation

reinforcement

## Driving Forces

bank angle

weight of bank

water in bank

# Factor of Safety Equation for Planar Failures

$$F_s = \frac{\sum c'_i L_i + (S_i \tan \phi_i^b) + [W_i \cos \beta - U_i + P_i \cos (\alpha - \beta)] \tan \phi_i'}{\sum W_i \sin \beta - P_i \sin (\alpha - \beta)}$$

$c'$  – effective cohesion;

$L$  = length of failure plane;

$S$  = force produced by matric suction on the unsaturated part of the failure surface;

$\phi^b$  = rate of increasing shear strength with increasing matric suction;

$W$  = weight of failure block;

$\beta$  = failure-plane angle;

$U$  = hydrostatic-uplift force due to positive pore-water pressures on the saturated part of the failure plane;

$P$  = hydrostatic-confining force provided by the water in the channel; and

$\phi'$  = angle of internal friction (rate of increasing shear strength with increasing normal force).

*Simon et al., 2000*

# **Bank-Failure Modes**

- **Planar Failures, with and without tension cracks**
- **Cantilever Failures following Undercutting**

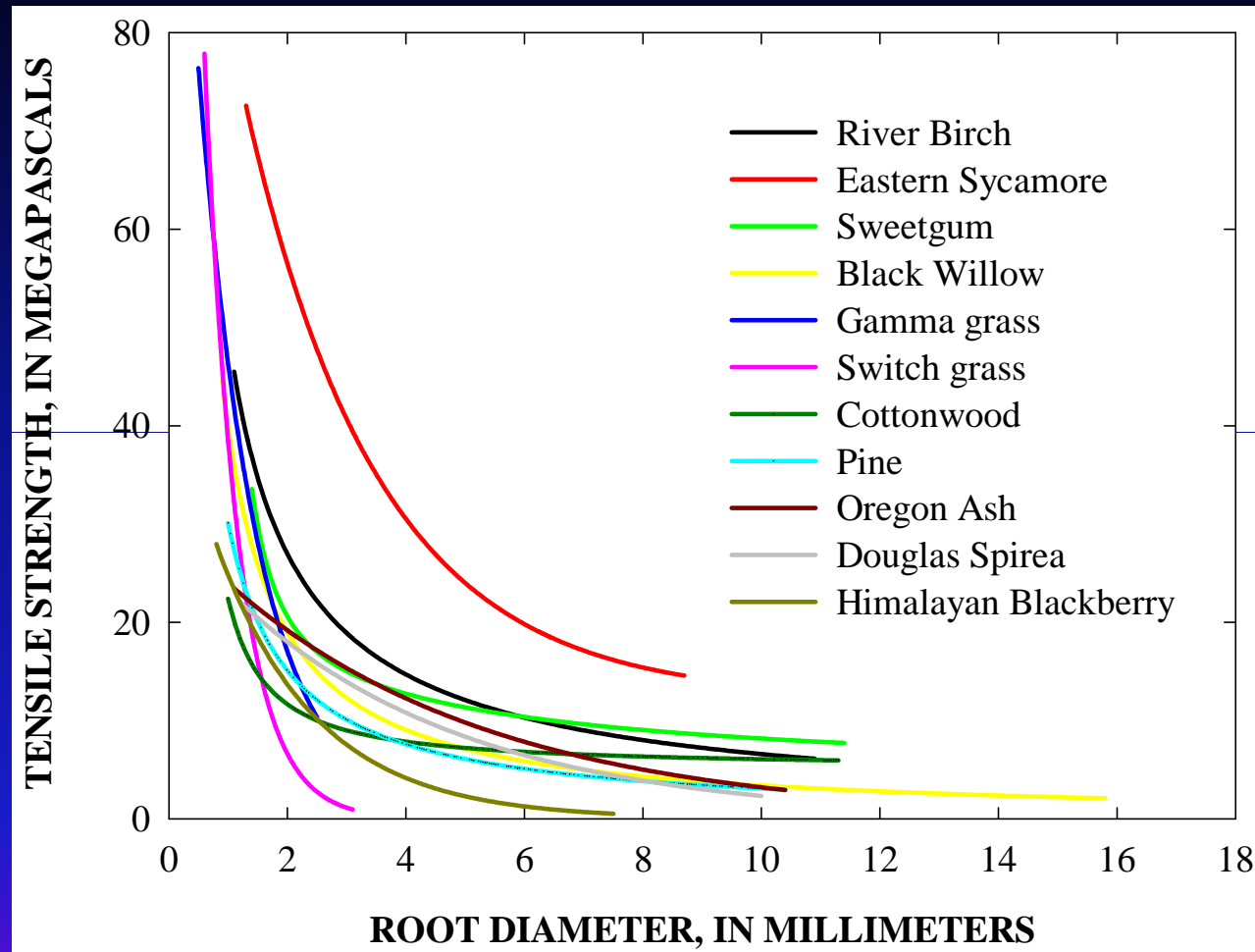
**Model Selects Failure Model based on  
minimum Factor of Safety**

# Effects of Vegetation on Bank Stability

	Mechanical	Hydrologic
<b>Stabilizing Effects</b>	<b>Increased strength due to roots</b>	<b>Canopy interception Transpiration</b>
<b>Destabilizing Effects</b>	<b>Surcharge</b>	<b>Increased infiltration rate and capacity</b>

- **Problem: how much effect (+ and -) do these combined factors have on bank stability?**
- **Practitioners need quantitative assessments**

# Root-Strength Is Incorporated



Cohesion due to roots is a function of the tensile strength of the roots and their distribution (root-area ratio)

# An Alternative Approach: Progressive Root Breaking

- The materials industry uses Fiber Bundle Models (FBMs) to study how composite materials act under stress.

## Advantages of FBMs:

- Simple rules allow analysis of load bearing by fibers, and redistribution of load after breaking of individual fibers.
- Thus, models incorporate *progressive root breaking*

# RipRoot Model Construction

Simple rules and assumptions:

- An initial load is distributed evenly between the  $n$  roots.
- This load is increased until one of the roots breaks.
- The load that was carried by the broken root is redistributed *equally* to the remaining  $(n-1)$  intact roots.
- This is known as a Global Load Sharing FBM.

# Root Reinforcement Estimates

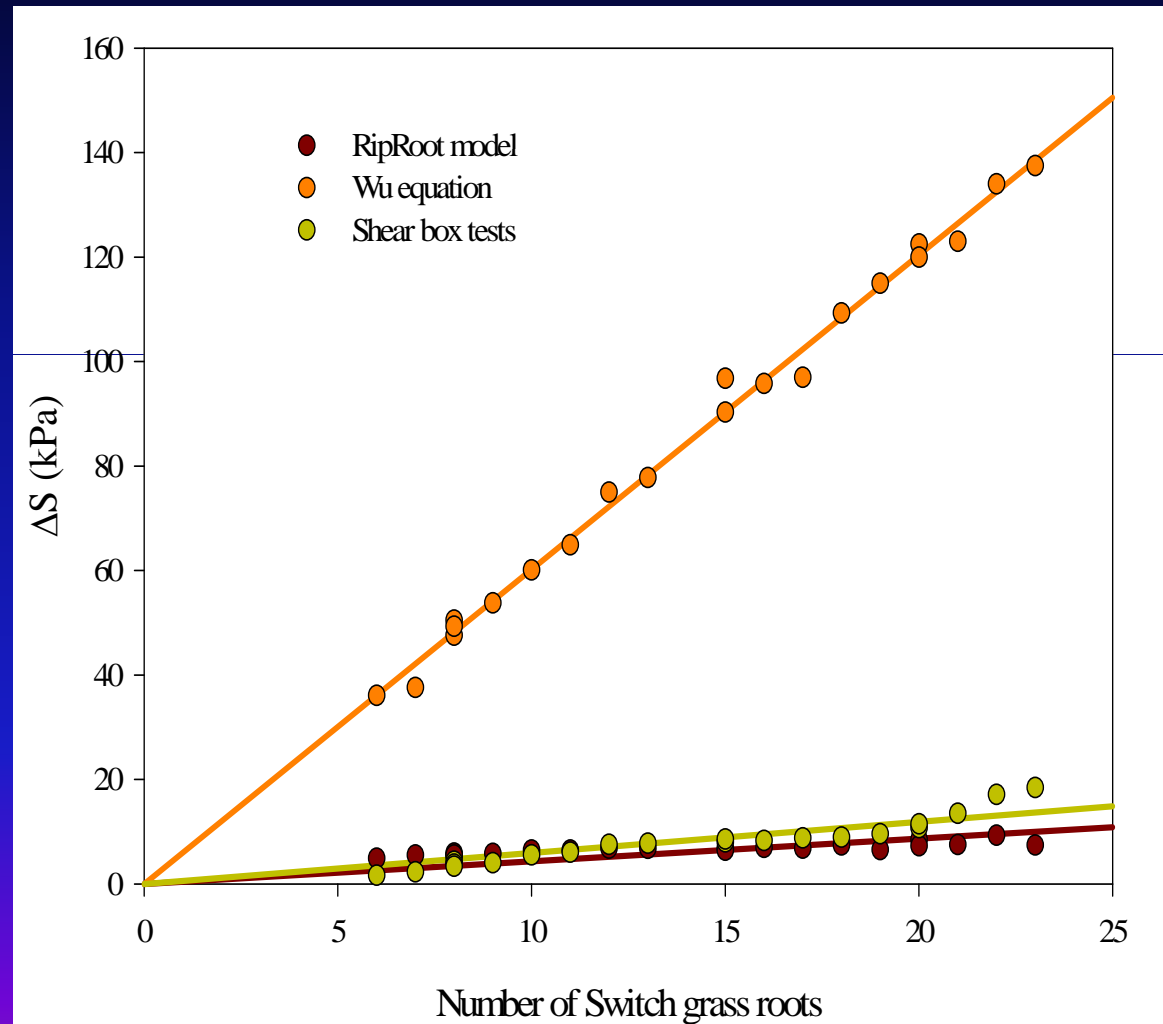
Species	Number of roots	RipRoot estimate (kPa)	Wu equation estimate (kPa)
Cottonwood	200	2.5	8.0
Black willow	200	4.7	13.2
River birch	200	5.8	18.9

# Validation of Root Reinforcement Estimates

- Direct-shear tests with and without roots were carried out
- 10 control samples
- 30 samples with roots – number and diameters of roots crossing the shear plane recorded
- Root reinforcement calculated by subtracting the mean control value from each sample with roots

# RipRoot: Validation

- Wu equation over-estimates root reinforcement by 600 to 1000 %
- RipRoot shows considerably less error



# Bank Stability Comparison

Species	Bank height (m)	$F_s$ no vegetation	$F_s$ with RipRoot estimate	$F_s$ with Wu estimate
River birch	1	3.87	5.51	30.9
	2	1.93	3.38	4.26
	3	1.18	1.75	2.1
Switch grass	1	3.87	5.6	51.0
	2	1.93	3.48	10.0
	3	1.18	1.96	4.35

Wu *et al* (1979) greatly overestimates the effects of root reinforcement on bank stability

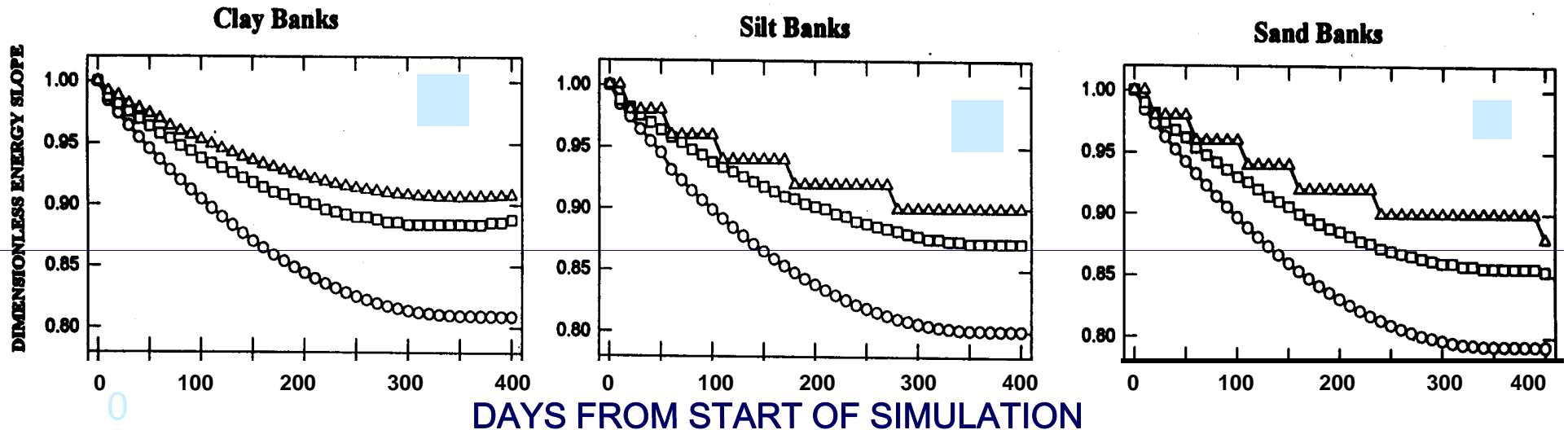
# Adjustment of a Sand-Bed Channel

- Assume that  $\gamma QS \propto Q_s d_{50}$  becomes un-balanced
- $Q_s d_{50} = 0.5 * \text{capacity}$
- Slope = 0.005
- Width/depth ratio = 13.5

Bank material	Bed $d_{50}$ (mm)	Bank cohesion (kPa)	Friction angle ( $^\circ$ )	Sand content (%)
Sand	1.0	4.0	32.5	100
Silt	1.0	7.5	32.5	20
Clay	1.0	40.0	32.5	10

Additional cohesive strength can also be used as an analog for the root-reinforcement (mechanical) effects of vegetation on bank stability

# Adjustment in Energy Slope for Different Boundary Materials and Slopes



- ▲ 0.00005 @ 0.90
- 0.0005 @ 0.87
- 0.005 @ 0.80

Energy adjustment is similar at given slope!

Do each of these channels reach equilibrium similarly?

# Adjustments for Different Boundary Materials

Gradient	0.005 m/m
Degradation	3.51
Widening	0
$W_o/D_o$	13.5
$W_f/D_f$	5.62
$\tau_o$	103
$\tau_f$	98.7
Degradation	2.74
Widening	11.3
$W_o/D_o$	13.5
$W_f/D_f$	8.62
$\tau_o$	103
$\tau_f$	69.3
Degradation	0.35
Widening	13.1
$W_o/D_o$	13.5
$W_f/D_f$	16.4
$\tau_o$	103
$\tau_f$	64.8

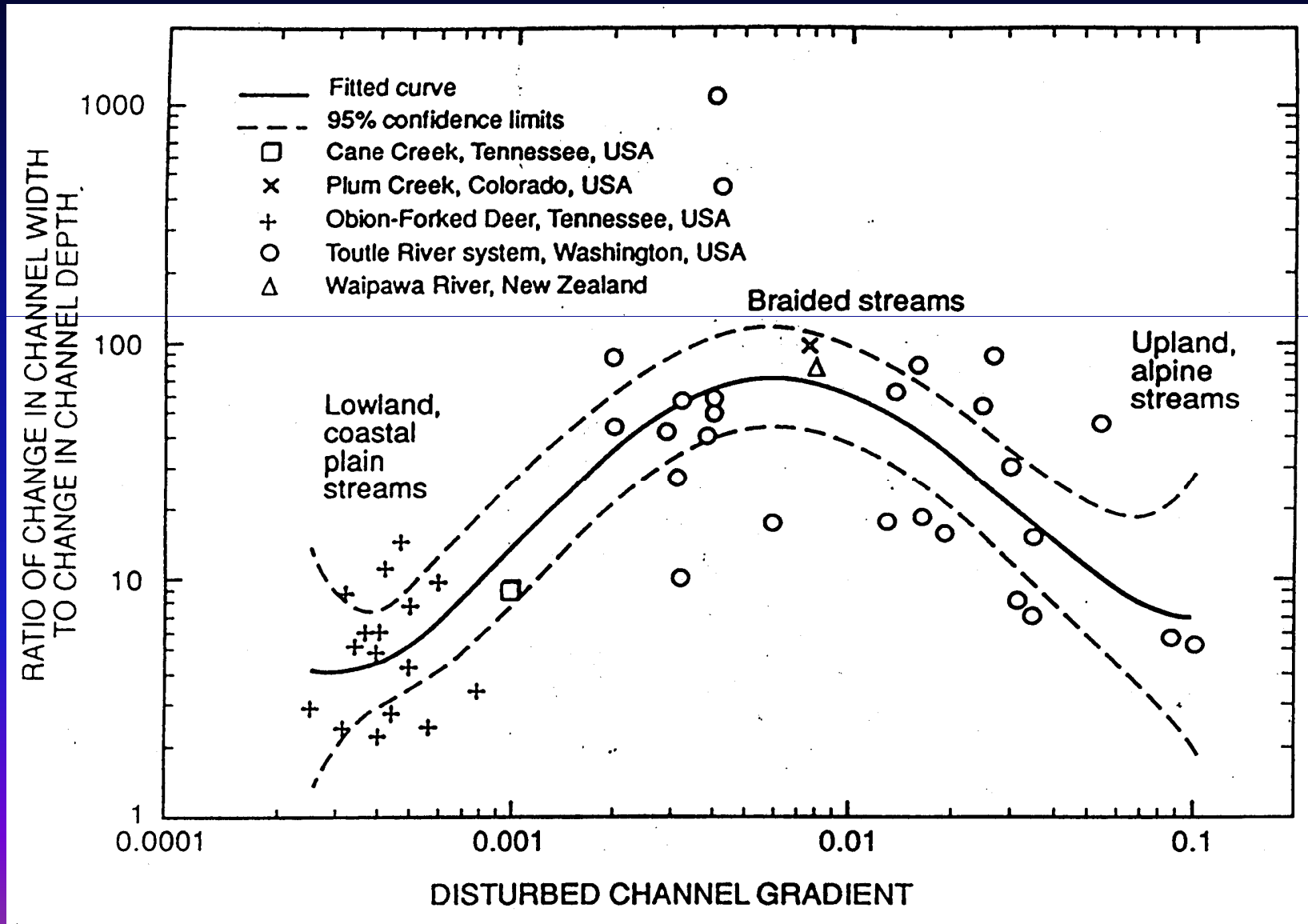
Clay-bank channel

Silt-bank channel

Sand-bank channel

From Simon and Darby (1997)

# Changes in Morphology During Adjustment

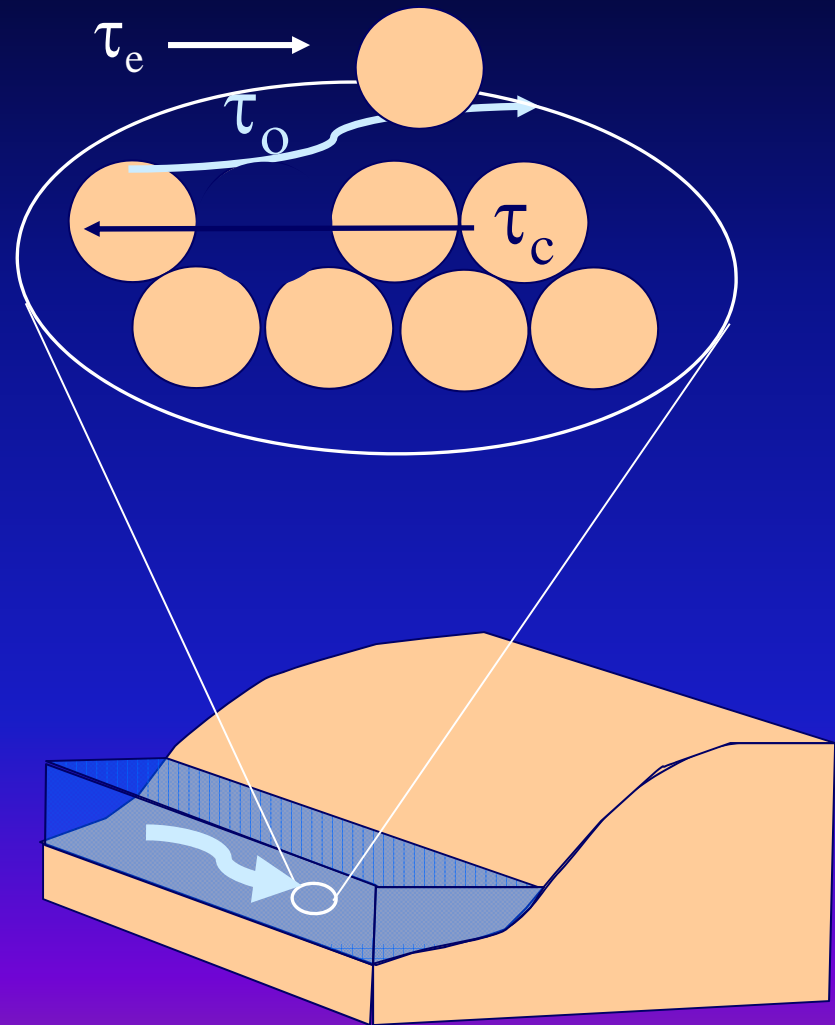


# Hydraulic Erosion Processes

The difference between total boundary shear stress,  $\tau_o$ , and critical shear stress,  $\tau_c$ , is the excess shear stress,  $\tau_e$ .

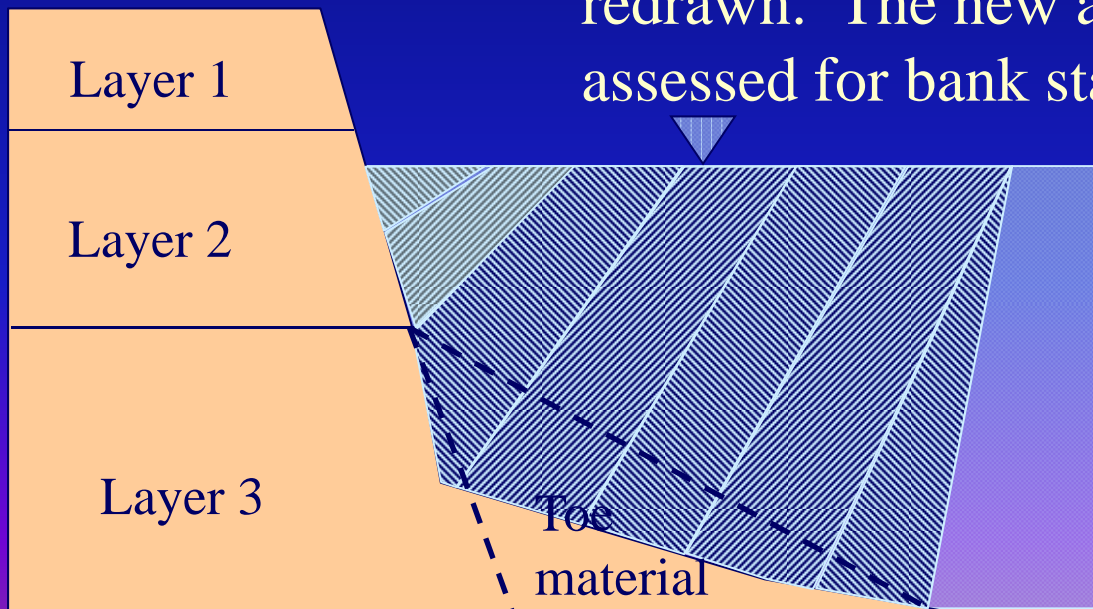
$$\tau_e = \tau_o - \tau_c$$

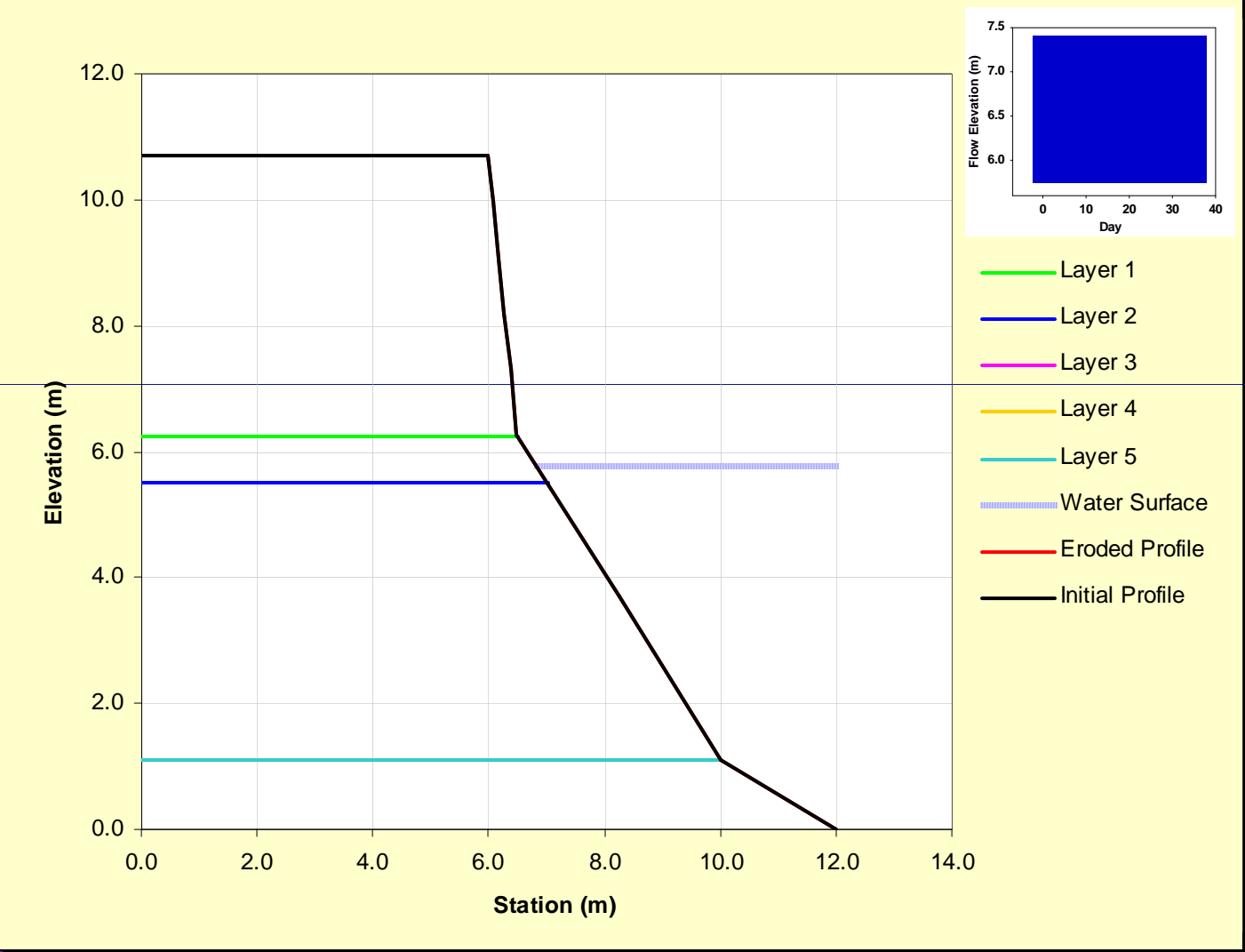
This is the shear stress that is available to cause erosion. The amount of erosion that occurs is a function of the erodibility,  $k$ , and the excess shear stress,  $\tau_e$ .

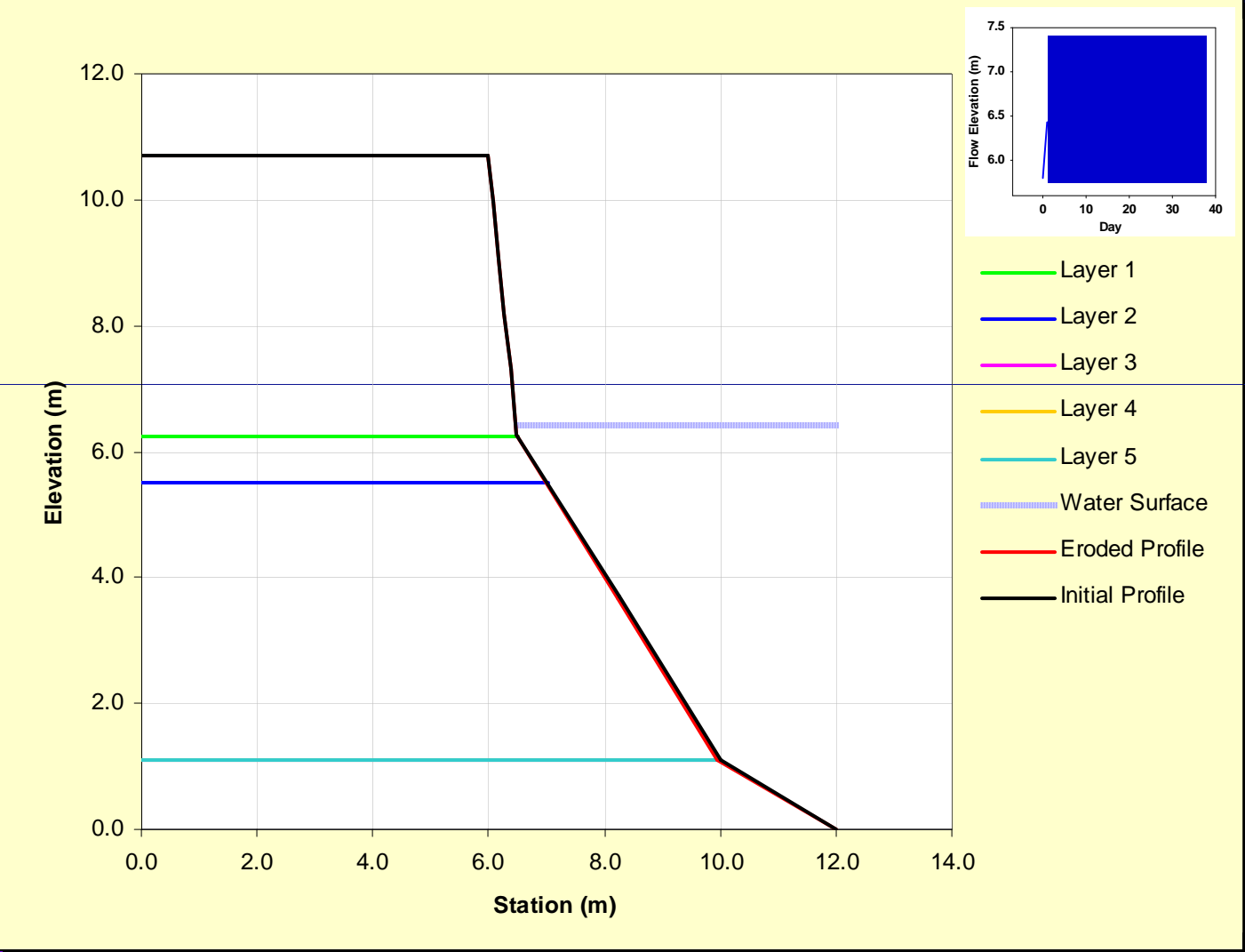


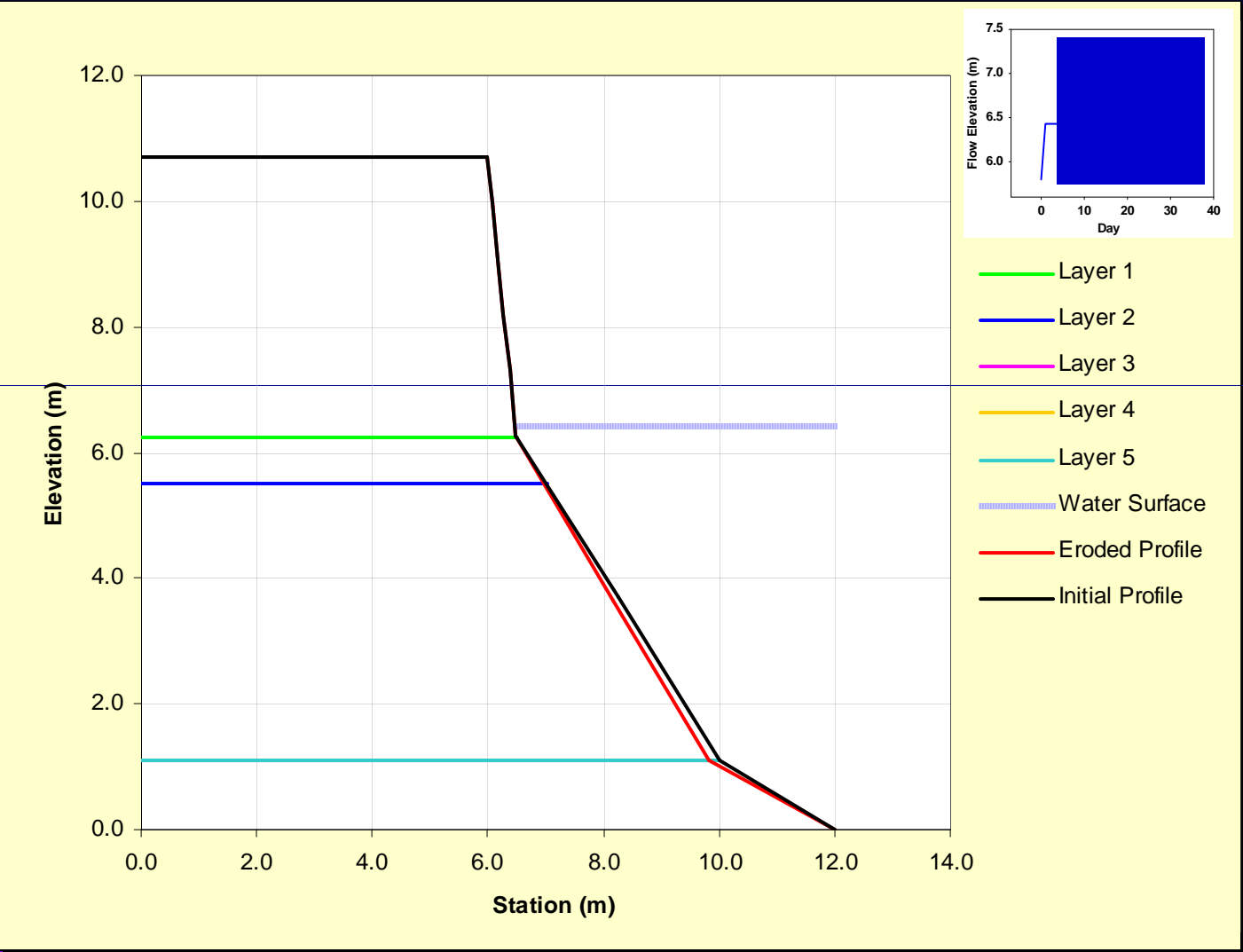
# Bank Toe Model

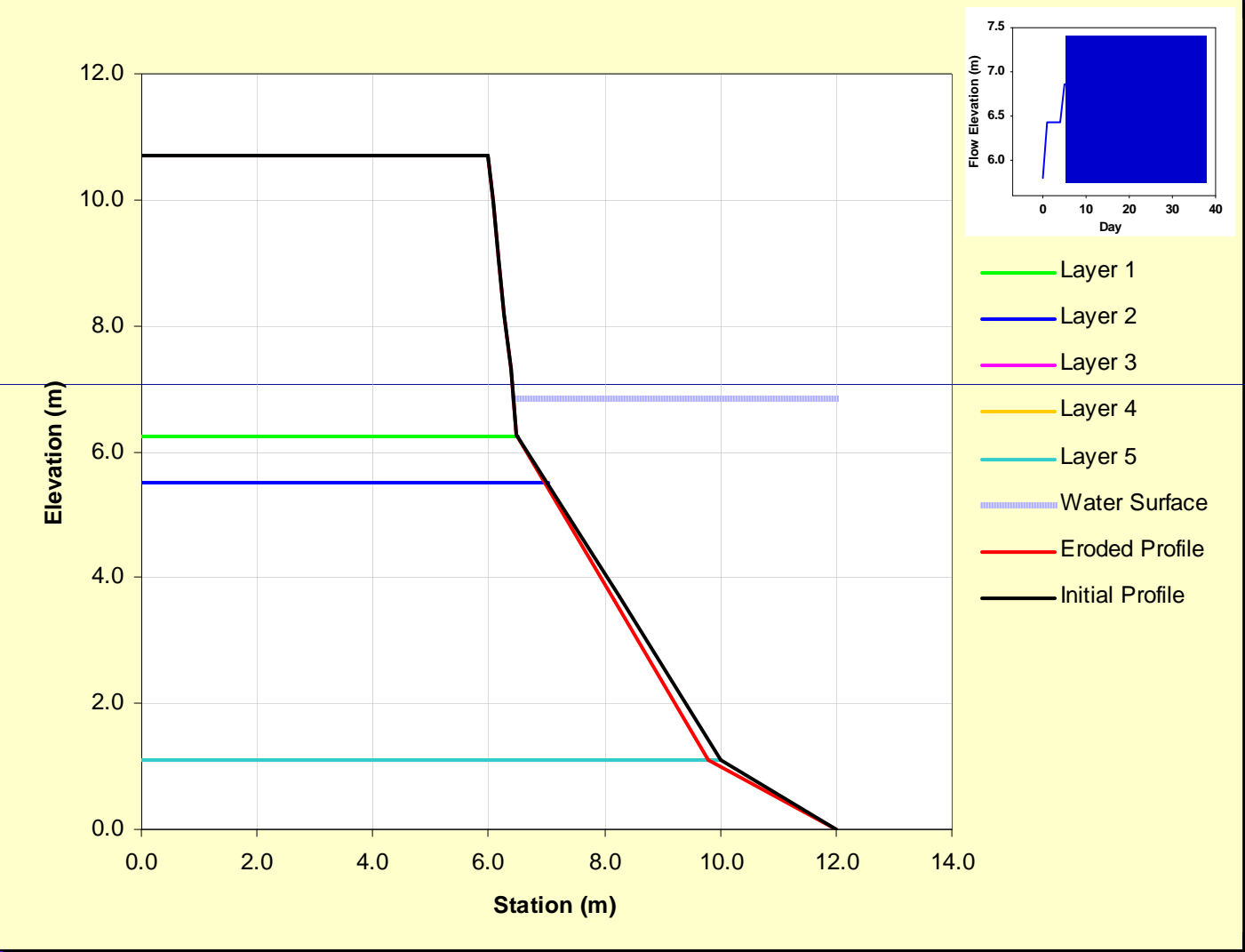
By comparing applied shear stress with critical shear stress and erodibility, actual erosion is calculated for each facet, and the profile is redrawn. The new and old profiles can be assessed for bank stability.

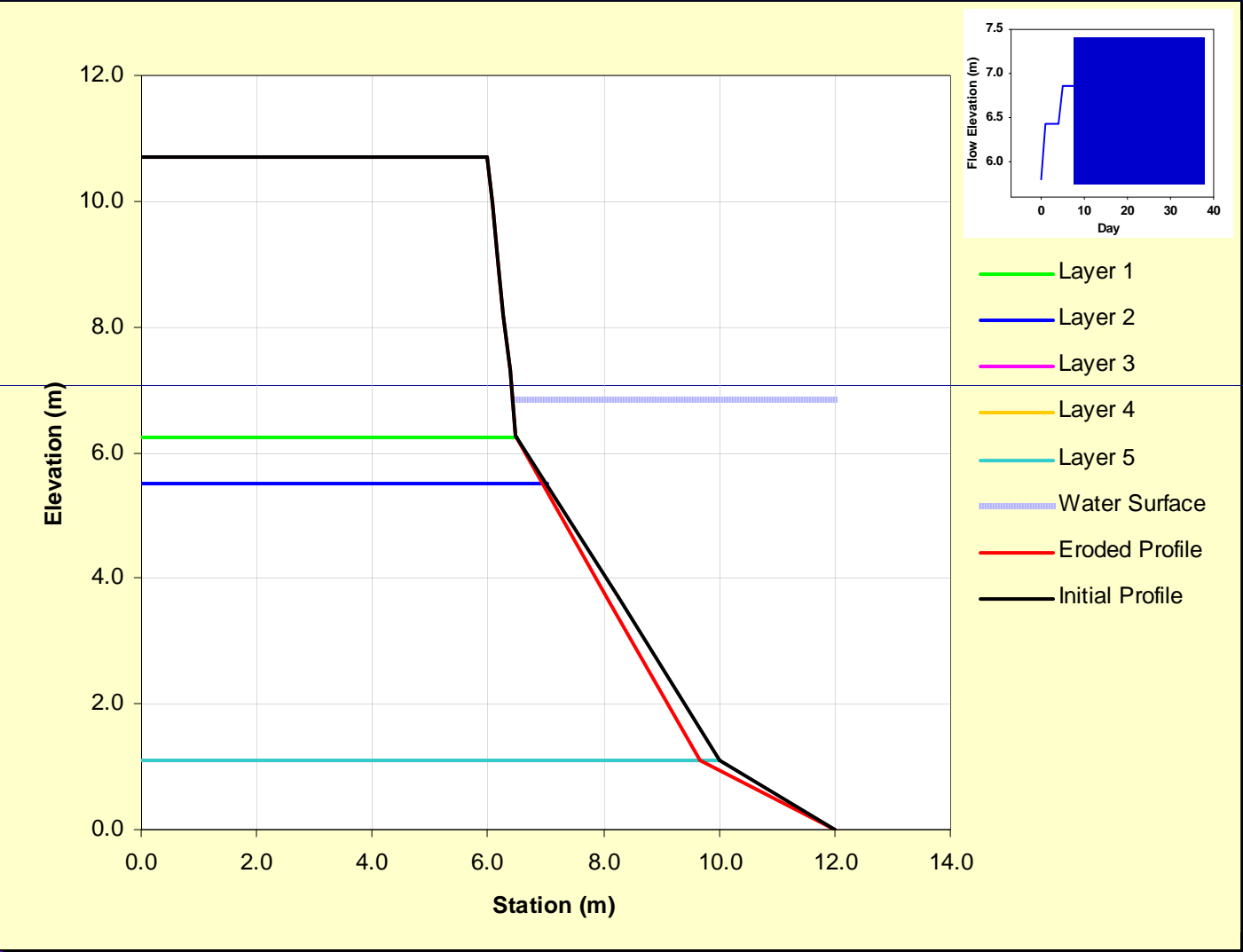


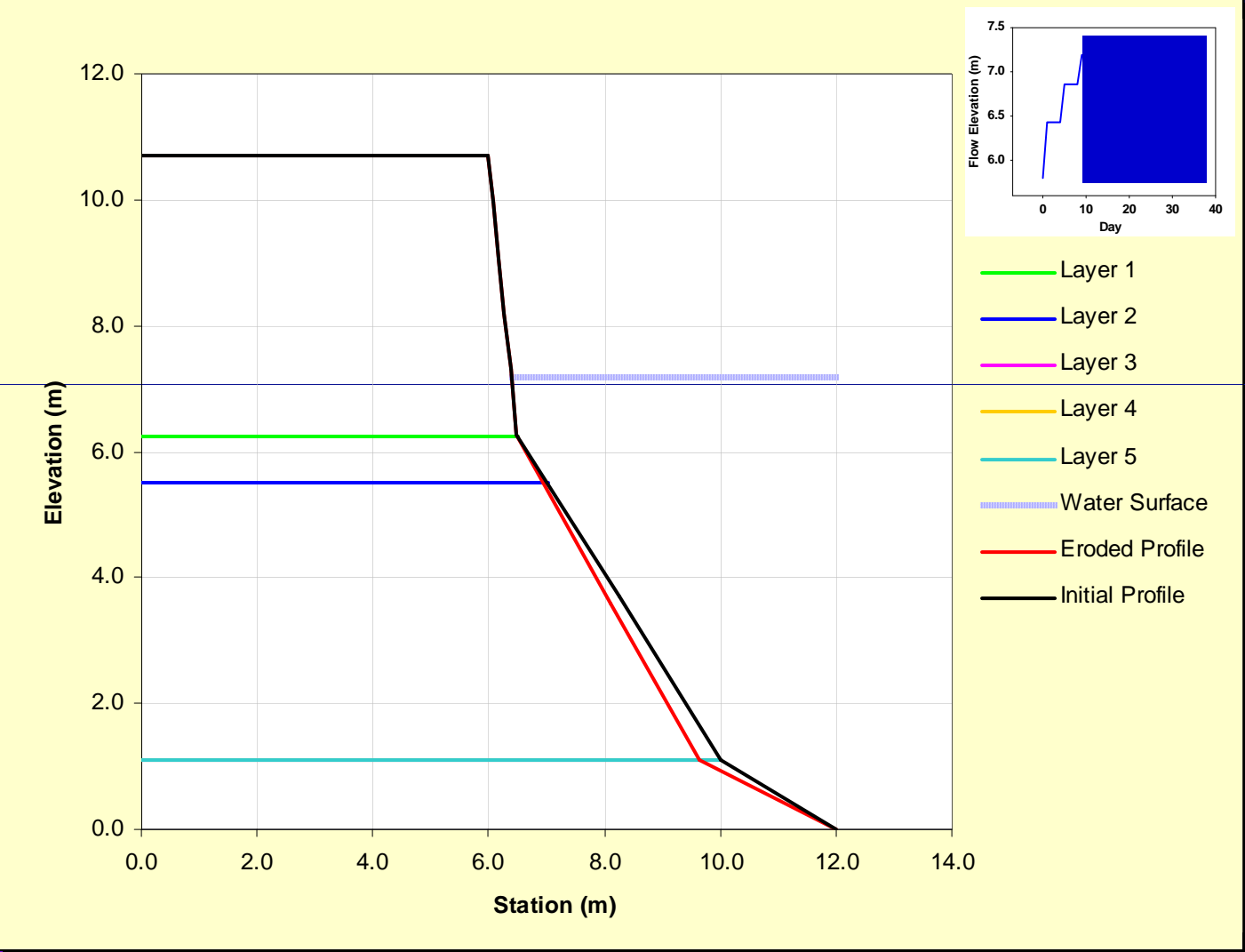


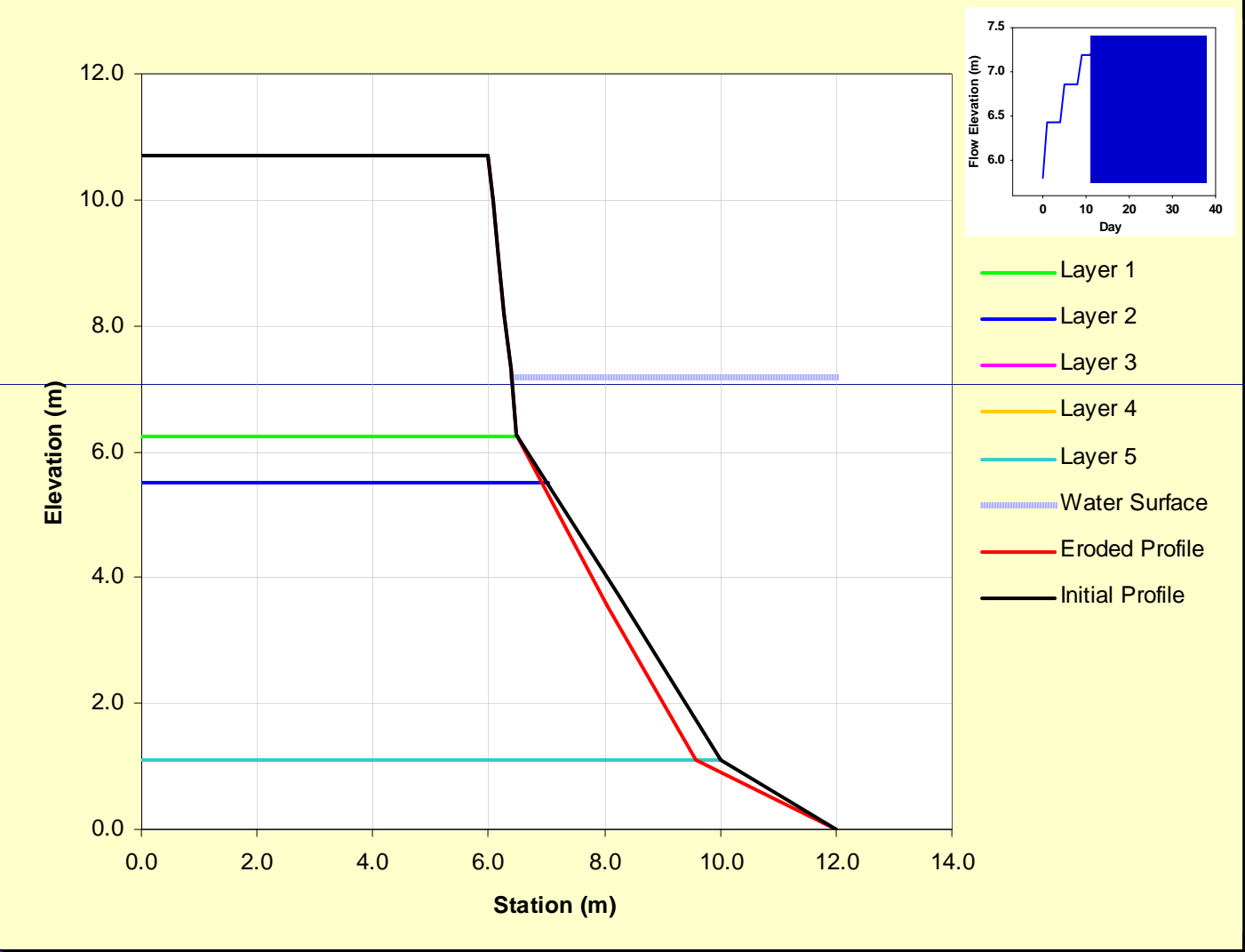


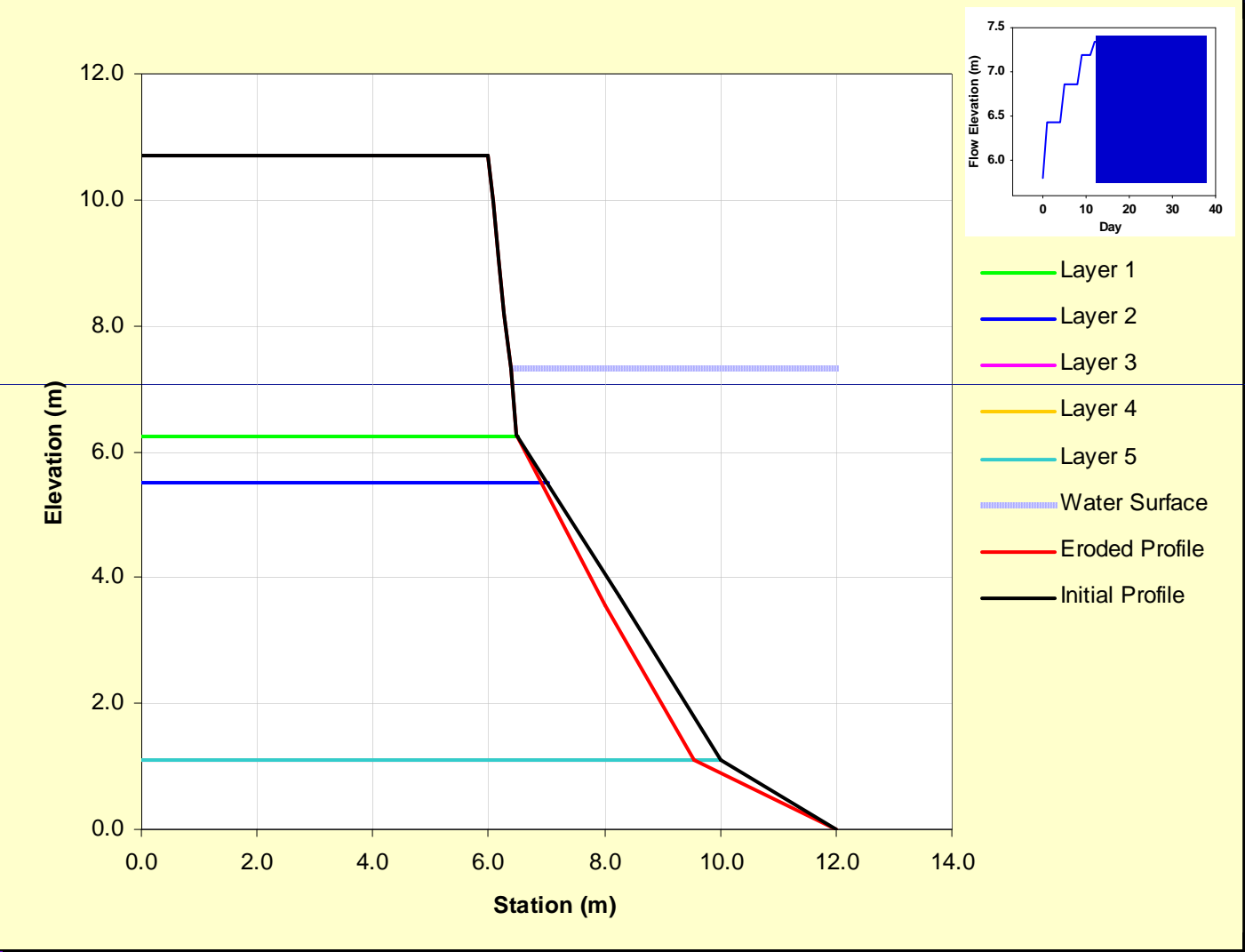


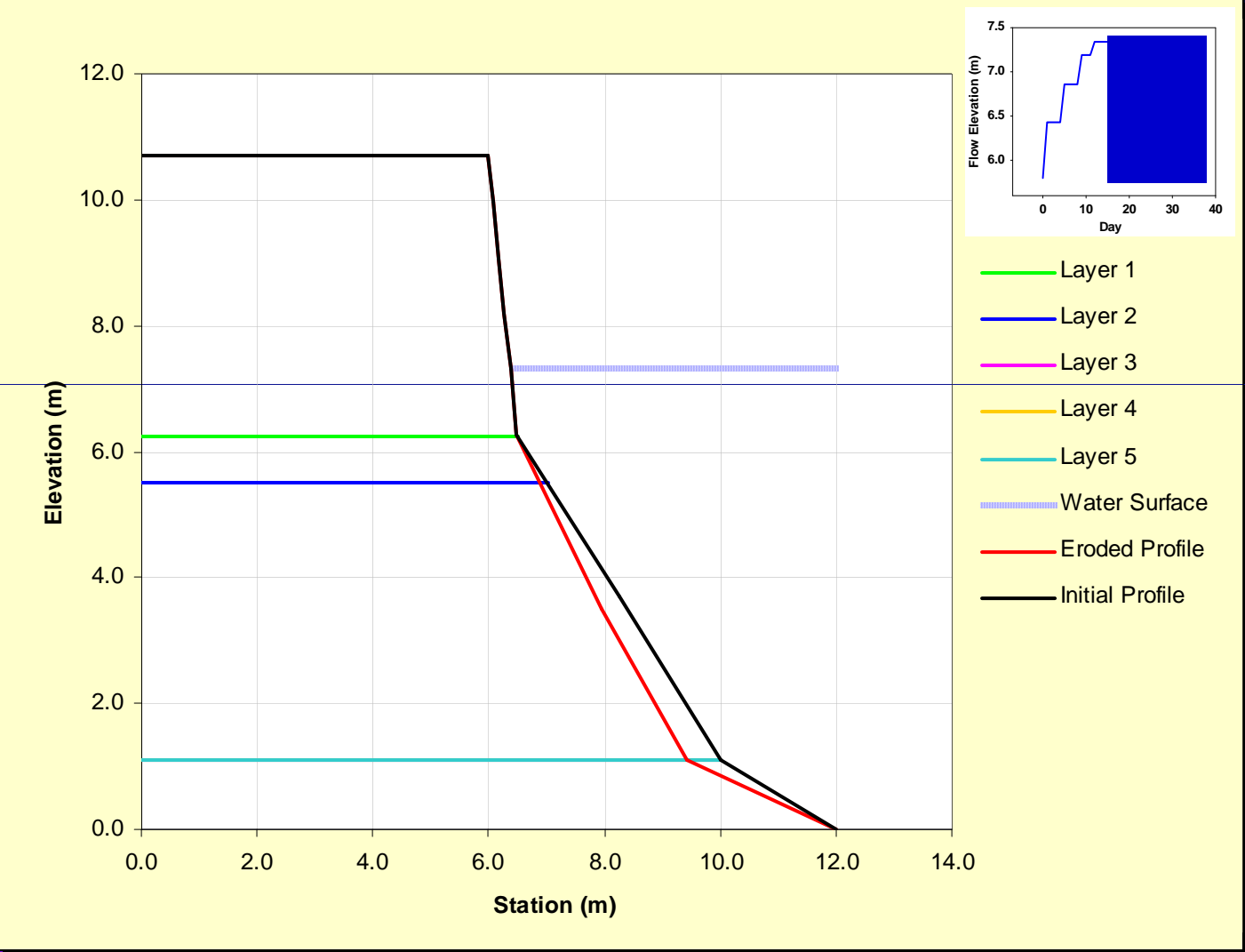


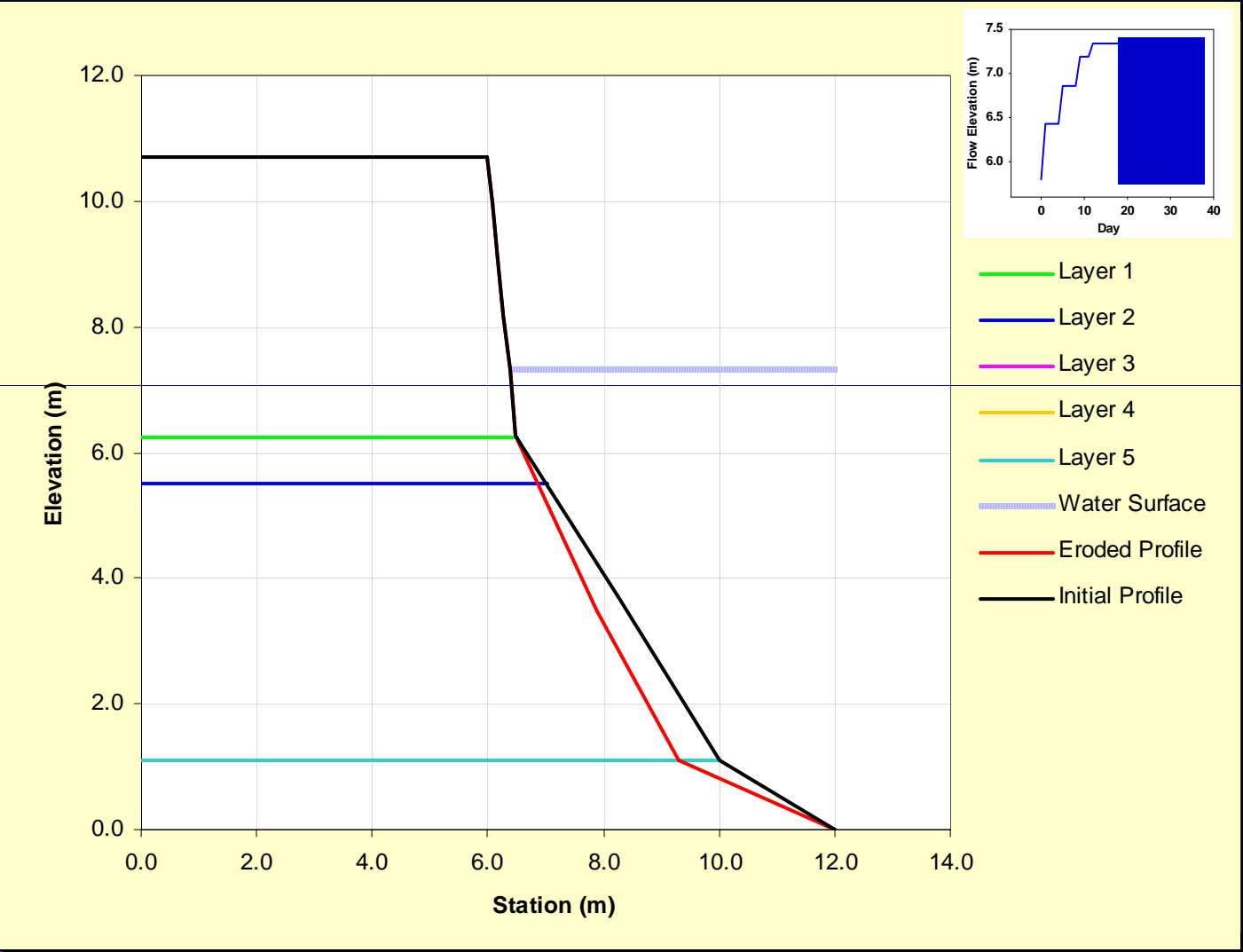


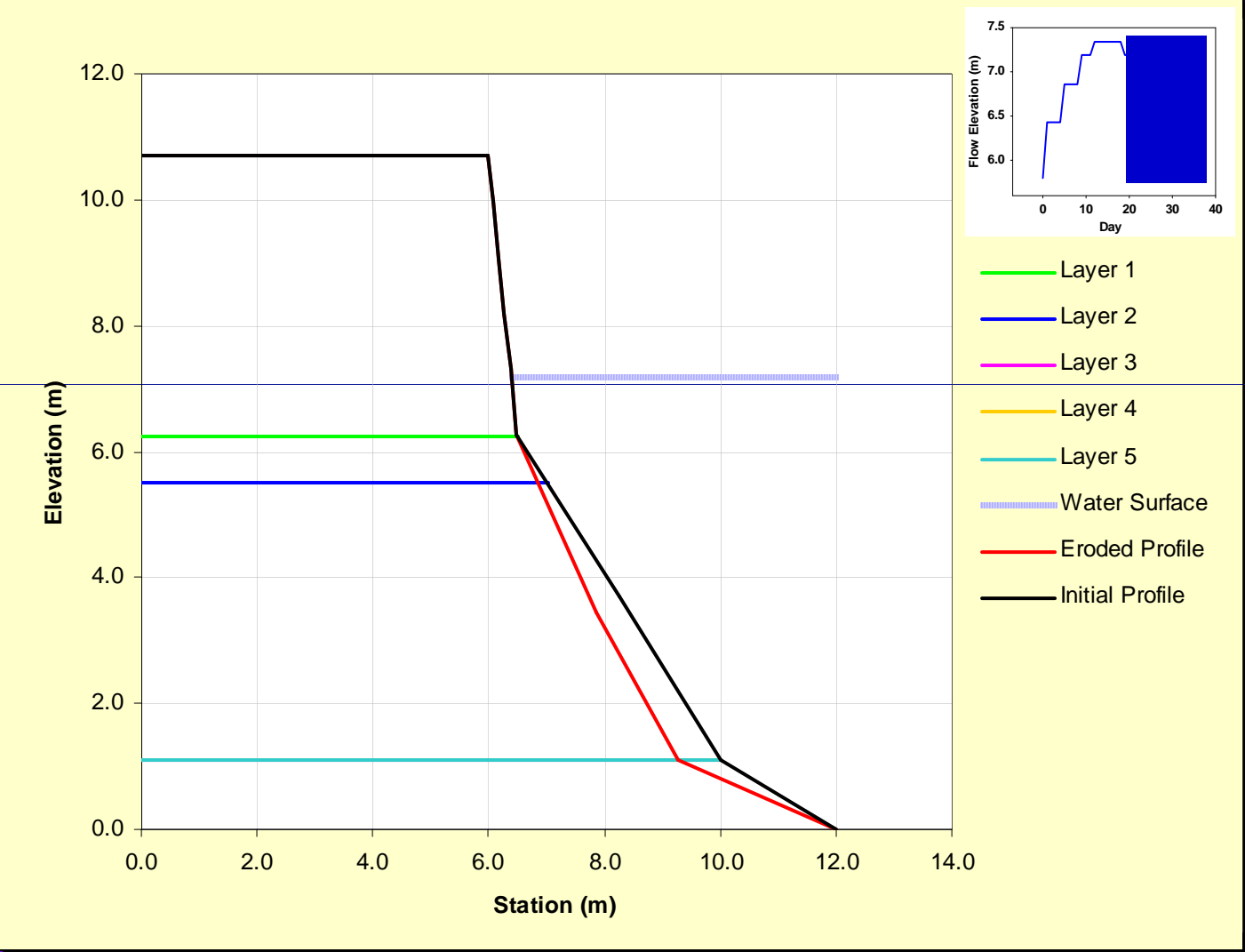


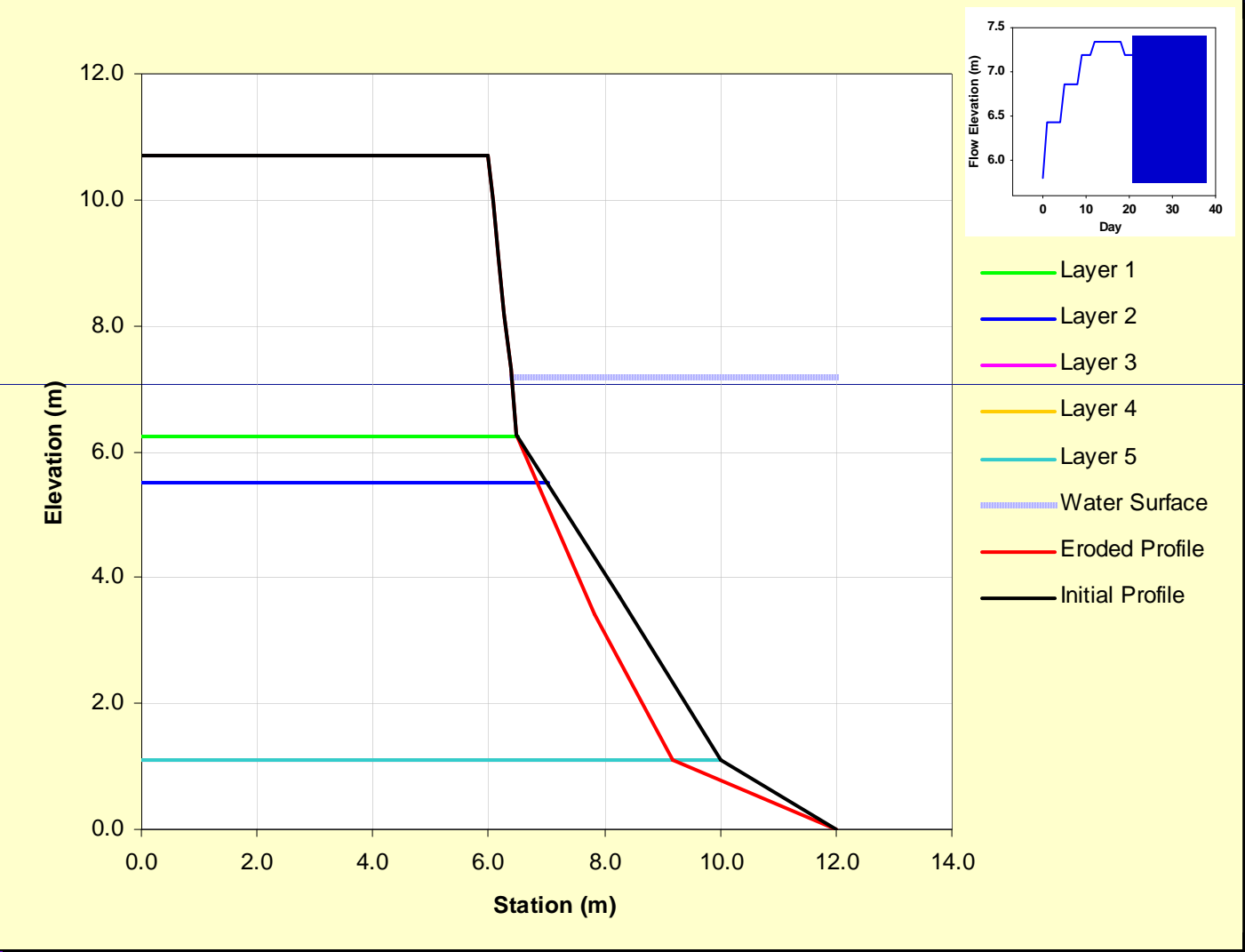


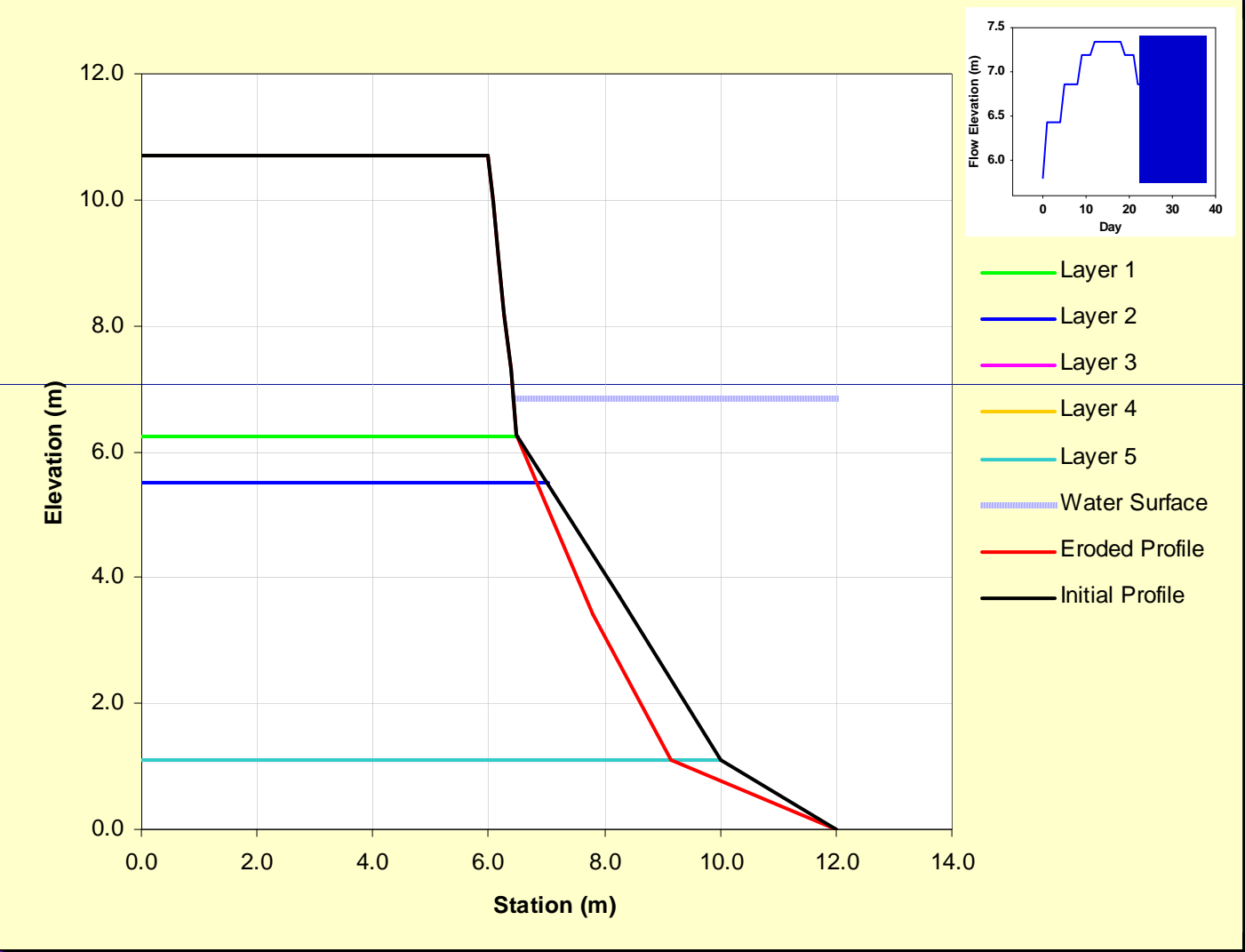


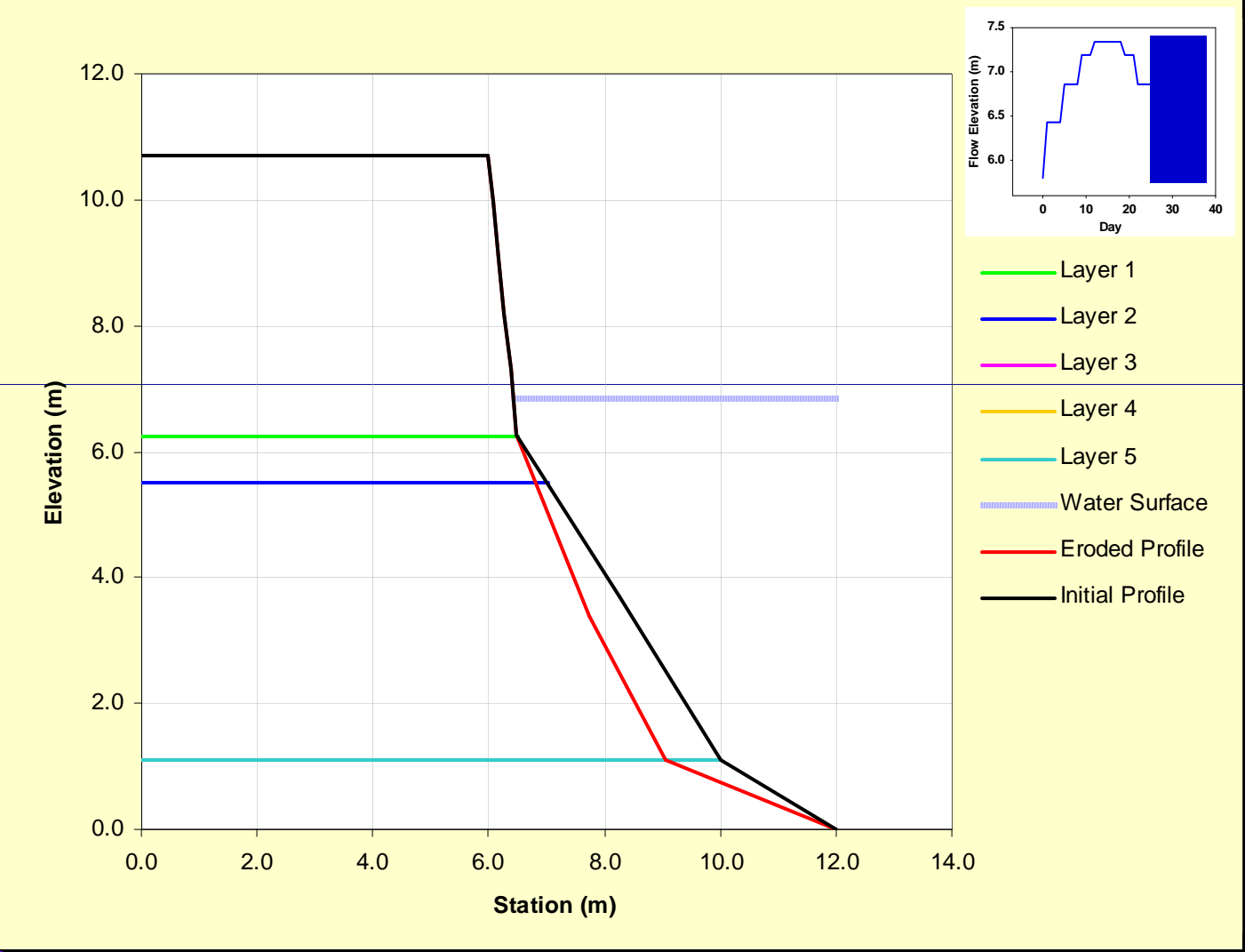


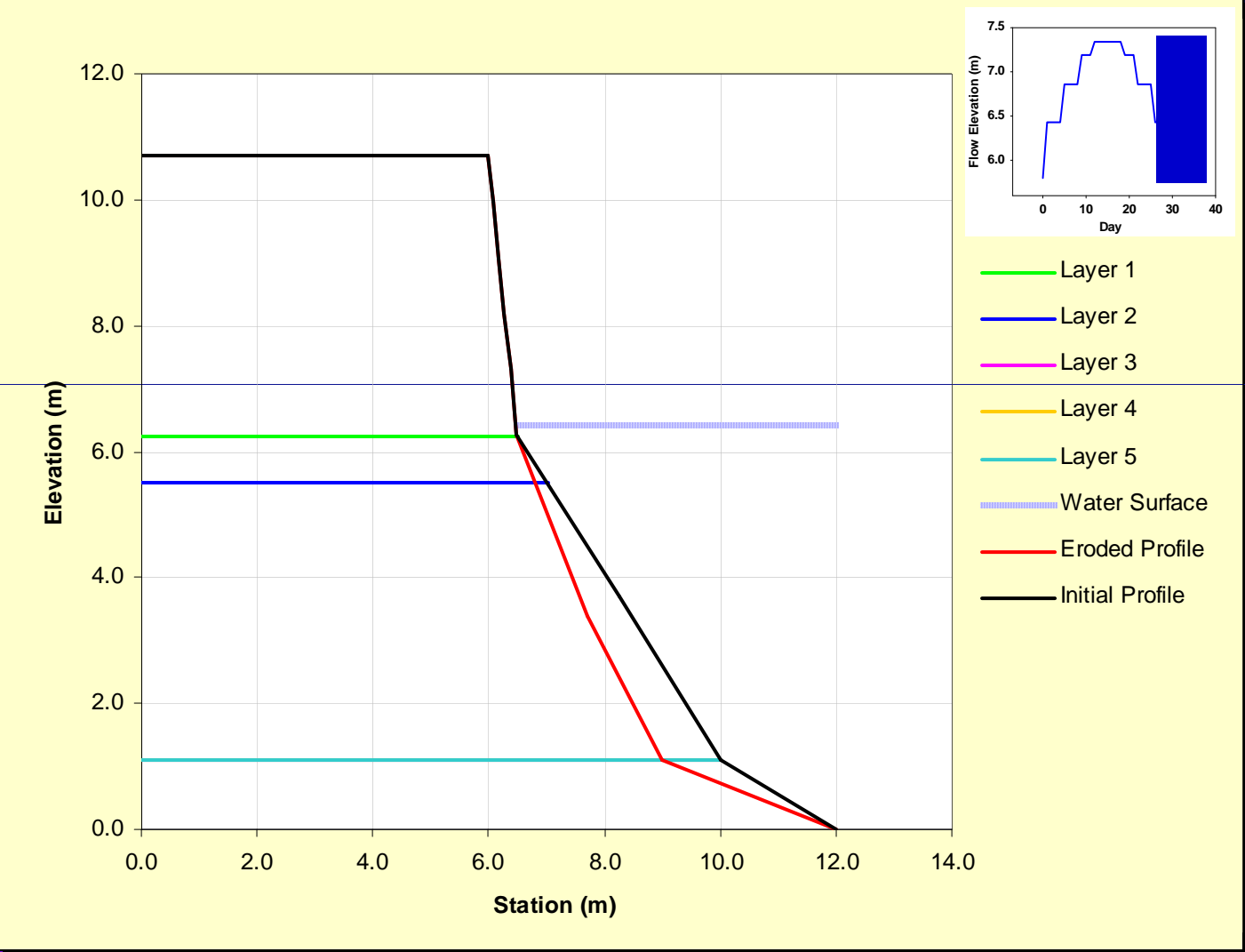


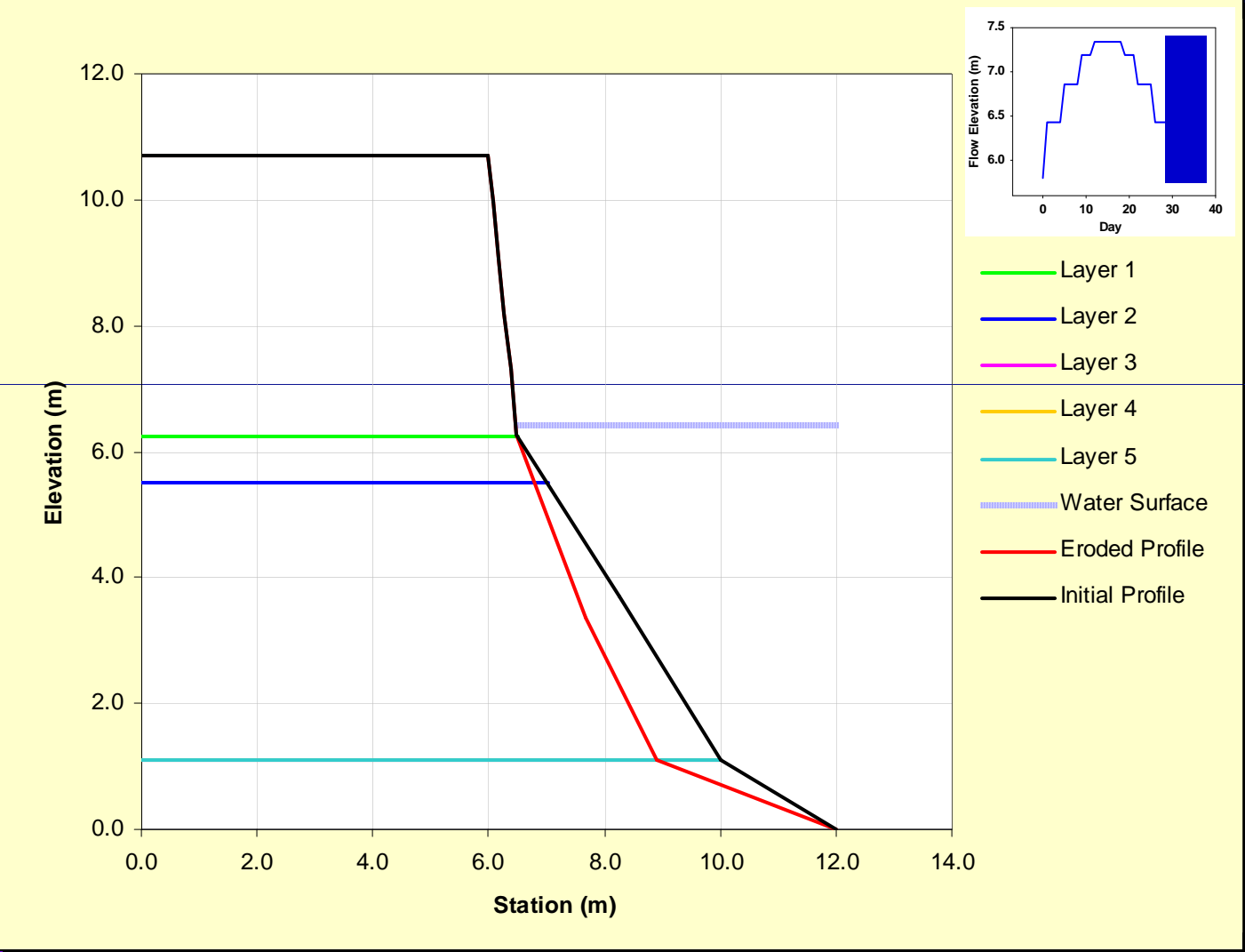




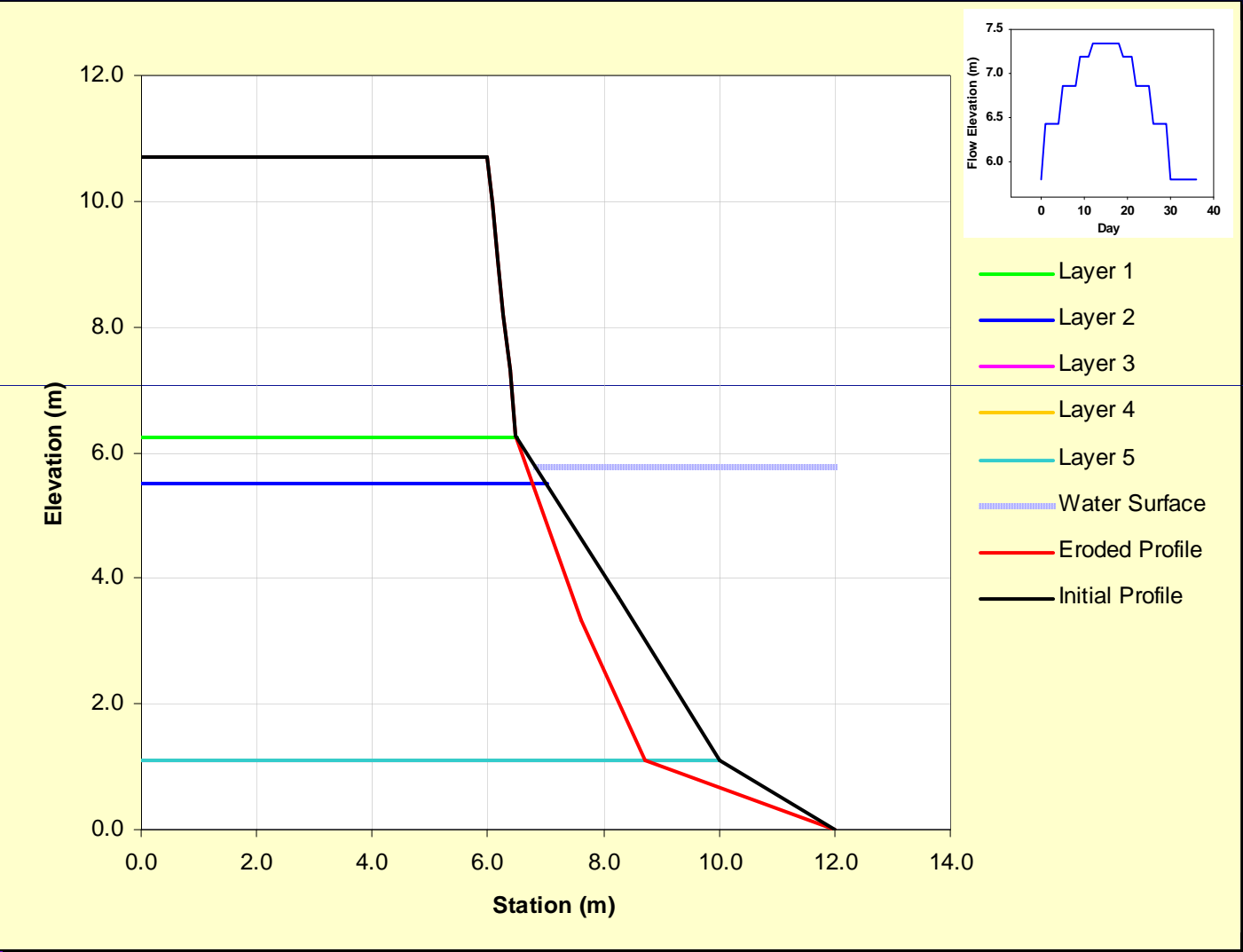






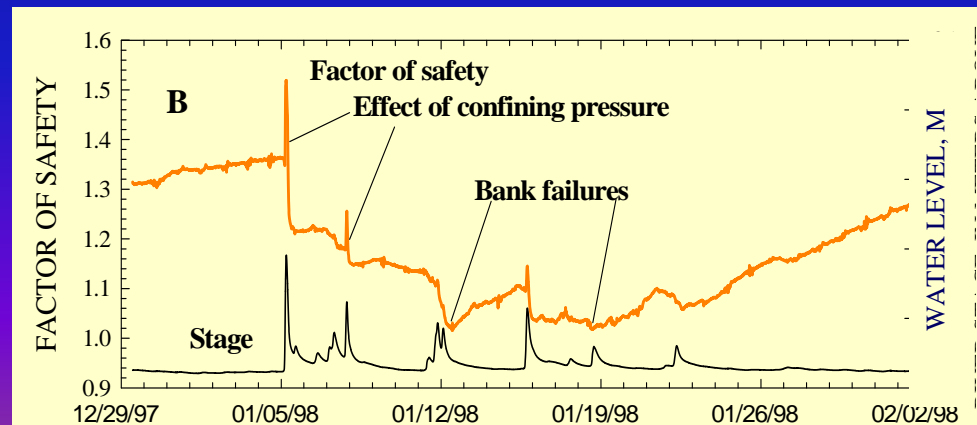
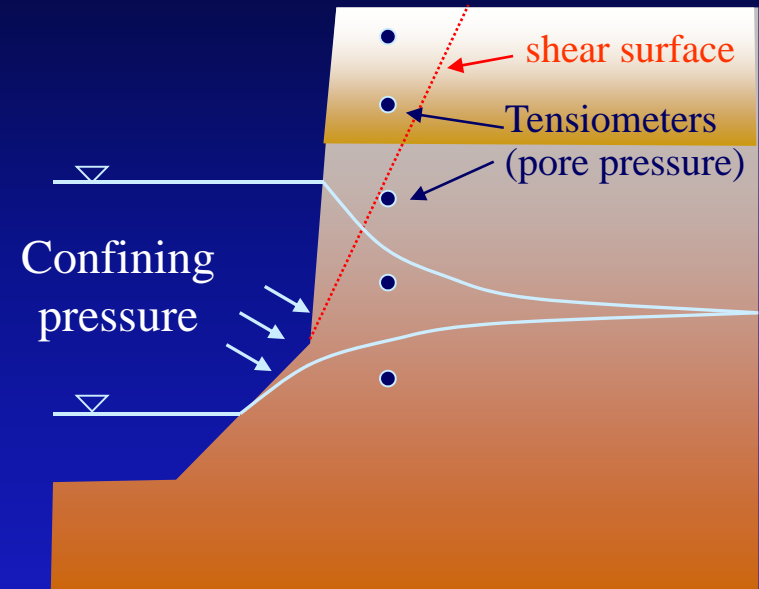






# Bank-Stability Model Version 5.4

- 2-D wedge- and cantilever-failures
- Tension cracks
- Search routine for failures
- Hydraulic toe erosion
- Increased shear in meanders
- Accounts for grain roughness
- Complex bank geometries
- Positive and negative pore-water pressures
- Confining pressure from flow
- Layers of different strength
- Vegetation effects: RipRoot
- Inputs:  $\gamma_s$ ,  $c'$ ,  $\phi'$ ,  $\phi^b$ ,  $h$ ,  $u_w$ ,  
 $k$ ,  $\tau_c$



# Input Geometry Sheet

## Input bank geometry and flow conditions

Work through all 4 sections then hit the "Run Bank Geometry Macro" button.

- 1) Select EITHER Option A or Option B for Bank Profile and enter the data in the relevant box-cells in the alternative option are ignored in the simulation and may be left blank if desired.
- 2) Enter bank material layer thicknesses (if bank is all one material it helps to divide it into several layers).
- 3) If bank is submerged then select the appropriate channel flow elevation to include confining pressure and calculate erosion amount; otherwise set to an elevation below the bank toe. To ensure bank profile is correct you can view it by clicking the "View Bank Geometry" button.

**Option A** - Draw a detailed bank profile using the boxes below

Option A

Point	Station (m)	Elevation (m)	Top of toe?
A	0.00	5.00	<input type="checkbox"/>
B	8.14	5.00	<input type="checkbox"/>
C	8.26	4.68	<input type="checkbox"/>
D	8.37	4.37	<input type="checkbox"/>
E	8.49	4.05	<input type="checkbox"/>
F	8.60	3.74	<input type="checkbox"/>
G	8.72	3.42	<input type="checkbox"/>
H	8.83	3.10	<input type="checkbox"/>
I	8.95	2.79	<input type="checkbox"/>
J	9.06	2.47	<input type="checkbox"/>
K	9.18	2.16	<input type="checkbox"/>
L	9.29	1.84	<input type="checkbox"/>
M	9.41	1.52	<input type="checkbox"/>
N	9.52	1.21	<input type="checkbox"/>
O	9.64	0.89	<input type="checkbox"/>
P	9.75	0.57	<input type="checkbox"/>
Q	9.87	0.26	<input checked="" type="checkbox"/>
R	10.06	0.21	<input type="checkbox"/>
S	10.25	0.16	<input type="checkbox"/>
T	10.45	0.10	<input type="checkbox"/>
U	10.64	0.05	<input type="checkbox"/>
V	10.83	0.00	<input type="checkbox"/>
W	11.83	0.00	<input type="checkbox"/>

**Option B** - Enter a bank height and angle, the model will generate a bank profile

Option B

a) Input bank height (m)

b) Input bank angle (°)

c) Input bank toe length (m)

d) Input bank toe angle (°)

Input shear surface angle

### Bank layer thickness (m)

Layer	Thickness (m)	Elevation of layer base (m)
Layer 1	<input type="text" value="1.00"/>	4.00
Layer 2	<input type="text" value="1.00"/>	3.00
Layer 3	<input type="text" value="1.00"/>	2.00
Layer 4	<input type="text" value="1.00"/>	1.00
Layer 5	<input type="text" value="1.00"/>	0.00

Parallel layers, starting from point B

Shear emergence elev

Shear surface angle

### Channel parameters

Input reach length (m)

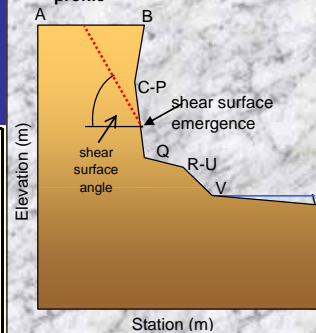
Input reach slope (m/m)

Input concentration (kg/kg)

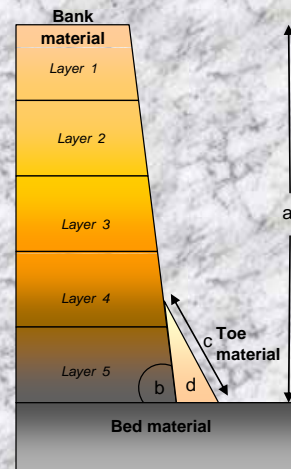
Input elevation of flow (m)

Input duration of flow (hrs)

### Definition of points used in bank profile



- A - bank top: place beyond start of shear surface
- B - bank edge
- C-P - breaks of slope on bank (if no breaks of slope place as intermediary points)
- Q - top of bank toe
- R-U - breaks of slope on bank toe (if no breaks of slope then insert as intermediary points)
- V - base of bank toe
- W - end point (typically mid point of channel)



Notes:  
Bank profile may overhang.  
If the bank profile is fully populated, the shear surface emergence point should be anywhere between points B and Q.  
The shear surface emergence point must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

**View Bank Geometry**

**Run Bank Geometry Macro**

# View Geometry and Select Top of Bank Toe

## Input bank geometry and flow conditions

Work through all 4 sections then hit the "Run Bank Geometry Macro" button.

- 1) Select EITHER Option A or Option B for Bank Profile and enter the data in the relevant box- cells in the alternative option are ignored in the simulation and may be left blank if desired.
  - 2) Enter bank material layer thicknesses (if bank is all one material it helps to divide it into several layers).
  - 3) If bank is submerged then select the appropriate channel flow elevation to include confining pressure and calculate erosion amount; otherwise set to an elevation below the bank toe.
- To ensure bank profile is correct you can view it by clicking the View Bank Geometry button.

**Option A - Draw a detailed bank profile using the boxes below**

Option A

Point	Station (m)	Elevation (m)	Top of toe?
A	0.00	5.00	<input type="checkbox"/>
B	8.14	5.00	<input type="checkbox"/>
C	8.26	4.68	<input type="checkbox"/>
D	8.37	4.37	<input type="checkbox"/>
E	8.49	4.05	<input type="checkbox"/>
F	8.60	3.74	<input type="checkbox"/>
G	8.72	3.42	<input type="checkbox"/>
H	8.83	3.10	<input type="checkbox"/>
I	8.95	2.79	<input type="checkbox"/>
J	9.06	2.47	<input type="checkbox"/>
K	9.18	2.16	<input type="checkbox"/>
L	9.29	1.84	<input type="checkbox"/>
M	9.41	1.52	<input type="checkbox"/>
N	9.52	1.21	<input type="checkbox"/>
O	9.64	0.89	<input type="checkbox"/>
P	9.75	0.57	<input type="checkbox"/>
Q	9.87	0.26	<input checked="" type="checkbox"/>
R	10.06	0.21	<input type="checkbox"/>
S	10.25	0.16	<input type="checkbox"/>
T	10.45	0.10	<input type="checkbox"/>
U	10.64	0.05	<input type="checkbox"/>
V	10.83	0.00	<input type="checkbox"/>
W	11.83	0.00	<input type="checkbox"/>

Shear emergence elev

Shear surface angle

**Option B - Enter a bank height and angle, the model will generate a bank profile**

Option B

a) Input bank height (m)

b) Input bank angle (°)

c) Input bank toe length (m)

d) Input bank toe angle (°)

Input shear surface angle

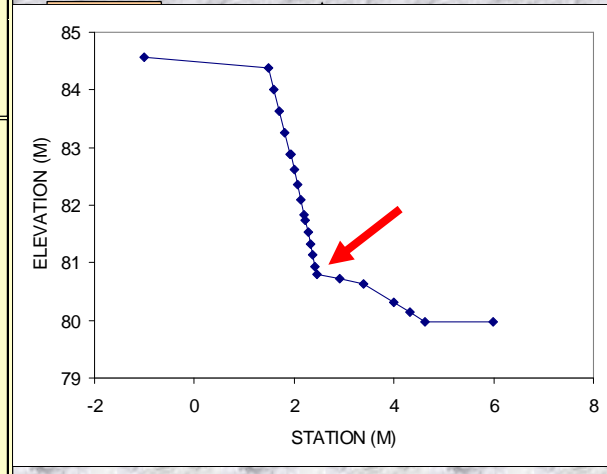
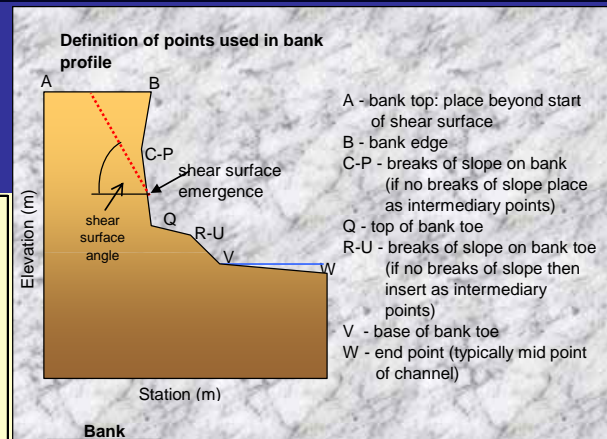
**Bank layer thickness (m)**

Elevation of layer base (m)

Layer	Thickness (m)	Elevation of layer base (m)
Layer 1	<input type="text" value="1.00"/>	4.00
Layer 2	<input type="text" value="1.00"/>	3.00
Layer 3	<input type="text" value="1.00"/>	2.00
Layer 4	<input type="text" value="1.00"/>	1.00
Layer 5	<input type="text" value="1.00"/>	0.00

Parallel layers, starting from point B

Bottom Layer



**Channel parameters**

Input reach length (m)

Input reach slope (m/m)

Input concentration (kg/kg)

Input elevation of flow (m)

Input duration of flow (hrs)

**View Bank Geometry**

**Run Bank Geometry Macro**

# Enter Bank-Layer Thickness

## Input bank geometry and flow conditions

Work through all 4 sections then hit the "Run Bank Geometry Macro" button.

- 1) Select EITHER Option A or Option B for Bank Profile and enter the data in the relevant box-cells in the alternative option are ignored in the simulation and may be left blank if desired.
  - 2) Enter bank material layer thicknesses (if bank is all one material it helps to divide it into several layers).
  - 3) If bank is submerged then select the appropriate channel flow elevation to include confining pressure and calculate erosion amount; otherwise set to an elevation below the bank toe.
- To ensure bank profile is correct you can view it by clicking the View Bank Geometry button.

**Option A** - Draw a detailed bank profile using the boxes below

Option A

Point	Station (m)	Elevation (m)	Top of toe?
A	0.00	5.00	<input type="checkbox"/>
B	8.14	5.00	<input type="checkbox"/>
C	8.26	4.68	<input type="checkbox"/>
D	8.37	4.37	<input type="checkbox"/>
E	8.49	4.05	<input type="checkbox"/>
F	8.60	3.74	<input type="checkbox"/>
G	8.72	3.42	<input type="checkbox"/>
H	8.83	3.10	<input type="checkbox"/>
I	8.95	2.79	<input type="checkbox"/>
J	9.06	2.47	<input type="checkbox"/>
K	9.18	2.16	<input type="checkbox"/>
L	9.29	1.84	<input type="checkbox"/>
M	9.41	1.52	<input type="checkbox"/>
N	9.52	1.21	<input type="checkbox"/>
O	9.64	0.89	<input type="checkbox"/>
P	9.75	0.57	<input type="checkbox"/>
Q	9.87	0.26	<input checked="" type="checkbox"/>
R	10.06	0.21	<input type="checkbox"/>
S	10.25	0.16	<input type="checkbox"/>
T	10.45	0.10	<input type="checkbox"/>
U	10.64	0.05	<input type="checkbox"/>
V	10.83	0.00	<input type="checkbox"/>
W	11.83	0.00	<input type="checkbox"/>

Shear emergence elev   
 Shear surface angle

**Option B** - Enter a bank height and angle, the model will generate a bank profile

Option B

a) Input bank height (m)  
 b) Input bank angle (°)  
 c) Input bank toe length (m)  
 d) Input bank toe angle (°)

Input shear surface angle

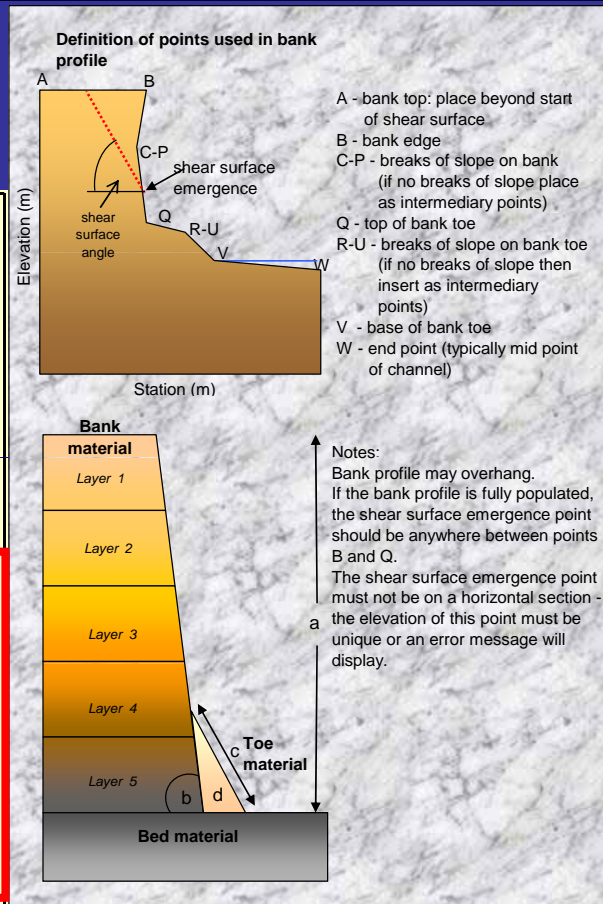
### Bank layer thickness (m)

Layer	Thickness (m)	Elevation of layer base (m)
Layer 1	<input type="text" value="1.00"/>	4.00
Layer 2	<input type="text" value="1.00"/>	3.00
Layer 3	<input type="text" value="1.00"/>	2.00
Layer 4	<input type="text" value="1.00"/>	1.00
Layer 5	<input type="text" value="1.00"/>	0.00

Parallel layers, starting from point B

### Channel parameters

Input reach length (m)  
 Input reach slope (m/m)  
 Input concentration (kg/kg)  
 Input elevation of flow (m)  
 Input duration of flow (hrs)



**View Bank Geometry**

**Run Bank Geometry Macro**



National Sedimentation Laboratory

# Channel and Flow Parameters

## (for Toe- and Total Erosion Calculations)

### Input bank geometry and flow conditions

Work through all 4 sections then hit the "Run Bank Geometry Macro" button.

- 1) Select EITHER Option A or Option B for Bank Profile and enter the data in the relevant box- cells in the alternative option are ignored in the simulation and may be left blank if desired.
- 2) Enter bank material layer thicknesses (if bank is all one material it helps to divide it into several layers).
- 3) If bank is submerged then select the appropriate channel flow elevation to include confining pressure and calculate erosion amount; otherwise set to an elevation below the bank toe.

To ensure bank profile is correct you can view it by clicking the View Bank Geometry button.

**Option A** - Draw a detailed bank profile using the boxes below

Option A

Point	Station (m)	Elevation (m)	Top of toe?
A	0.00	5.00	<input type="checkbox"/>
B	8.14	5.00	<input type="checkbox"/>
C	8.26	4.68	<input type="checkbox"/>
D	8.37	4.37	<input type="checkbox"/>
E	8.49	4.05	<input type="checkbox"/>
F	8.60	3.74	<input type="checkbox"/>
G	8.72	3.42	<input type="checkbox"/>
H	8.83	3.10	<input type="checkbox"/>
I	8.95	2.79	<input type="checkbox"/>
J	9.06	2.47	<input type="checkbox"/>
K	9.18	2.16	<input type="checkbox"/>
L	9.29	1.84	<input type="checkbox"/>
M	9.41	1.52	<input type="checkbox"/>
N	9.52	1.21	<input type="checkbox"/>
O	9.64	0.89	<input type="checkbox"/>
P	9.75	0.57	<input type="checkbox"/>
Q	9.87	0.26	<input checked="" type="checkbox"/>
R	10.06	0.21	<input type="checkbox"/>
S	10.25	0.16	<input type="checkbox"/>
T	10.45	0.10	<input type="checkbox"/>
U	10.64	0.05	<input type="checkbox"/>
V	10.83	0.00	<input type="checkbox"/>
W	11.83	0.00	<input type="checkbox"/>

Shear emergence elev

Shear surface angle

**Option B** - Enter a bank height and angle, the model will generate a bank profile

Option B

a) Input bank height (m)

b) Input bank angle (°)

c) Input bank toe length (m)

d) Input bank toe angle (°)

Input shear surface angle

**Bank layer thickness (m)**

Elevation of layer base (m)

Top Layer

Layer 1  4.00

Layer 2  3.00

Layer 3  2.00

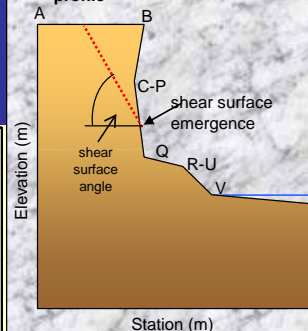
Layer 4  1.00

Layer 5  0.00

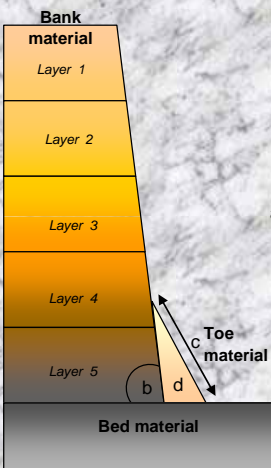
Bottom Layer

Parallel layers, starting from point B

**Definition of points used in bank profile**



- A - bank top: place beyond start of shear surface
- B - bank edge
- C-P - breaks of slope on bank (if no breaks of slope place as intermediary points)
- Q - top of bank toe
- R-U - breaks of slope on bank toe (if no breaks of slope then insert as intermediary points)
- V - base of bank toe
- W - end point (typically mid point of channel)



Notes:

Bank profile may overhang.

If the bank profile is fully populated, the shear surface emergence point should be anywhere between points B and Q.

The shear surface emergence point must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

#### Channel parameters

- Input reach length (m)
- Input reach slope (m/m)
- Input concentration (kg/kg)
- Input elevation of flow (m)
- Input duration of flow (hrs)

**View Bank Geometry**

**Run Bank Geometry Macro**



National Sedimentation Laboratory

# Run Bank Geometry Macro

## Input bank geometry and flow conditions

Work through all 4 sections then hit the "Run Bank Geometry Macro" button.

- 1) Select EITHER Option A or Option B for Bank Profile and enter the data in the relevant box- cells in the alternative option are ignored in the simulation and may be left blank if desired.
- 2) Enter bank material layer thicknesses (if bank is all one material it helps to divide it into several layers).
- 3) If bank is submerged then select the appropriate channel flow elevation to include confining pressure and calculate erosion amount; otherwise set to an elevation below the bank toe.

To ensure bank profile is correct you can view it by clicking the View Bank Geometry button.

**Option A** - Draw a detailed bank profile using the boxes below

Option A

Point	Station (m)	Elevation (m)	Top of toe?
A	0.00	5.00	<input type="checkbox"/>
B	8.14	5.00	<input type="checkbox"/>
C	8.26	4.68	<input type="checkbox"/>
D	8.37	4.37	<input type="checkbox"/>
E	8.49	4.05	<input type="checkbox"/>
F	8.60	3.74	<input type="checkbox"/>
G	8.72	3.42	<input type="checkbox"/>
H	8.83	3.10	<input type="checkbox"/>
I	8.95	2.79	<input type="checkbox"/>
J	9.06	2.47	<input type="checkbox"/>
K	9.18	2.16	<input type="checkbox"/>
L	9.29	1.84	<input type="checkbox"/>
M	9.41	1.52	<input type="checkbox"/>
N	9.52	1.21	<input type="checkbox"/>
O	9.64	0.89	<input type="checkbox"/>
P	9.75	0.57	<input type="checkbox"/>
Q	9.87	0.26	<input checked="" type="checkbox"/>
R	10.06	0.21	<input type="checkbox"/>
S	10.25	0.16	<input type="checkbox"/>
T	10.45	0.10	<input type="checkbox"/>
U	10.64	0.05	<input type="checkbox"/>
V	10.83	0.00	<input type="checkbox"/>
W	11.83	0.00	<input type="checkbox"/>

Shear emergence elev

Shear surface angle

**Option B** - Enter a bank height and angle, the model will generate a bank profile

Option B

a) Input bank height (m)

b) Input bank angle (°)

c) Input bank toe length (m)

d) Input bank toe angle (°)

Input shear surface angle

**Bank layer thickness (m)**

Elevation of layer base (m)

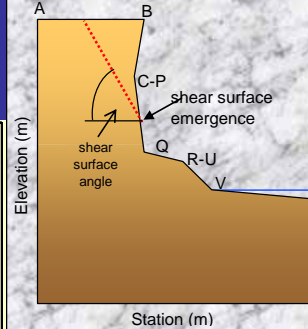
Layer	Thickness (m)	Elevation of layer base (m)
Layer 1	<input type="text" value="1.00"/>	4.00
Layer 2	<input type="text" value="1.00"/>	3.00
Layer 3	<input type="text" value="1.00"/>	2.00
Layer 4	<input type="text" value="1.00"/>	1.00
Layer 5	<input type="text" value="1.00"/>	0.00

Parallel layers, starting from point B

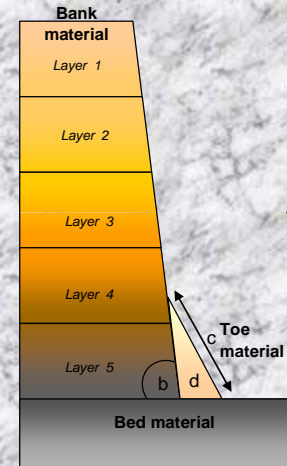
### Channel parameters

- Input reach length (m)
- Input reach slope (m/m)
- Input concentration (kg/kg)
- Input elevation of flow (m)
- Input duration of flow (hrs)

### Definition of points used in bank profile



- A - bank top: place beyond start of shear surface
- B - bank edge
- C-P - breaks of slope on bank (if no breaks of slope place as intermediary points)
- Q - top of bank toe
- R-U - breaks of slope on bank toe (if no breaks of slope then insert as intermediary points)
- V - base of bank toe
- W - end point (typically mid point of channel)



- Notes:
- Bank profile may overhang.
  - If the bank profile is fully populated, the shear surface emergence point should be anywhere between points B and Q.
  - The shear surface emergence point must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

**View Bank Geometry**

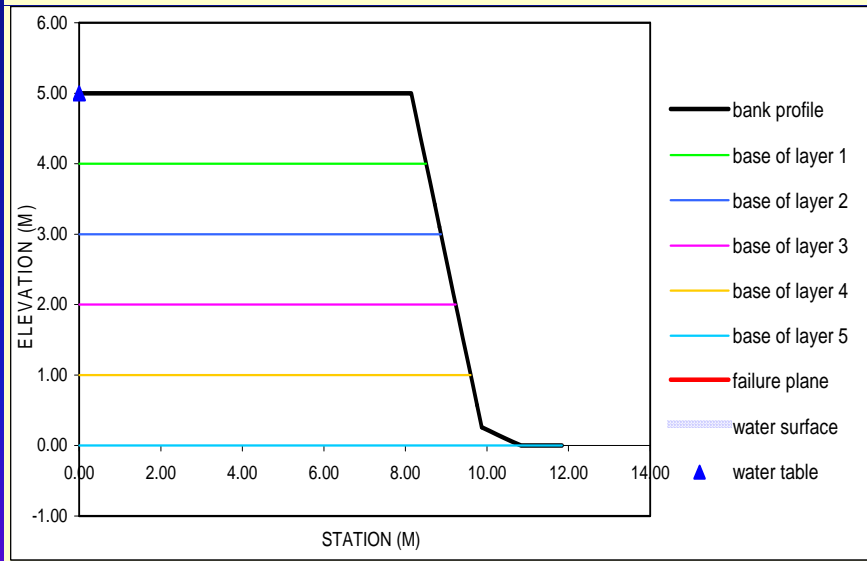
**Run Bank Geometry Macro**

# On Bank-Model Output Page

*(if you want to check layering)*

## Bank model output

Verify the bank material and bank and bank-toe protection information entered in the "Bank Material" and "Bank Vegetation and Protection" worksheets. Once you are satisfied that you have completed all necessary inputs, hit the "Run Bank Stability Model" button (Center of this page).



### Water table depth (m) below bank top

 Use water table

 Input own pore pressures (kPa)

Own Pore  
Pressures

kPa

Pore Pressure From  
Water Table

Layer 1



Layer 2



Layer 3



Layer 4



Layer 5

# Select and Input Bank Materials

Select material types (or select "own data" and add values below)

**Bank Material**

Layer 1: Own data    Layer 2: Own data    Layer 3: Own data    Layer 4: Own data    Layer 5: Own data

**Bank Toe Material**

Own data

Select material types (or select "own data" and add values below)

**Bank Material**

Layer 1: Moderate soft clay    Layer 2: Moderate soft clay    Layer 3: Moderate silt    Layer 4: Erodible silt    Layer 5: Moderate silt

**Bank Toe Material**

Own data

**Hydraulic resistance**

**Bank and bank-toe material data tables.**

These are the default parameters used in the model. Changing the values or descriptions will change the values used when selecting soil types from the list boxes above. Add your own data using the white boxes.

Material Descriptors			Bank Model Input Data				Groundwater Model Input Data						Toe Model Input Data		
Bank material type	Description	Mean grain size, $D_{50}$ (m)	Friction angle $\phi'$ (degrees)	Cohesion $c'$ (kPa)	Saturated unit weight (kN/m <sup>3</sup> )	$\phi^b$ (degrees)	Chemical concentration (kg/kg)	Hydraulic Conductivity $k_{sat}$ (m/s)	Bank Modulus (Pa)	Porosity	Residual water content	van Genuchten $\alpha$ (1/m)	van Genuchten $n$	$\tau_c$ (Pa)	$k$ (cm <sup>3</sup> /Ns)
1	Boulders	0.512	42.0	0.0	20.0	15.0	-	1.745E-03	6.556E+06	0.280	0.090	3.5237	2.3286	498	0.004
2	Cobbles	0.128	42.0	0.0	20.0	15.0	-	1.745E-03	6.556E+06	0.280	0.090	3.5237	2.3286	124	0.009
3	Gravel	0.0113	36.0	0.0	20.0	15.0	-	3.180E-03	1.354E+06	0.280	0.090	3.5237	2.3286	11.0	0.030
4a and 4b	Angular sand	0.00035	36.0	0.0	18.0	15.0	-	7.439E-05	1.354E+07	0.489	0.850	0.6577	1.8786	Coarse (0.71 mm) or Fine (0.18 mm)	
5a and 5b	Rounded sand	0.00035	27.0	0.0	18.0	15.0	-	1.130E-06	6.058E+07	0.280	0.090	3.5237	2.3286	Erodible (0.100 Pa), Moderate (5.00 Pa), or Resistant (50.0 Pa)	
6a, 6b and 6c	Silt	-	30.0	3.0	18.0	15.0	-	5.064E-06	1.049E+07	0.489	0.850	0.6577	1.8786		
7a, 7b and 7c	Soft clay	-	25.0	10.0	18.0	15.0	-	9.479E-07	1.954E+08	0.489	0.850	1.5812	1.4158		
8a, 8b and 8c	Stiff clay	-	20.0	15.0	18.0	15.0	-	1.708E-06	5.417E+06	0.489	0.850	1.4962	1.2531		
9	Own data layer 1														
	Own data layer 2														
	Own data layer 3														
	Own data layer 4														
	Own data layer 5														
	Own data Bank Toe														

**COMING SOON!**

<b>Need to know the critical shear stress (<math>\tau_c</math>) ?</b>	<b>Need to know the erodibility coefficient (<math>k</math>) ?</b>
Input non-cohesive particle diameter (mm) <input type="text"/>	Input critical shear stress $\tau_c$ (Pa) <input type="text"/>
Critical Shear Stress $\tau_c$ (Pa) <input type="text"/>	Erodibility Coefficient (cm <sup>3</sup> /Ns) <input type="text"/>

**Geotechnical resistance**

# Bank Material Sheet: Geotechnical Data

Select material types (or select "own data" and add values below)

## Bank Material

Layer 1 
 Layer 2 
 Layer 3 
 Layer 4 
 Layer 5

### Bank and bank-toe material data tables.

These are the default parameters used in the model. Changing the values or descriptions will change the values used when selecting soil types from the list boxes above. Add your own data using the white boxes.

Material Descriptors			Bank Model Input Data			
Bank material type	Description	Mean grain size, $D_{50}$ (m)	Friction angle $\phi'$ (degrees)	Cohesion $c'$ (kPa)	Saturated unit weight ( $kN/m^3$ )	$\phi^b$ (degrees)
1	Boulders	0.512	42.0	0.0	20.0	5.0
2	Cobbles	0.128	42.0	0.0	20.0	5.0
3	Gravel	0.0113	36.0	0.0	20.0	5.0
4a and 4b	Angular sand	0.00035	36.0	0.0	18.0	15.0
5a and 5b	Rounded sand	0.00035	27.0	0.0	18.0	15.0
6a, 6b and 6c	Silt	-	25.0	5.0	18.0	15.0
7a, 7b and 7c	Soft clay	-	30.0	10.0	16.0	15.0
8a, 8b and 8c	Stiff clay	-	10.0	15.0	18.0	15.0
9	Own data layer 1		<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	Own data layer 2		<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	Own data layer 3		<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	Own data layer 4		<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	Own data layer 5		<input type="text"/>	<input type="text"/>	<input type="text"/>	<input type="text"/>
	Own data Bank Toe					

# Bank Material Sheet: Hydraulic Data

Toe Model Input Data	
$\tau_c$ (Pa)	$k$ (cm <sup>3</sup> /Ns)
498	0.004
124	0.009
11.0	0.030
Coarse (0.71 mm) or Fine (0.18 mm)	
Erodible (0.100 Pa), Moderate (5.00 Pa), or Resistant (50.0 Pa)	
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>
<input type="text"/>	<input type="text"/>

Own data layer 1  
Own data layer 2  
Own data layer 3  
Own data layer 4  
Own data layer 5  
Own data Bank Toe

## Need to know the critical shear stress ( $\tau_c$ ) ?

Input non-cohesive particle diameter (mm)

Critical Shear Stress  $\tau_c$  (Pa)

## Need to know the erodibility coefficient ( $k$ ) ?

Input critical shear stress  $\tau_c$  (Pa)

Erodibility Coefficient (cm<sup>3</sup>/Ns)

# Toe Erosion

Select material types (or select "own data" and add values below)

Bank Material					Bank Toe Material
Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	
Erodible silt	Erodible silt	Erodible silt	Erodible silt	Erodible silt	Erodible silt

For the case: slope = 0.003, flow depth = 2 m; duration = 6 hrs.

## Toe Model Output

Verify the bank material and bank and bank-toe protection information entered in the "Bank Material" and "Bank Vegetation and Protection" worksheets. Once you are satisfied that you have completed all necessary inputs, hit the "Run Shear Stress Macro" button (Center Right of this page).

Bank Material					Bank Toe Material	
Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Material	
Erodible cohesive	Erodible cohesive	Erodible cohesive	Erodible cohesive	Erodible cohesive	Erodible cohesive	Material
0.10	0.10	0.10	0.10	0.10	0.10	Critical shear stress (Pa)
0.316	0.316	0.316	0.316	0.316	0.316	Erodibility Coefficient (cm <sup>3</sup> /Ns)

## Run Toe-Erosion Model

Average applied boundary shear stress		Pa
Maximum Lateral Retreat	0.000	cm
Eroded Area - Bank	0.000	m <sup>2</sup>
Eroded Area - Bank Toe	0.000	m <sup>2</sup>
Eroded Area - Bed	0.000	m <sup>2</sup>
Eroded Area - Total	0.000	m <sup>2</sup>

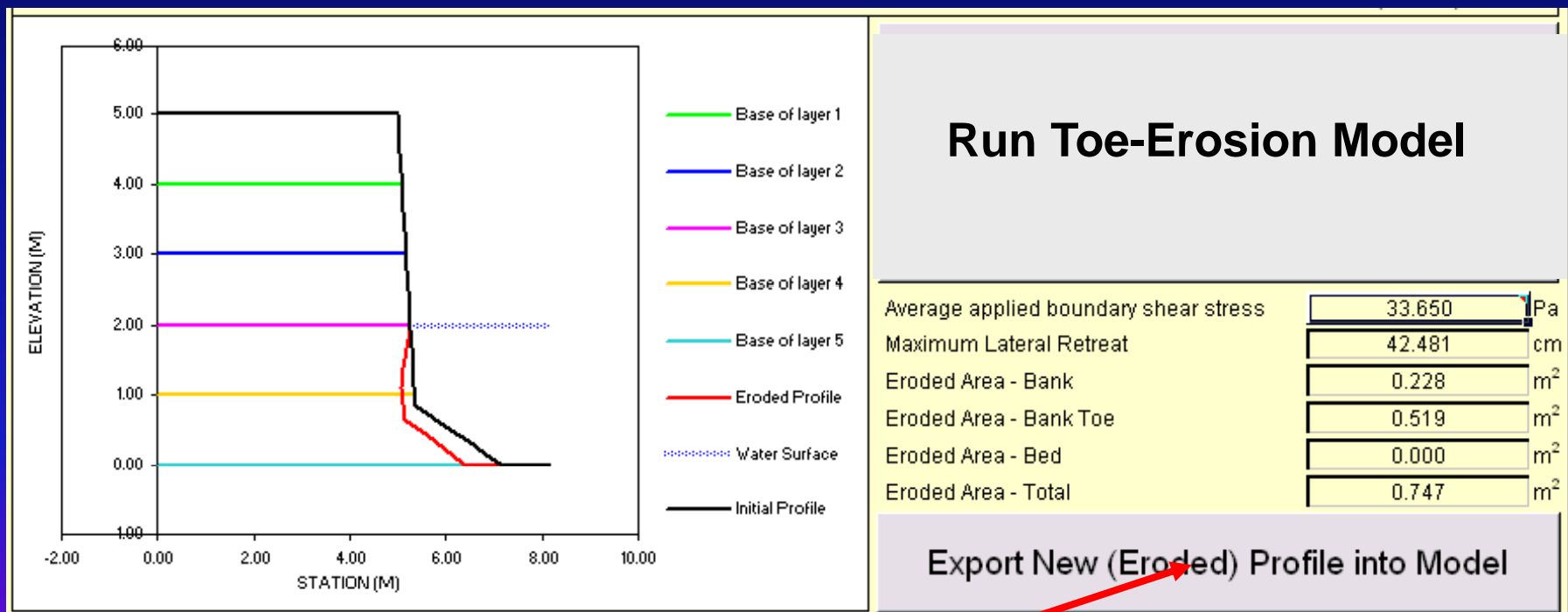
Export New (Eroded) Profile into model

# Toe Erosion

Select material types (or select "own data" and add values below)

Bank Material					Bank Toe Material
Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	
Erodible silt	Erodible silt	Erodible silt	Erodible silt	Erodible silt	Erodible silt

For the case: slope = 0.003, flow depth = 2 m; duration = 6 hrs.



Click this button to export eroded profile to Option A in Input Geometry worksheet

# Profile Exported into Option A

**Option A** - Draw a detailed bank profile using the boxes below

Option A

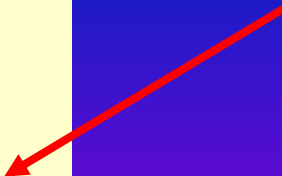
Point	Station (m)	Elevation (m)	Top of toe?
A	0.00	5.00	
B	10.08	5.00	
C	10.16	4.72	<input type="checkbox"/>
D	10.23	4.45	<input type="checkbox"/>
E	10.30	4.17	<input type="checkbox"/>
F	10.38	3.89	<input type="checkbox"/>
G	10.45	3.62	<input type="checkbox"/>
H	10.53	3.34	<input type="checkbox"/>
I	10.60	3.06	<input type="checkbox"/>
J	10.68	2.78	<input type="checkbox"/>
K	10.75	2.51	<input type="checkbox"/>
L	10.82	2.23	<input type="checkbox"/>
M	10.89	1.95	<input type="checkbox"/>
N	10.92	1.66	<input type="checkbox"/>
O	10.91	1.36	<input type="checkbox"/>
P	10.90	1.06	<input type="checkbox"/>
Q	10.97	0.62	<input checked="" type="checkbox"/>
R	11.45	0.44	
S	11.80	0.25	
T	12.15	0.06	
U	12.26	0.00	
V	12.72	0.00	
W	13.76	0.00	

Shear emergence elev

Shear surface angle

**Model redirects you back to the “Input Geometry” sheet. You can run another flow event or run the Bank-Stability model.**

**To run Bank-Stability Model you can select a shear-surface emergence elevation and shear-surface angle or leave blank and search routine will solve.**



# Results: Factor of Safety

Factor of Safety		
1.09	Conditionally stable	
Failure width	2.35	m
Failure volume	487	m <sup>3</sup>
Sediment loading	814176	kg
Constituent load	814	kg

Partly controlled by failure plane angle

Based on reach length

Based on constituent concentration

Select material types, vegetation cover and water table depth below bank top  
(or select "own data" and add values in 'Bank Model Data' worksheet)

Layer 1 Gravel Angular sand Rounded sand Silt Stiff clay	Layer 2 Gravel Angular sand Rounded sand Silt Stiff clay	Layer 3 Gravel Angular sand Rounded sand Silt Stiff clay	Layer 4 Gravel Angular sand Rounded sand Silt Stiff clay	Layer 5 Gravel Angular sand Rounded sand Silt Stiff clay	Bank top vegetation cover (age) None	Reach Length (m) 100	Constituent concentration (kg/kg) 0.001
---	---	---	---	---	---	-------------------------	--

Vegetation safety margin: 50

Water table depth (m) below bank top: 4.00

Own Pore Pressures (kPa): Layer 1: [ ], Layer 2: [ ], Layer 3: [ ], Layer 4: [ ], Layer 5: [ ]

Pore Pressure From Water Table: Layer 1: -34.34, Layer 2: -24.53, Layer 3: -14.72, Layer 4: -4.91, Layer 5: 4.91

Factor of Safety: 1.09 Conditionally stable

Failure width	2.35	m
Failure volume	487	m <sup>3</sup>
Sediment loading	814176	kg
Constituent load	814	kg

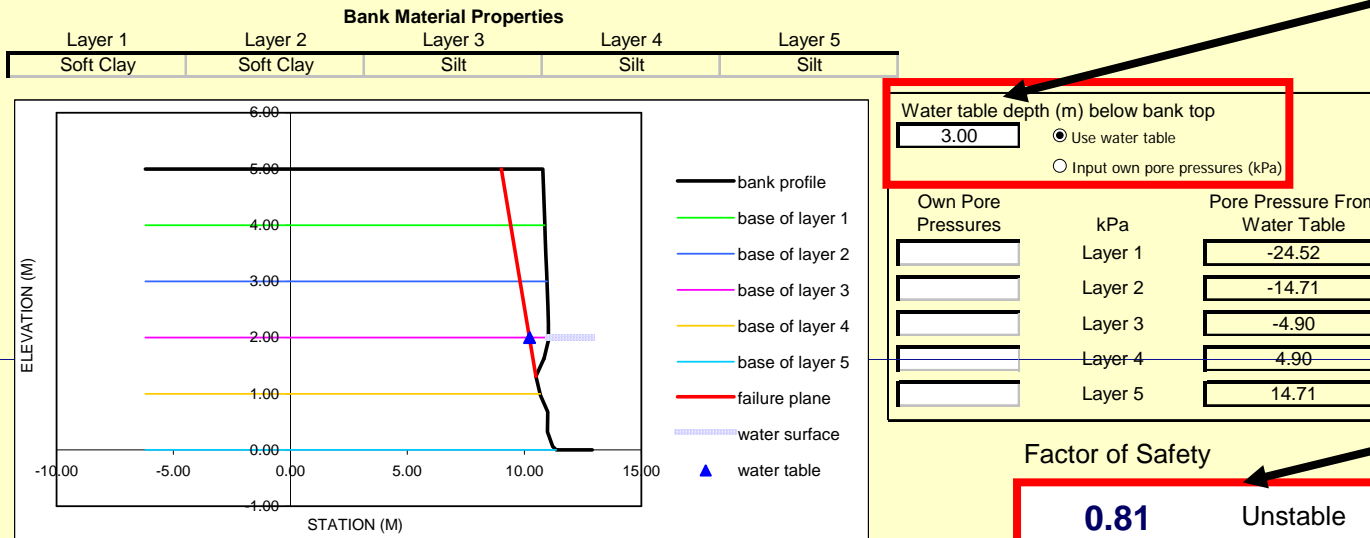
57.5 Shear surface angle used

Export Coordinates back into model

# Bank Model Output

## Bank model output

Verify the bank material and bank and bank-toe protection information entered in the "Bank Material" and "Bank Vegetation and Protection" worksheets. Once you are satisfied that you have completed all necessary inputs, hit the "Run Bank-Stability Model" button.



Water-table depth at 3.0 m

Bank is Unstable

$$F_s < 1.0$$

Run Bank-Stability Model

Click "Run Bank-Stability Model"

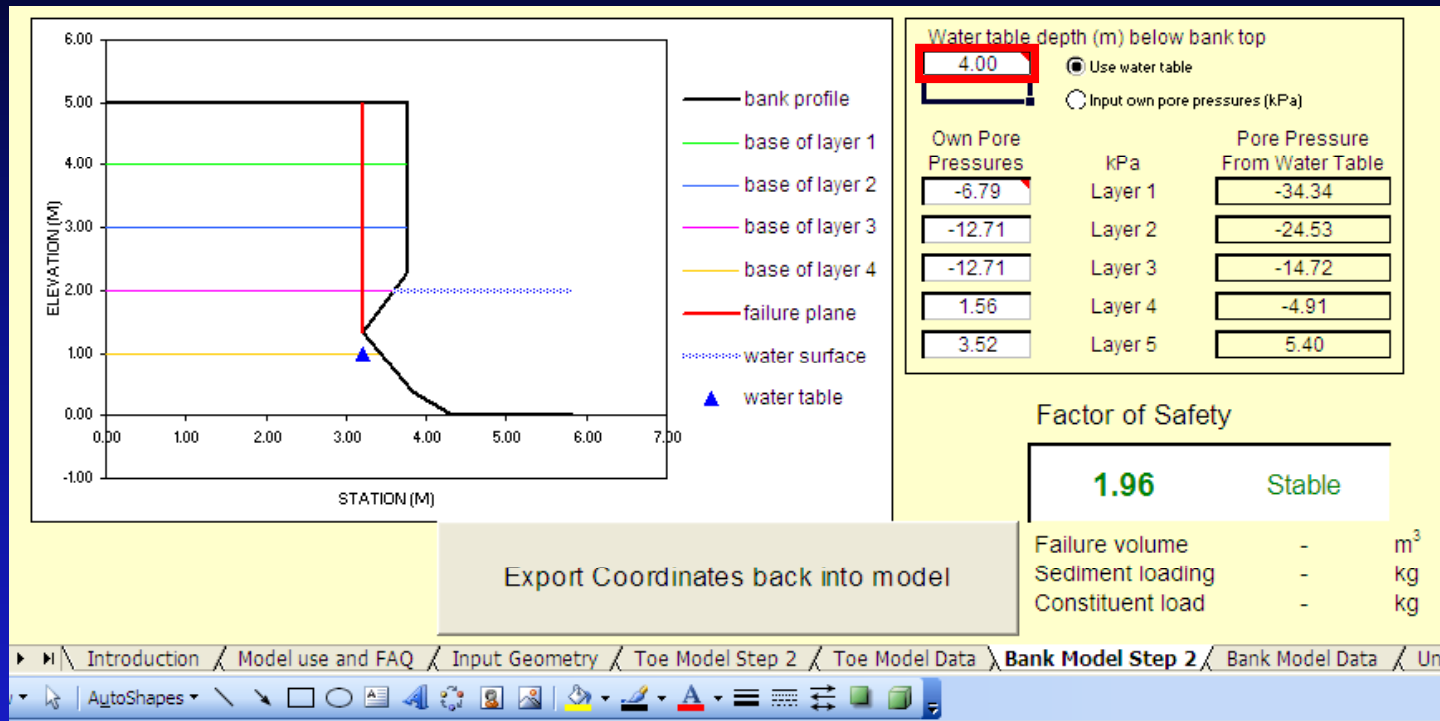
# Bank Model Output: Specific Results

## Failure plane from search routine

## Failure dimensions (loading)

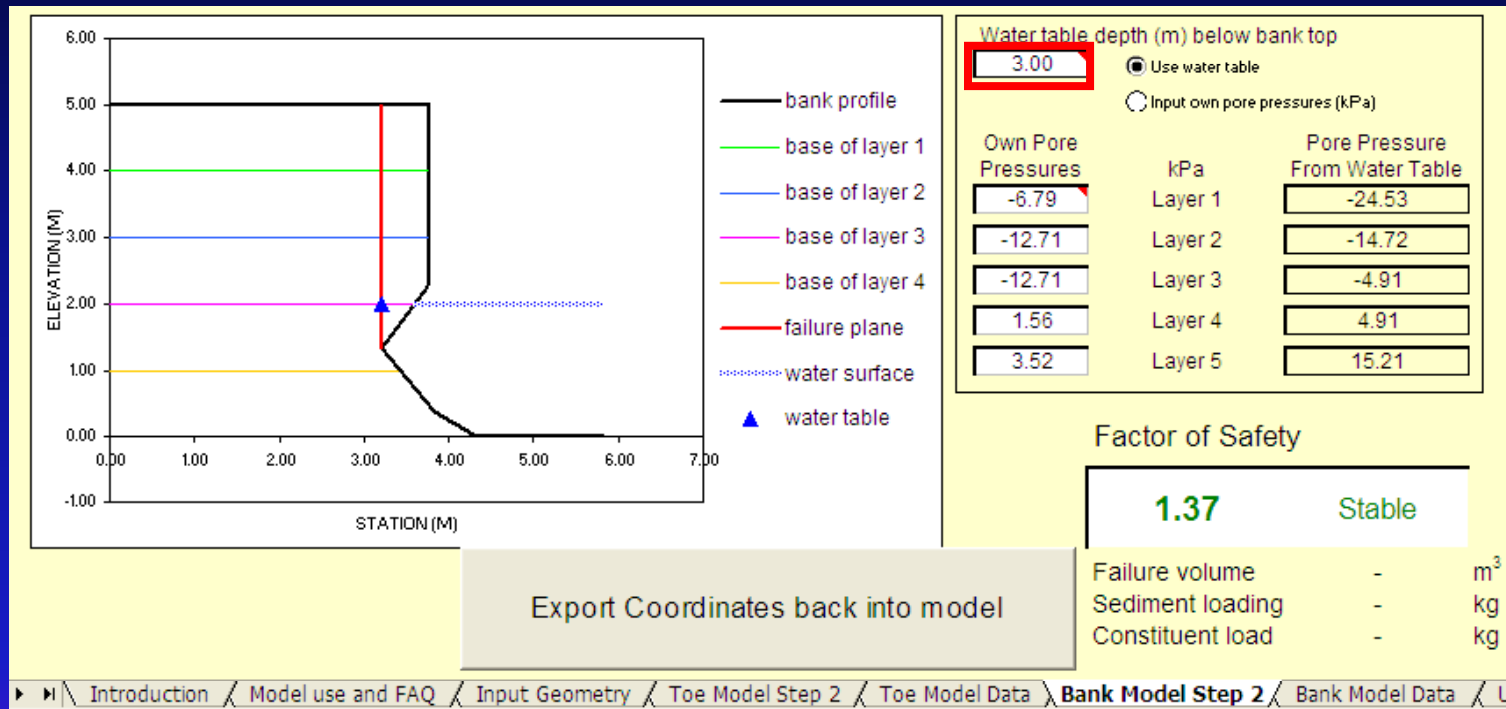
1.3	Shear emergence elevation	Export New (Failed) Profile into Model	Failure width	1.77	m
68.1	Shear surface angle used		Failure volume	422	m <sup>3</sup>
			Sediment loading	674210	kg
			Constituent load	0	kg

# Example With Undercut Toe

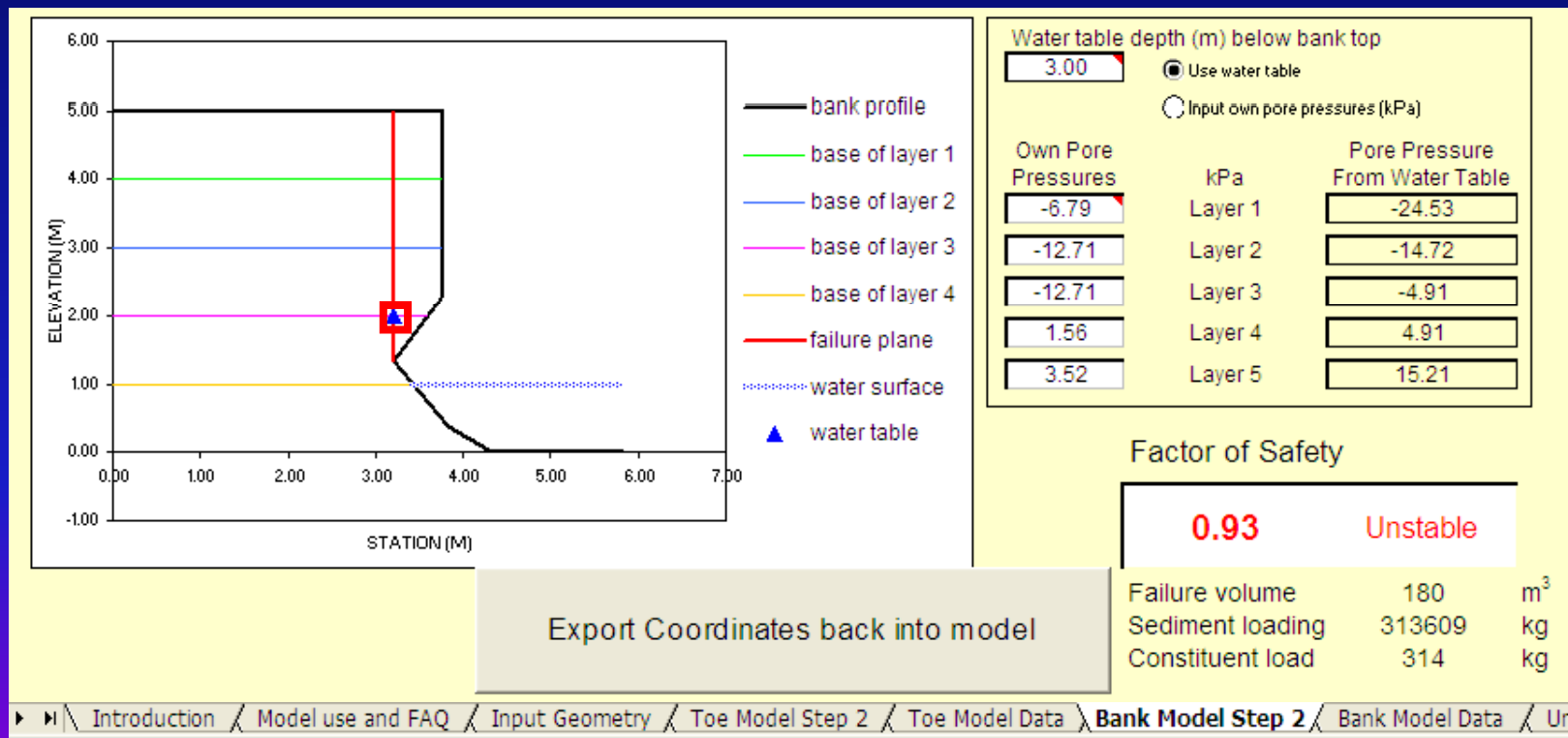


Under these conditions the bank is stable

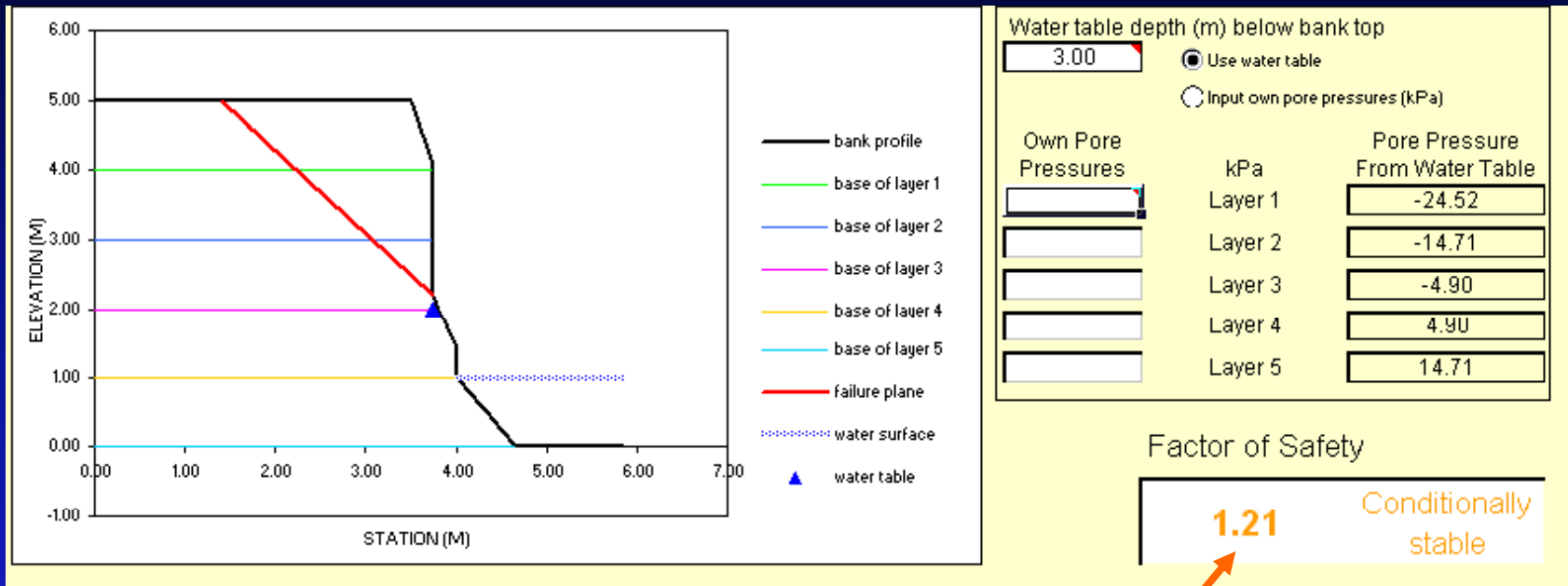
- **Bank stability is reduced, but bank is still stable.**



# Bank is now unstable ( $F_s = 0.93$ ) with loss of confining pressure



# Factor of Safety without tension crack

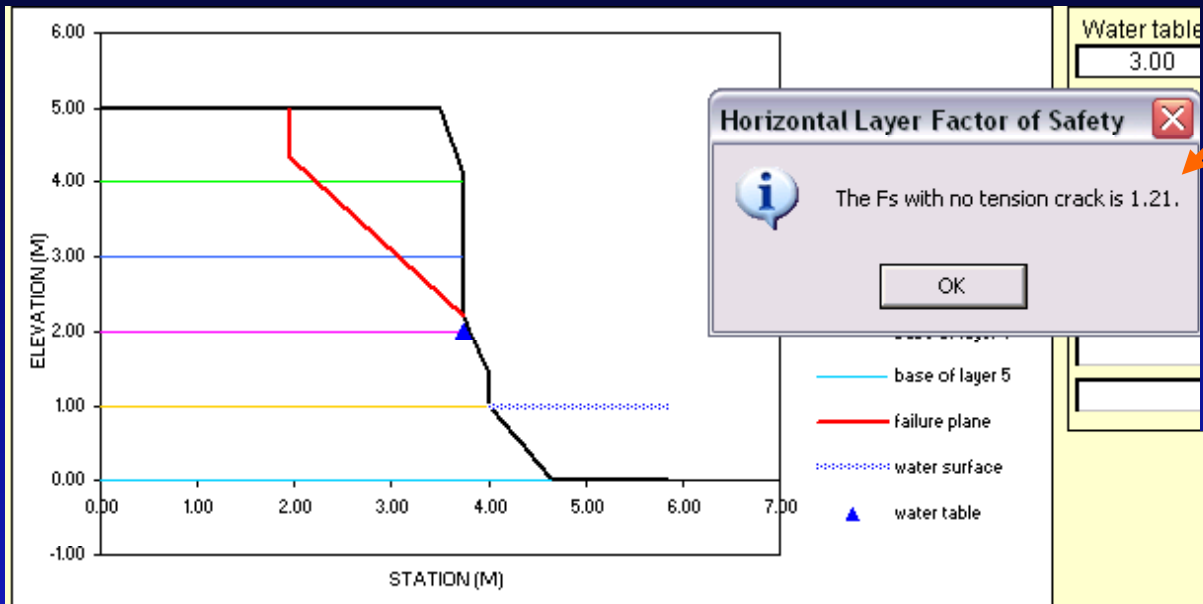


- In this case bank  $F_s$  without a tension crack is 1.21

Failure width	2.10	m
Failure volume	318	m <sup>3</sup>
Sediment loading	543285	kg
Constituent load	0	kg

# Factor of Safety with a tension crack

- Bank  $F_s$  was 1.21 without a tension crack but is 0.99 with a tension crack



Factor of Safety  
**0.99** Unstable

**Run Bank-Stability Model**

2.2 Shear emergence elevation  
50.0 Shear surface angle used

**Export New (Failed) Profile into Model**

Failure width	1.54	m
Failure volume	299	m <sup>3</sup>
Sediment loading	511997	kg
Constituent load	0	kg

# Root Reinforcement using RipRoot

## Simulate the mechanical effects of *bank top* vegetation on bank stability using a root-reinforcement model

RipRoot (Pollen and Simon, 2005) is a global load-sharing fiber-bundle model. It explicitly simulates both the snapping of roots and the slipping of roots through the soil matrix, by determining the minimum applied load required to either break each root or pull each root out of the soil matrix. As the strength of each root is removed from the fiber bundle, the load is redistributed to the remaining roots according to the ratio of the diameter of each root to the sum of the diameters of all the intact roots. RipRoot builds on earlier work by Waldron (1977), Wu *et al.* (1979) and Waldron and Dakessian (1981).

Run  
Root-Reinforcement  
Model

## Root-Reinforcement Model Output

List of Species  
Percent of Assemblage

Added cohesion due to roots,  $c_r$

kPa

## Enter the maximum rooting depth

First, please enter the maximum rooting depth of your vegetation stand, in meters.  
A value of 1.0 m is typical for many riparian environments, except in semi-arid areas where depths may be greater

OK

Cancel

## RipRoot

1. Select the species
2. Select the method to determine the distribution of root diameters
  - Specify plant age and percent contribution to assemblage
  - Input the number of roots in each of seven size classes

### Footnotes:

\* Uses mean growth curve for woody vegetation to estimate root numbers (Pollen-Bankhead and Simon, 2008)

+ Uses growth curve for Alamo Switch Grass to estimate root numbers

\$ Growth curve is a result of combining data from stands of Eastern and Western Cottonwoods

# Root Reinforcement using RipRoot

The screenshot shows the RipRoot software window with the following elements:

- 1. Select the species:** A dropdown menu is set to "Meadow, Wet +".
- 2. Select the method to determine the distribution of root diameters:** Two radio buttons are present. The first, "Specify plant age and percent contribution to assemblage", is selected. It is accompanied by input fields for "7" years and "100" %.
- Input the number of roots in each of seven size classes:** This option is not selected.
- Buttons:** A "Click to add another species" button is on the left. A "Click when you are finished entering assemblage data" button is on the right.
- Status:** The text "You have assembled 100 % of your assemblage" is displayed in the center.
- Footnotes:** Located at the bottom, they include: "\* Uses mean growth curve for woody vegetation to estimate root numbers (Pollen-Bankhead and Simon, 2008)", "+ Uses growth curve for Alamo Switch Grass to estimate root numbers", and "\$ Growth curve is a result of combining data from stands of Eastern and Western Cottonwoods".

## Simple Case: 1 species

1. Select "Meadow, Wet"
2. Enter age and percent contribution to stand
3. Click when finished

# RipRoot: Results

Microsoft Excel - BSTEM 5.1.xls

File Edit View Insert Format Tools Data Window Help Add-In PDF

4 26238935219773

**Simulate the mechanical effects of bank top vegetation on bank stability using a root-reinforcement model**

RipRoot (Pollen and Simon, 2005) is a global load-sharing fiber-bundle model. It explicitly simulates both the snapping of roots and the slipping of roots through the soil matrix, by determining the minimum applied load required to either break each root or pull each root out of the soil matrix. As the strength of each root is removed from the fiber bundle, the load is redistributed to the remaining roots according to the ratio of the diameter of each root to the sum of the diameters of all the intact roots. RipRoot builds on earlier work by Waldron (1977), Wu *et al.* (1979) and Waldron and Dakessian (1981).

**Protect the bank and/or bank-toe against adding treatments (or select "own data")**

**Protection**

Bank Protection: No protection  
Bank Toe: No protection

**Bank and bank-toe protection data table**

These are the default parameters used in the model. Changing the values used when selecting soil types from the list boxes above. Add

Protection type	Description
1	No protection
	Coir fiber
	Geotextile (synthetic)
	Jute net
	Large Woody Debris
	Live fascine
	Plant cuttings
	Rip Rap ( $D_{50}$ 0.256 m)
	-
10	-
11	-
12	-
13	Own Data

**Run Root-Reinforcement Model**

**Root-Reinforcement Model Output**

List of Species: Wet Meadow;  
Percent of Assemblage: 100;

Added cohesion due to roots,  $c_r$ : 4.3 kPa

**References and Data Sources:**

Pollen N. 2007. Temporal and spatial variability in root reinforcement of streambanks: accounting for soil shear strength and moisture. *Catena* 69, 197-205.

Pollen N, Simon A. 2005. Estimating the mechanical effects of riparian vegetation on streambank stability using a fiber bundle model. *Water Resources Research* 41: W07025. DOI: 10.1029/2004WR003801.

Pollen-Bankhead N, Simon A. 2009. Enhanced application of root-reinforcement algorithms for bank stability modeling. *Earth Surface Processes and Landforms* 34(4): 471-480. DOI: 10.1002/esp.1890.

Pollen N, Simon A, Collision AJC. 2004. Advances in assessing the mechanical and hydrologic effects of riparian vegetation on streambank stability. In: *Riparian Vegetation and Fluvial Geomorphology: Water Science and Applications* 8. Bennett S, Simon A (eds). AGU: Washington, DC; 125-139.

**Data Sources:**

Allen HH, Fischenich JC. 1999. *Coir geotextile roll and wetland plant EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-04)*, U.S. Development Center, Vicksburg, MS. (<http://el.erc.usace.army.mil>)

Austin DN, Theisin MS. 1994. BMW extends vegetation performance. *Water Resources Research* 12 (4), 8-16.

Fischenich, C. 2001. *Stability thresholds for stream restoration materials Collection (ERDC TN-EMRRP-SR-29)*, U.S. Army Engineer Research and Development Center, Vicksburg, MS. (<http://el.erc.usace.army.mil>)

Gray DH, Sotir RD. 1996. *Geotechnical and soil bioengineering: a practical approach*. Wiley & Sons, New York.

**Output**

Additional cohesion according to RipRoot = 4.26  
Additional cohesion according to Wu et al (1979) = 9.4

OK

**Root-Reinforcement Model Output**

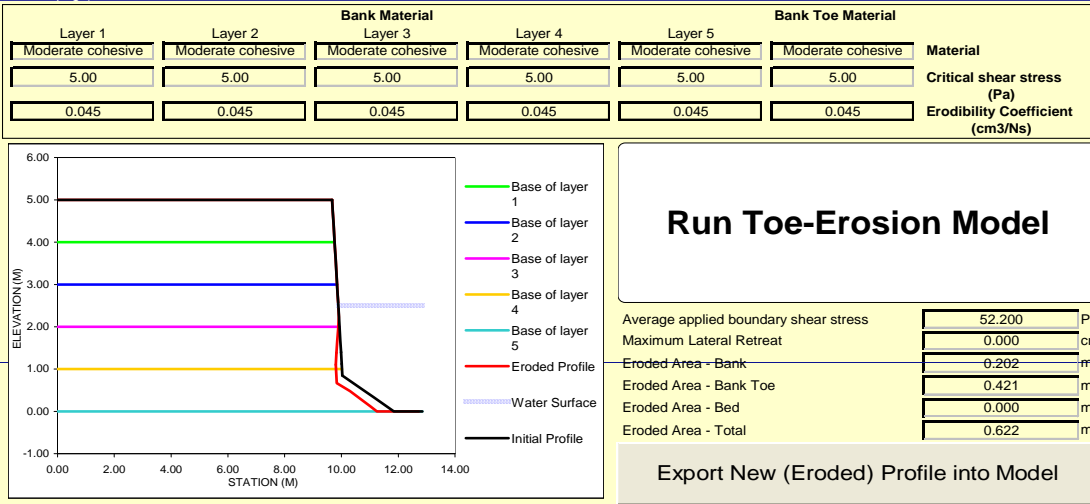
List of Species: Wet Meadow;  
Percent of Assemblage: 100;

Added cohesion due to roots,  $c_r$ : 4.3 kPa

# Evaluating the Role of Toe Protection

## Toe Model Output

Verify the bank material and bank and bank-toe protection information entered in the "Bank Material" and "Bank Vegetation and Protection" worksheets. Once you are satisfied that you have completed all necessary inputs, hit the "Run Toe-Erosion Model" button (Center Right of this page).



**Slope = 0.0035 m/m**

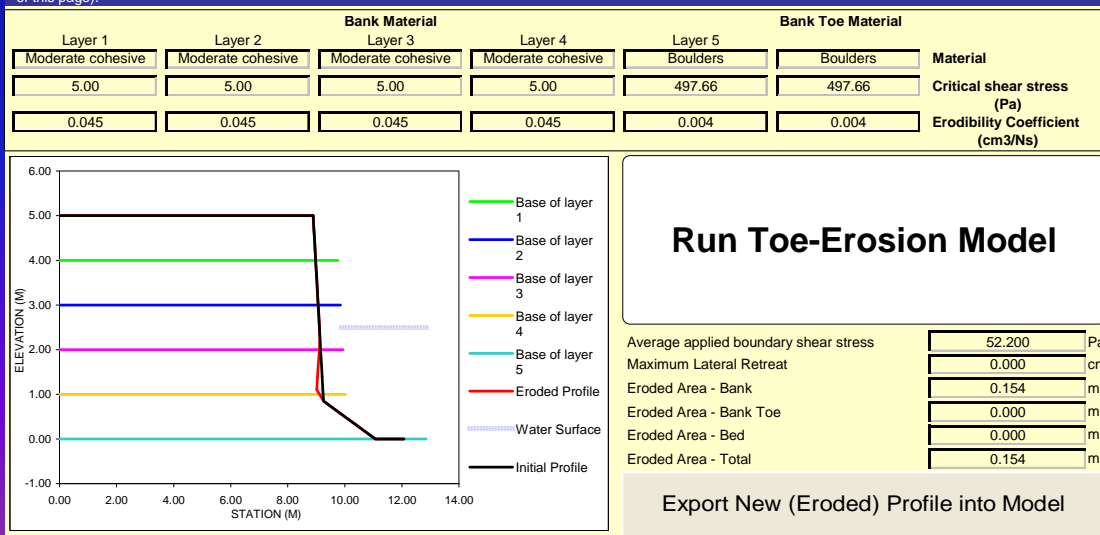
**Depth = 2.5 m**

**Toe material: silt**

**Eroded: 0.65 m<sup>2</sup>**

## Toe Model Output

Verify the bank material and bank and bank-toe protection information entered in the "Bank Material" and "Bank Vegetation and Protection" worksheets. Once you are satisfied that you have completed all necessary inputs, hit the "Run Toe-Erosion Model" button (Center Right of this page).



**Slope = 0.0035 m/m**

**Depth = 2.5 m**

**Toe material: rip rap**

**Eroded: 0.18 m<sup>2</sup>**

# Summary

- The Bank-Stability and Toe-Erosion Model is a simple spreadsheet tool that can be populated with field or default values
- It can be used to test the effects of hydraulic scour, water-table height, vegetation, and stage on stability
- Used iteratively with a knowledge of the flow regime, it can be used to predict widening rates.
- It can be used to test various mitigation strategies (rock, vegetation, etc.) to control undercutting and mass failure.
- It also contains sound effects for bank collapse!