# Bank-Stability and Toe-Erosion Model

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USDA

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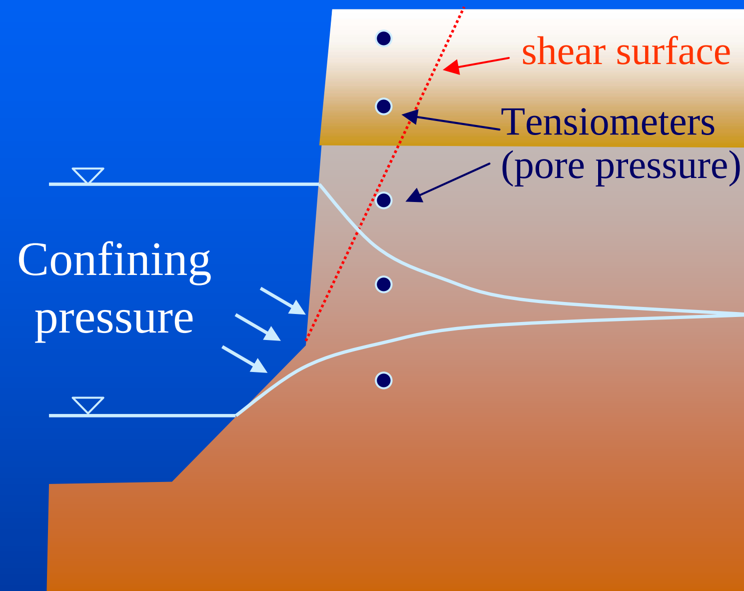
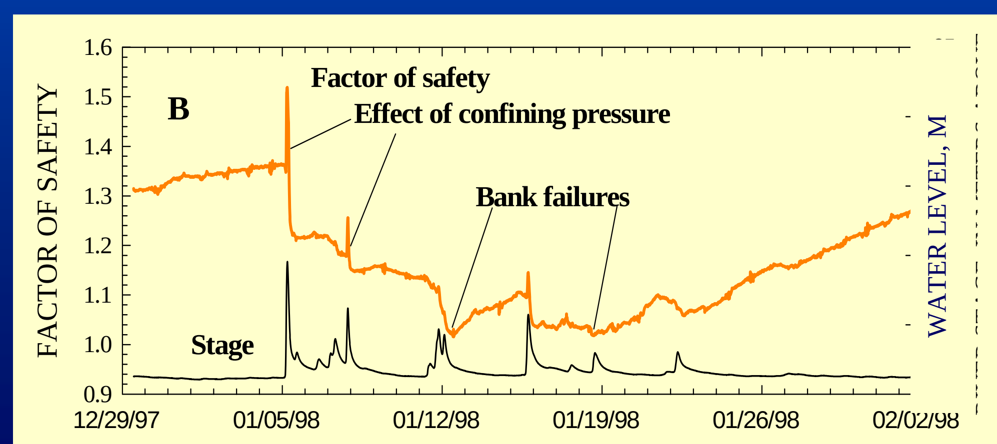
# Bank-Stability Model Version 5.0

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



# Web Address

http://www.ars.usda.gov/Research/docs.htm?docid=5044

# Model Structure

- **Introduction page**: provides general background

- **Technical Background page**: provides equations for stability analysis including positive and negative pore-water pressures, effects of vegetation, and the toe-erosion algorithm.

- **Model Use and FAQ page**: provides methodology for application of model features including hints for working with bank geometry, selecting the shear surface, soil layers, pore-water pressure/water table, vegetation, and the toe-erosion algorithm.

# Model Structure (cont'd)

- **Input Geometry page**: Enter coordinates for bank profile, soil layer thickness, and flow parameters..
- **Bank Material page**: Enter bank-material properties (geotechnical and hydraulic)
- **Bank Vegetation and Protection** page: Run root reinforcement (RipRoot) model and to input default values of bank and toe protection.
- **Bank Model Output page**: Enter water-table depth and obtain results.

# Model Structure (cont’d)

- **Toe Model Output page**: Run shear stress macro and obtain toe-erosion results.
- **Unit Converter page**: Imperial (English) to metric units

# Modeling Steps

- Model the current bank profile by first evaluating the effect of hydraulic erosion at the bank toe.
- Take the resulting new profile and run this in the bank-stability model to see if the eroded bank is stable.
- Investigate the effects of water-table elevation, stage, tension cracks, vegetation, and toe protection.

# Operational Steps

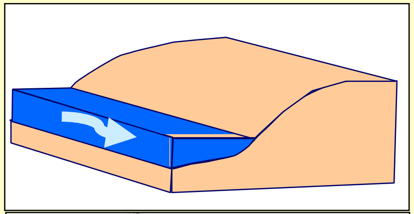
1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet

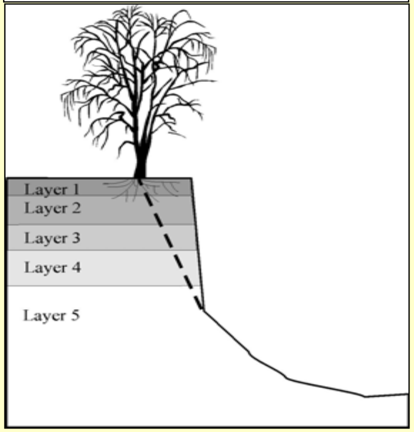
# Introduction Sheet

## Bank Stability and Toe Erosion Model

**Static Version 5.0**

### Bank Stability Model






The Bank Stability Model combines three limit equilibrium-method models that calculate Factor of Safety (*Fs*) for multi-layer streambanks. The methods simulated are horizontal layers (Simon *et al*., 2000), vertical slices with tension crack (Morgenstern and Price, 1965) and cantilever failures (Thorne and Tovey, 1981). The model can easily be adapted to incorporate the effects of geotextiles or other bank stabilization measures that affect soil strength.

The model accounts for the strength of up to five soil layers, the effect of pore-water pressure (both positive and negative (matric suction)), confining pressure due to streamflow and soil reinforcement and surcharge due to vegetation.

Input the bank coordinates (**Input Geometry**) and run the geometry macro to set up the bank profile, then input your soil types, vegetation cover and water table or pore-water pressures (**Bank Material**, **Bank Vegetation and Protection** and **Bank Model Output**) to find *Fs*.

The bank is said to be 'stable' if *Fs* is greater than 1.3, to provide a safety margin for uncertain or variable data. Banks with a *Fs* value between 1.0 and 1.3 are said to be 'conditionally stable', i.e. stable but with little safety margin. Slopes with an *Fs* value less than 1.0 are unstable.

This version of the model assumes hydrostatic conditions below the water table, and a linear interpolation of matric suction above the water table (unless the user's own pore-water pressure data are used).

The model can either use estimated input data where no field data are available or as a first pass solution, or can be set to run using your own data. Your own data can be added to white boxes. Don't change values in yellow boxes - they are output.

### Bank Toe Erosion Model

The Bank Toe Erosion Model can be used as a tool for making reasonably informed estimates of hydraulic erosion of the bank and bank toe by hydraulic shear stress. The model is primarily intended for use in studies where bank toe erosion threatens bank stability. The effects of erosion protection on the bank and toe can be incorporated to show the effects of erosion control measures.

The model estimates boundary shear stress from channel geometry, and considers critical shear stress and erodibility of two separate zones with potentially different materials: the bank and bank toe; the bed elevation is assumed to be fixed. This is because the model assumes that erosion is not transport limited and does not incorporate, in any way, the simulation of sediment transport.

# Operational Steps

1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet

# 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 | | | |
| B | | | |
| C | | | ☐ |
| D | | | ☐ |
| E | | | ☐ |
| F | | | ☐ |
| G | | | ☐ |
| H | | | ☐ |
| I | | | ☐ |
| J | | | ☐ |
| K | | | ☐ |
| L | | | ☐ |
| M | | | ☐ |
| N | | | ☐ |
| O | | | ☐ |
| P | | | ☐ |
| Q | | | |
| R | | | |
| S | | | |
| T | | | |
| U | | | |
| V | | | |
| W | | | |

Shear emergence elev [ ]

Shear surface angle [ ]

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

◉ Option B

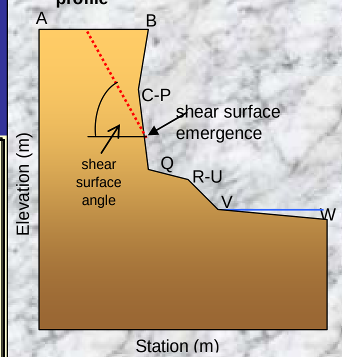
| Value | Parameter |
|---|---|
| 5.0 | a) Input bank height (m) |
| 85.0 | b) Input bank angle ($^o$) |
| 1.0 | c) Input bank toe length (m) |
| 25.0 | d) Input bank toe angle ($^o$) |
| | Input shear surface angle |

**Bank layer thickness (m)**

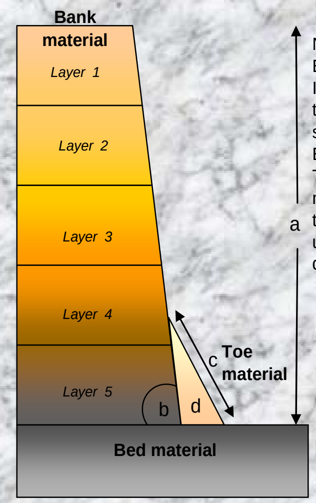
Parallel layers, starting from point B (Top Layer → Bottom Layer)

| Layer | Thickness | Elevation of layer base (m) |
|---|---|---|
| Layer 1 | | 5.00 |
| Layer 2 | | 5.00 |
| Layer 3 | | 5.00 |
| Layer 4 | | 5.00 |
| Layer 5 | | 5.00 |

**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**

# Operational Steps

1. Open Excel file "BSTEM-5.0"
2. Click on "Enable Macros"…to "Introduction" sheet
3. Click on "Input Geometry" sheet
4. Select EITHER Option *A* or Option *B* for bank geometry and input geometry data. For this first example select Option *B*.

# 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 | | | |
| B | | | |
| C | | | ☐ |
| D | | | ☐ |
| E | | | ☐ |
| F | | | ☐ |
| G | | | ☐ |
| H | | | ☐ |
| I | | | ☐ |
| J | | | ☐ |
| K | | | ☐ |
| L | | | ☐ |
| M | | | ☐ |
| N | | | ☐ |
| O | | | ☐ |
| P | | | ☐ |
| Q | | | ☐ |
| R | | | |
| S | | | |
| T | | | |
| U | | | |
| V | | | |
| W | | | |

Shear emergence elev

Shear surface angle

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

◉ Option B

5.0 a) Input bank height (m)

85.0 b) Input bank angle ($^o$)

1.0 c) Input bank toe length (m)

25.0 d) Input bank toe angle ($^o$)

Input shear surface angle

**Bank layer thickness (m)**

Elevation of layer base (m)

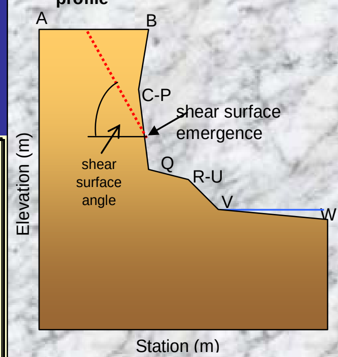
Top Layer

| | Thickness | Elevation of layer base (m) |
|---|---|---|
| Layer 1 | | 5.00 |
| Layer 2 | | 5.00 |
| Layer 3 | | 5.00 |
| Layer 4 | | 5.00 |
| Layer 5 | | 5.00 |

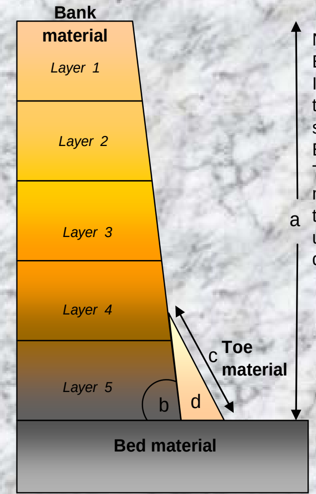
Bottom Layer

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)

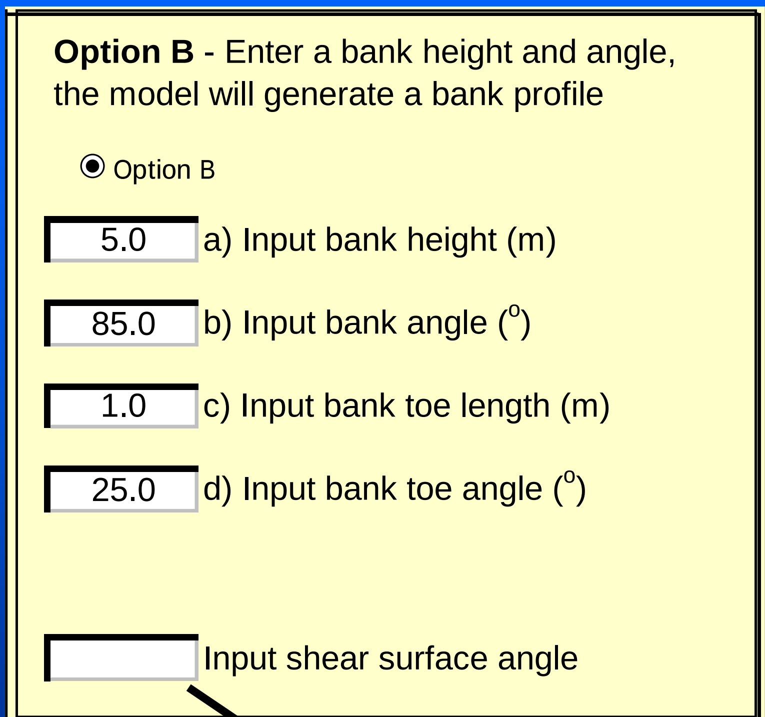
Input elevation of flow (m)

Input duration of flow (hrs)

**View Bank Geometry**

**Run Bank Geometry Macro**

# Starting with Option *B*




**Select: Option B**

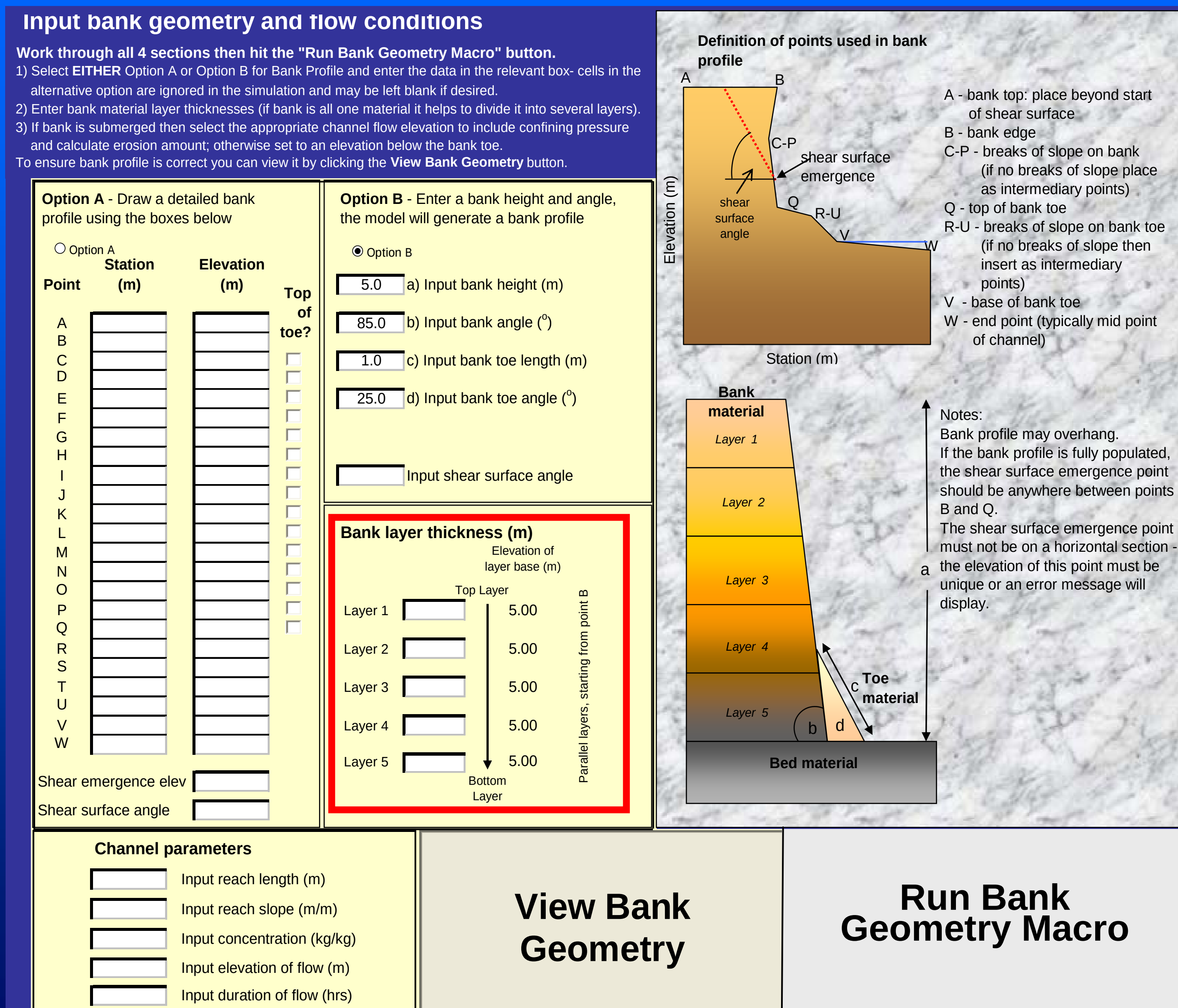
- **5m high bank**
- **85 degree angle**
- **1m toe length**
- **25 degree toe angle**

If you don't know failure-plane angle, search routine will solve for it.

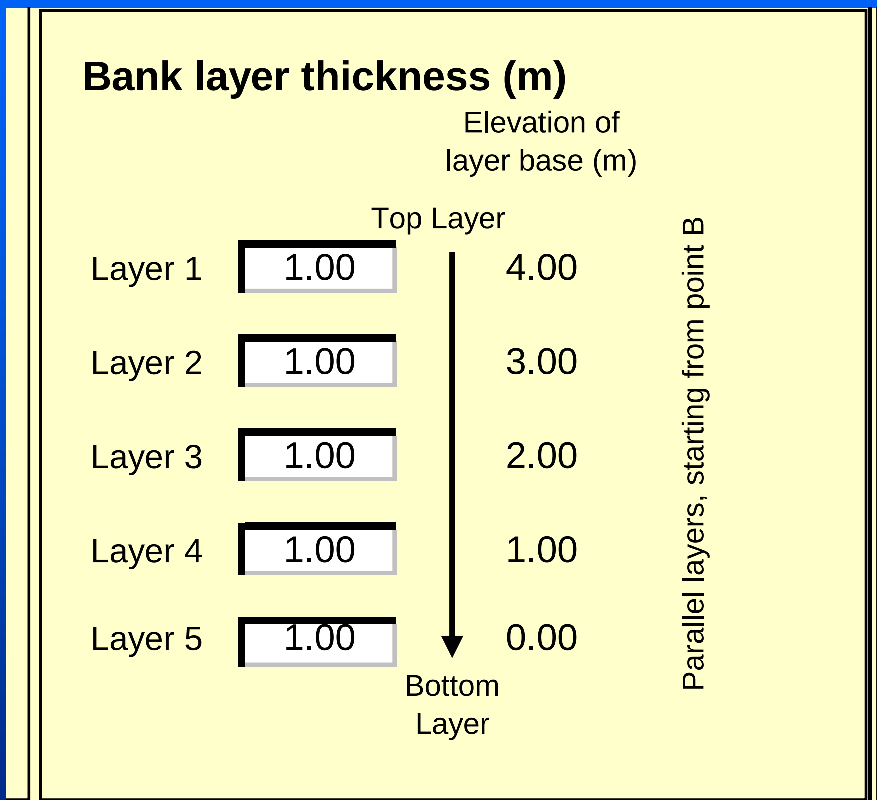
# Operational Steps

1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness

# Enter Bank Layer Thickness



# Enter Bank Layer Thickness: Detail




**For this example, enter 1m thicknesses for all five layers**

Layer 5 should (but does not have to) end at or below the base of the bank toe. Therefore, the basal elevation of layer 5 should be equal to or less than the elevation of point V (base of bank toe) if Option A is selected or 0 (zero) if Option B is selected.

# Operational Steps

1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter bank-layer thickness
6. Enter channel and flow parameters, and check cross section inputs:
   a. View Geometry
   b. Bank Geometry Macro

# Channel and Flow Parameters

## 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 | |
| B | 10.79 | 5.00 | |
| C | 10.82 | 4.69 | ☐ |
| D | 10.84 | 4.39 | ☐ |
| E | 10.87 | 4.08 | ☐ |
| F | 10.90 | 3.78 | ☐ |
| G | 10.92 | 3.47 | ☐ |
| H | 10.95 | 3.17 | ☐ |
| I | 10.98 | 2.86 | ☐ |
| J | 11.00 | 2.56 | ☐ |
| K | 11.03 | 2.25 | ☐ |
| L | 11.06 | 1.95 | ☐ |
| M | 11.08 | 1.64 | ☐ |
| N | 11.11 | 1.34 | ☐ |
| O | 11.14 | 1.03 | ☐ |
| P | 11.16 | 0.73 | ☐ |
| Q | 11.19 | 0.42 | ☑ |
| R | 11.37 | 0.34 | |
| S | 11.55 | 0.25 | |
| T | 11.74 | 0.17 | |
| U | 11.92 | 0.08 | |
| V | 12.10 | 0.00 | |
| W | 13.10 | 0.00 | |

Shear emergence elev

Shear surface angle

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

◉ Option B

| | |
|---|---|
| 5.0 | a) Input bank height (m) |
| 85.0 | b) Input bank angle (°) |
| 1.0 | c) Input bank toe length (m) |
| 25.0 | d) Input bank toe angle (°) |

0.84524

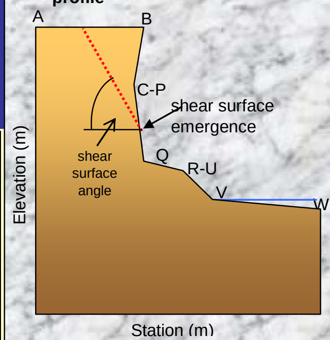
Input shear surface angle

**Bank layer thickness (m)**

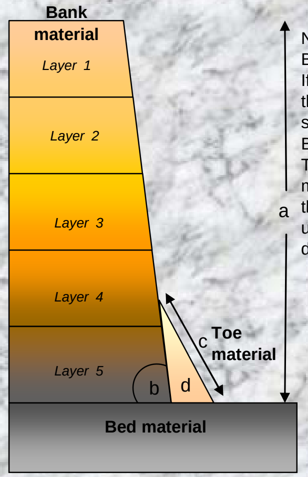
| | Thickness (m) | Elevation of layer base (m) |
|---|---|---|
| Layer 1 (Top Layer) | 1.00 | 4.00 |
| Layer 2 | 1.00 | 3.00 |
| Layer 3 | 1.00 | 2.00 |
| Layer 4 | 1.00 | 1.00 |
| Layer 5 (Bottom Layer) | 1.00 | 0.00 |

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**

| | |
|---|---|
| 100 | Input reach length (m) |
| 0.0035 | Input reach slope (m/m) |
| | Input concentration (kg/kg) |
| 2.00 | Input elevation of flow (m) |
| 12 | Input duration of flow (hrs) |

**View Bank Geometry**

**Run Bank Geometry Macro**

# Channel and Flow Parameters: Detail

**Channel and flow parameters**

| Value | Parameter |
|---|---|
| 100 | Input reach length (m) |
| 0.0035 | Input reach slope (m/m) |
| | Input concentration (kg/kg) |
| 2.00 | Input elevation of flow (m) |
| 12 | Input duration of flow (hrs) |

**Input the above values for this example**

# Check Cross Section Inputs I: (*View Geometry*)

## 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 | |
| B | 10.79 | 5.00 | |
| C | 10.82 | 4.69 | ☐ |
| D | 10.84 | 4.39 | ☐ |
| E | 10.87 | 4.08 | ☐ |
| F | 10.90 | 3.78 | ☐ |
| G | 10.92 | 3.47 | ☐ |
| H | 10.95 | 3.17 | ☐ |
| I | 10.98 | 2.86 | ☐ |
| J | 11.00 | 2.56 | ☐ |
| K | 11.03 | 2.25 | ☐ |
| L | 11.06 | 1.95 | ☐ |
| M | 11.08 | 1.64 | ☐ |
| N | 11.11 | 1.34 | ☐ |
| O | 11.14 | 1.03 | ☐ |
| P | 11.16 | 0.73 | ☐ |
| Q | 11.19 | 0.42 | ☑ |
| R | 11.37 | 0.34 | |
| S | 11.55 | 0.25 | |
| T | 11.74 | 0.17 | |
| U | 11.92 | 0.08 | |
| V | 12.10 | 0.00 | |
| W | 13.10 | 0.00 | |

Shear emergence elev [ ]

Shear surface angle [ ]

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

◉ Option B

| | |
|---|---|
| 5.0 | a) Input bank height (m) |
| 85.0 | b) Input bank angle (°) |
| 1.0 | c) Input bank toe length (m) |
| 25.0 | d) Input bank toe angle (°) |

0.84524

[ ] Input shear surface angle

**Bank layer thickness (m)**

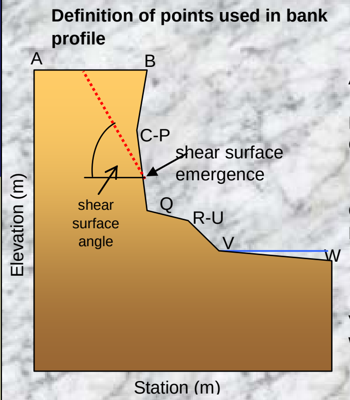
Parallel layers, starting from point B

| | Thickness | Elevation of layer base (m) |
|---|---|---|
| Layer 1 (Top Layer) | 1.00 | 4.00 |
| Layer 2 | 1.00 | 3.00 |
| Layer 3 | 1.00 | 2.00 |
| Layer 4 | 1.00 | 1.00 |
| Layer 5 (Bottom Layer) | 1.00 | 0.00 |

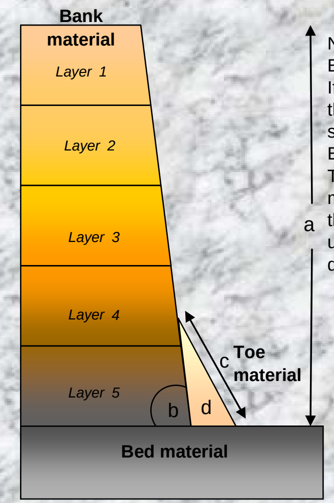
**Channel and flow parameters**

| | |
|---|---|
| 100 | Input reach length (m) |
| 0.0035 | Input reach slope (m/m) |
| | Input concentration (kg/kg) |
| 2.00 | Input elevation of flow (m) |
| 12 | 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 of Input Cross Section

## 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 | | | |
| B | | | |
| C | | | ☐ |
| D | | | ☐ |
| E | | | ☐ |
| F | | | ☐ |
| G | | | ☐ |
| H | | | ☐ |
| I | | | ☐ |
| J | | | ☐ |
| K | | | ☐ |
| L | | | ☐ |
| M | | | ☐ |
| N | | | ☐ |
| O | | | ☐ |
| P | | | ☐ |
| Q | | | ☑ |
| R | | | |
| S | | | |
| T | | | |
| U | | | |
| V | | | |
| W | | | |

Shear emergence elev

Shear surface angle

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

◉ Option B

| | |
|---|---|
| 5.0 | a) Input bank height (m) |
| 85.0 | b) Input bank angle (°) |
| 1.0 | c) Input bank toe length (m) |
| 25.0 | d) Input bank toe angle (°) |
| 0.84524 | |
| | Input shear surface angle |

**Bank layer thickness (m)**

Parallel layers, starting from point B

| | Thickness | Elevation of layer base (m) |
|---|---|---|
| Layer 1 (Top Layer) | 1.00 | 4.00 |
| Layer 2 | 1.00 | 3.00 |
| Layer 3 | 1.00 | 2.00 |
| Layer 4 | 1.00 | 1.00 |
| Layer 5 (Bottom Layer) | 1.00 | 0.00 |

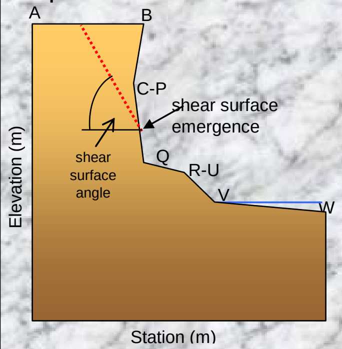
**Channel and flow parameters**

| | |
|---|---|
| 100 | Input reach length (m) |
| 0.0035 | Input reach slope (m/m) |
| | Input concentration (kg/kg) |
| 2.00 | Input elevation of flow (m) |
| 12 | Input duration of flow (hrs) |

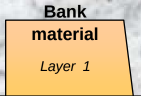
**View Bank Geometry**

**Run Bank Geometry Macro**

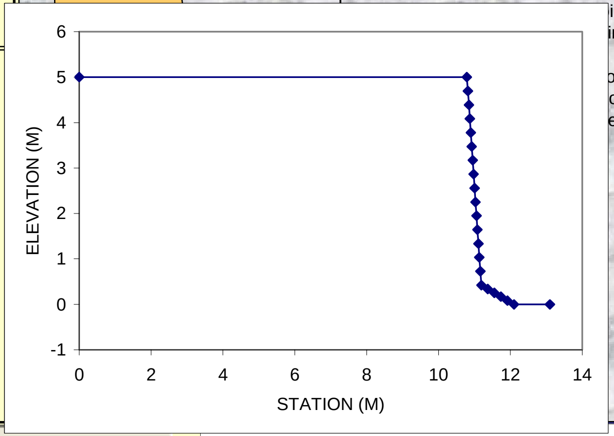
**Definition of points used in bank profile**




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, ...int ...ints ...oint ...on - ...e



# Check Cross Section Inputs: II (*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 | |
| B | 10.79 | 5.00 | |
| C | 10.82 | 4.69 | ☐ |
| D | 10.84 | 4.39 | ☐ |
| E | 10.87 | 4.08 | ☐ |
| F | 10.90 | 3.78 | ☐ |
| G | 10.92 | 3.47 | ☐ |
| H | 10.95 | 3.17 | ☐ |
| I | 10.98 | 2.86 | ☐ |
| J | 11.00 | 2.56 | ☐ |
| K | 11.03 | 2.25 | ☐ |
| L | 11.06 | 1.95 | ☐ |
| M | 11.08 | 1.64 | ☐ |
| N | 11.11 | 1.34 | ☐ |
| O | 11.14 | 1.03 | ☐ |
| P | 11.16 | 0.73 | ☐ |
| Q | 11.19 | 0.42 | ☑ |
| R | 11.37 | 0.34 | |
| S | 11.55 | 0.25 | |
| T | 11.74 | 0.17 | |
| U | 11.92 | 0.08 | |
| V | 12.10 | 0.00 | |
| W | 13.10 | 0.00 | |

Shear emergence elev [ ]

Shear surface angle [ ]

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

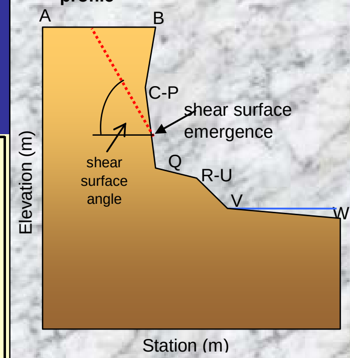
◉ Option B

| Value | Input |
|---|---|
| 5.0 | a) Input bank height (m) |
| 85.0 | b) Input bank angle (°) |
| 1.0 | c) Input bank toe length (m) |
| 25.0 | d) Input bank toe angle (°) |
| 0.84524 | |
| | Input shear surface angle |

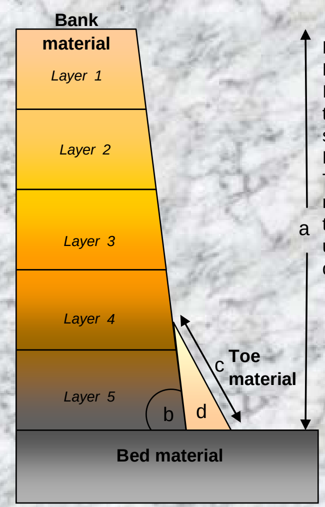
**Bank layer thickness (m)**

Parallel layers, starting from point B (Top Layer → Bottom Layer)

| Layer | Thickness (m) | Elevation of layer base (m) |
|---|---|---|
| Layer 1 | 1.00 | 4.00 |
| Layer 2 | 1.00 | 3.00 |
| Layer 3 | 1.00 | 2.00 |
| Layer 4 | 1.00 | 1.00 |
| Layer 5 | 1.00 | 0.00 |




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 and flow parameters**

| Value | Parameter |
|---|---|
| 100 | Input reach length (m) |
| 0.0035 | Input reach slope (m/m) |
| | Input concentration (kg/kg) |
| 2.00 | Input elevation of flow (m) |
| 12 | Input duration of flow (hrs) |

**View Bank Geometry**

**Run Bank Geometry Macro**

# Check Geometry and Flow Level

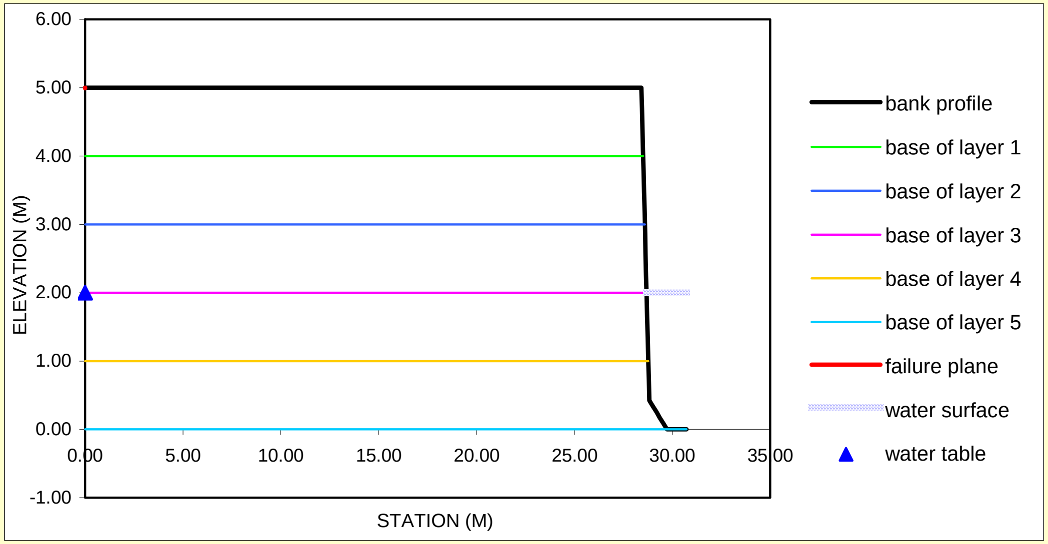
1. Model will direct you to the Bank Material sheet
2. Click on Bank Model Output sheet

## Bank model output

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

**Bank Material Properties**

| Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 |
|---|---|---|---|---|
| Own Data | Own Data | Own Data | Stiff Clay | Own Data |



# Operational Steps

1. Open Excel file "BSTEM-5.0"
2. Click on "Enable Macros"…to "Introduction" sheet
3. Click on "Input Geometry" sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on "Bank Material" sheet

# Select Bank Materials by Layer

**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 | |
| Moderate soft clay | Moderate soft clay | Moderate silt | Erodible silt | Moderate silt | Own data |

**Select bank materials by layer from drop down boxes. For this case:**

**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

# Selecting Bank Materials

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

| Bank Material: Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 | Bank Toe Material |
|---|---|---|---|---|---|
| Erodible silt | Moderate silt | Moderate silt | Erodible silt | Moderate silt | Own data |

**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 | | | | Toe Model Input Data | |
|---|---|---|---|---|---|---|---|---|
| *Bank material type* | *Description* | *Mean grain size, $D_{50}$ (m)* | *Friction angle $\phi'$ (degrees)* | *Cohesion c' (kPa)* | *Saturated unit weight ($kN/m^3$)* | *$\phi^b$ (degrees)* | $\tau_c$ (Pa) | $k$ ($cm^3/Ns$) |
| 1 | Boulders | 0.512 | 42.0 | 0.0 | 20.0 | 5.0 | 498 | 0.004 |
| 2 | Cobbles | 0.128 | 42.0 | 0.0 | 20.0 | 5.0 | 124 | 0.009 |
| 3 | Gravel | 0.0113 | 36.0 | 0.0 | 20.0 | 5.0 | 11.0 | 0.030 |
| 4a and 4b | Angular sand | 0.00035 | 36.0 | 0.0 | 18.0 | 15.0 | Coarse (0.71 mm) or | |
| 5a and 5b | Rounded sand | 0.00035 | 27.0 | 0.0 | 18.0 | 15.0 | Fine (0.18 mm) | |
| 6a, 6b and 6c | Silt | - | 25.0 | 5.0 | 18.0 | 15.0 | Erodible (0.100 Pa), | |
| 7a, 7b and 7c | Soft clay | - | 30.0 | 10.0 | 16.0 | 15.0 | Moderate (5.00 Pa), or | |
| 8a, 8b and 8c | Stiff clay | - | 10.0 | 15.0 | 18.0 | 15.0 | Resistant (50.0 Pa) | |
| | Own data layer 1 | | | | | | | |
| | Own data layer 2 | | | | | | | |
| 9 | Own data layer 3 | | | | | | | |
| | Own data layer 4 | | | | | | | |
| | Own data layer 5 | | | | | | | |
| | Own data Bank Toe | | | | | | 2.00 | 0.071 |

COMING JANUARY 2009!

**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) 2.000

Erodibility Coefficient ($cm^3/Ns$) 0.071

Input value (2.00) and hit enter

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

Input critical shear stress $\tau_c$ (Pa) 2.000

Erodibility Coefficient ($cm^3/Ns$) 0.071

Enter values (2.00 and 0.071)

# Operational Steps

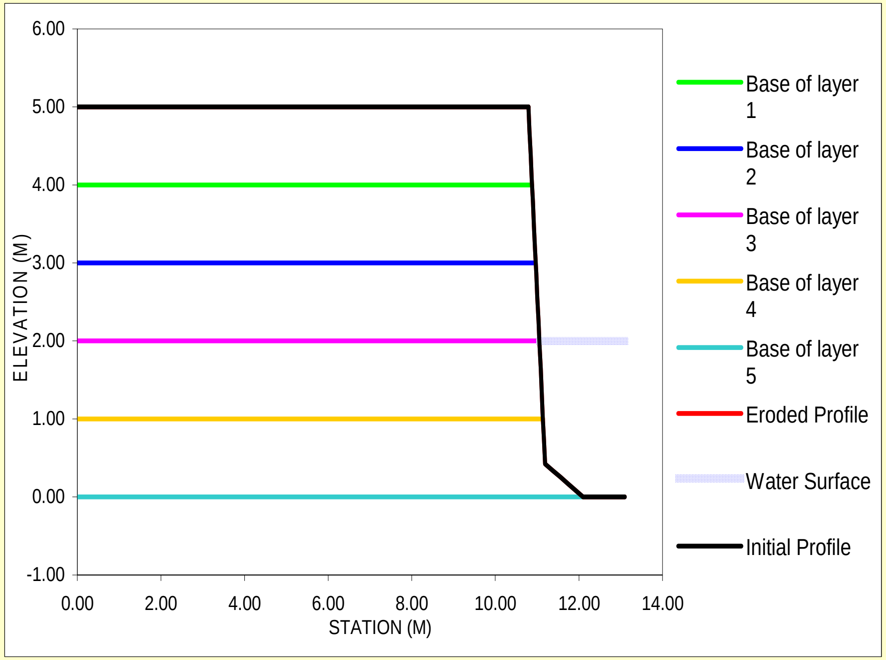
1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”

# Toe Model Output Sheet

## 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).

| Bank Material | | | | | Bank Toe Material | |
|---|---|---|---|---|---|---|
| Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 | | |
| Moderate cohesive | Moderate cohesive | Moderate cohesive | Erodible cohesive | Moderate cohesive | Own data | **Material** |
| 5.00 | 5.00 | 5.00 | 0.10 | 5.00 | 2.00 | **Critical shear stress (Pa)** |
| 0.045 | 0.045 | 0.045 | 0.316 | 0.045 | 0.071 | **Erodibility Coefficient (cm3/Ns)** |

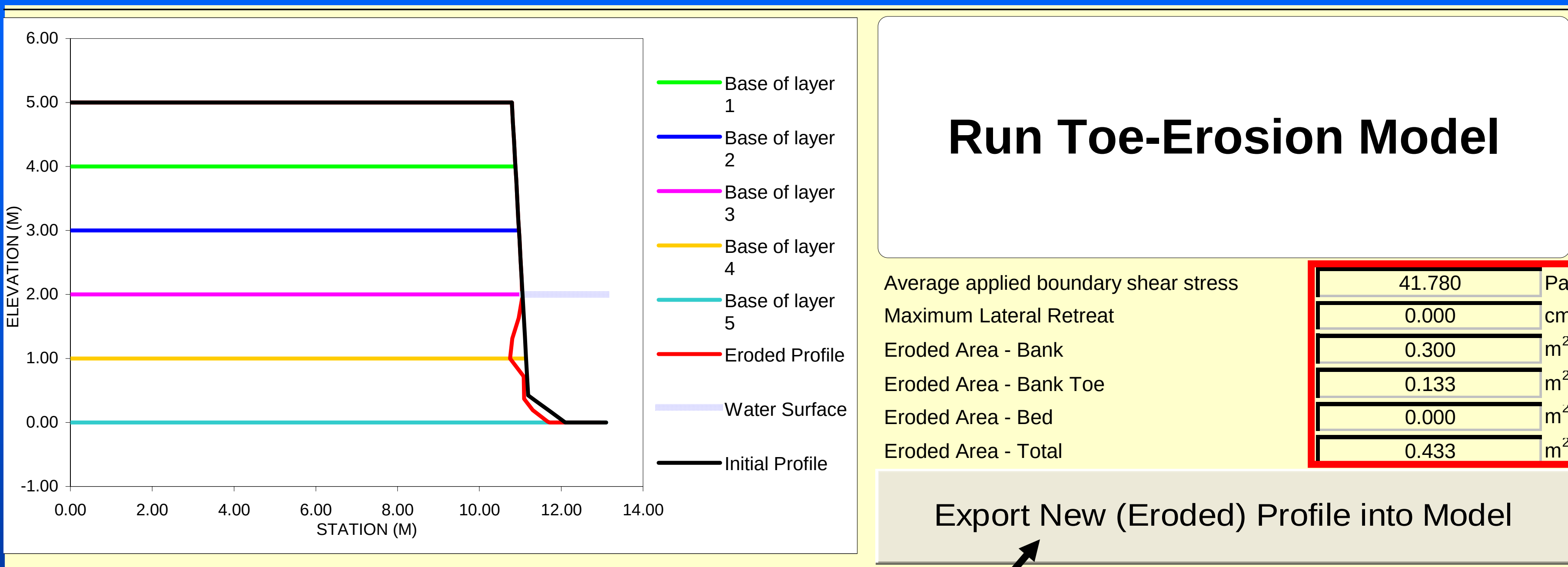



**Run Toe-Erosion Model**

| | | |
|---|---|---|
| Average applied boundary shear stress | | Pa |
| Maximum Lateral Retreat | 0.000 | cm |
| Eroded Area - Bank | 0.000 | $m^2$ |
| Eroded Area - Bank Toe | 0.000 | $m^2$ |
| Eroded Area - Bed | 0.000 | $m^2$ |
| Eroded Area - Total | 0.000 | $m^2$ |

Export New (Eroded) Profile into Model

# Results of Toe-Erosion Model




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

# Operational Steps

1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)

# Profile Exported into Option *A*

## *(Model Directs you to "Input Geometry" sheet)*

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

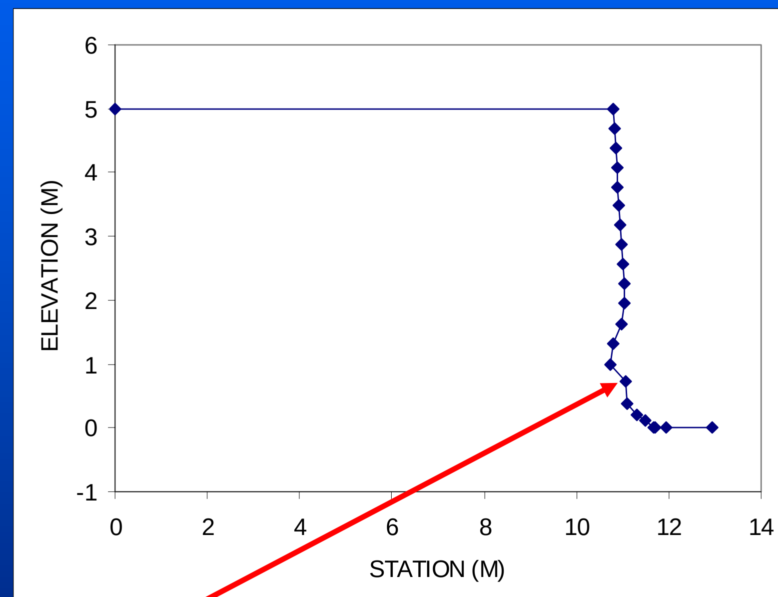
(•) Option A

| Point | Station (m) | Elevation (m) | Top of toe? |
|---|---|---|---|
| A | 0.00 | 5.00 | |
| B | 10.79 | 5.00 | |
| C | 10.82 | 4.69 | ☐ |
| D | 10.84 | 4.39 | ☐ |
| E | 10.87 | 4.08 | ☐ |
| F | 10.90 | 3.78 | ☐ |
| G | 10.92 | 3.47 | ☐ |
| H | 10.95 | 3.17 | ☐ |
| I | 10.98 | 2.86 | ☐ |
| J | 11.00 | 2.56 | ☐ |
| K | 11.03 | 2.25 | ☐ |
| L | 11.04 | 1.95 | ☐ |
| M | 10.96 | 1.63 | ☐ |
| N | 10.81 | 1.31 | ☐ |
| O | 10.75 | 1.00 | ☐ |
| P | 11.08 | 0.72 | ☐ |
| Q | 11.09 | 0.37 | ☑ |
| R | 11.31 | 0.19 | |
| S | 11.48 | 0.10 | |
| T | 11.66 | 0.02 | |
| U | 11.72 | 0.00 | |
| V | 11.95 | 0.00 | |
| W | 12.96 | 0.00 | |

Shear emergence elev ______

Shear surface angle ______

Check profile (View Geometry) and select top of bank toe




For this case select Point *Q*

**Either: (1) Select shear emergence elevation and shear angle or (2) leave blank for search routine**

# Operational Steps

1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)
10. Run “Bank Geometry Macro” and Click on “Bank Model Output” sheet; Set water-table depth and Click “Run Bank Stability Model”

# Data for Pore-Water Pressure

## In "Bank Model Output" worksheet

Water table depth (m) below bank top

3.00

◉ Use water table

○ Input own pore pressures (kPa)

Or

| Own Pore Pressures | kPa | Pore Pressure From Water Table |
|---|---|---|
| | Layer 1 | -24.52 |
| | Layer 2 | -14.71 |
| | Layer 3 | -4.90 |
| | Layer 4 | 4.90 |
| | Layer 5 | 14.71 |

In this case select option to use water table depth, and enter a value of 3.0m below the bank top

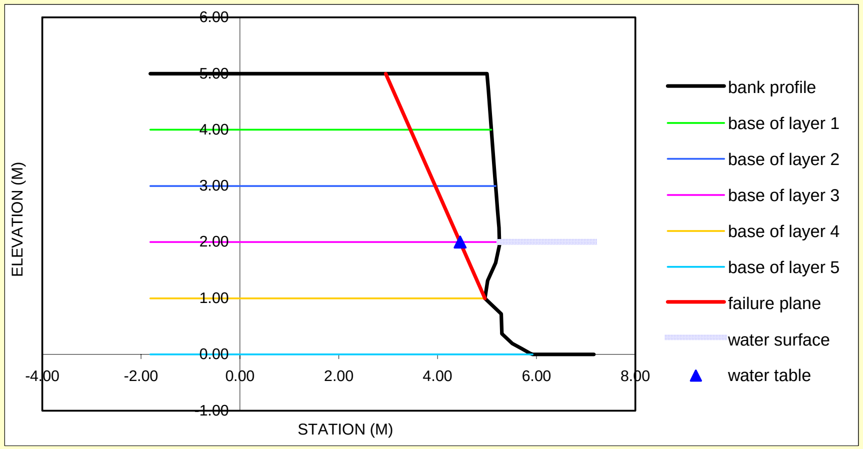
# Bank Model Output: No Tension Crack

## 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.

**Bank Material Properties**

| Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 |
|---|---|---|---|---|
| Soft Clay | Soft Clay | Silt | Silt | Silt |




Water table depth (m) below bank top

3.00

◉ Use water table

○ Input own pore pressures (kPa)

| Own Pore Pressures | kPa | Pore Pressure From Water Table |
|---|---|---|
| | Layer 1 | -24.52 |
| | Layer 2 | -14.71 |
| | Layer 3 | -4.90 |
| | Layer 4 | 4.90 |
| | Layer 5 | 14.71 |

Factor of Safety

| 0.87 | Unstable |
|---|---|

**Run Bank-Stability Model**

**Set water-table depth to 3.0 m**

**Bank is Unstable**

$F_s < 1.0$

**Click "Run Bank-Stability Model"**

# Bank Model Output: Specific Results

## Failure plane from search routine

| | |
|---|---|
| 1.0 | Shear emergence elevation |
| 63.4 | Shear surface angle used |

Export New (Failed) Profile into Model

## Failure dimensions (loading)

| | | |
|---|---|---|
| Failure width | 2.05 | m |
| Failure volume | 468 | $m^3$ |
| Sediment loading | 813163 | kg |
| Constituent load | 0 | kg |

# Save your file under a different name

# Operational Steps

1. Open Excel file "BSTEM-5.0"
2. Click on "Enable Macros"…to "Introduction" sheet
3. Click on "Input Geometry" sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on "Bank Material" sheet
8. Select "Toe Model Output" sheet and Click on "Run Toe-Erosion Model"
9. Export Coordinates to Model (Returned to "Input Geometry" sheet)
10. Run "Bank Geometry Macro" and Click on "Bank Model Output" sheet; Set water-table depth and Click "Run Bank Stability Model"
11. Save file under different name

# How can you make this bank more stable or more unstable?

Try experimenting with the following parameters to get a feel for the model:

- Water surface elevation (Input Geometry Sheet)
- Shear angle (Input Geometry Sheet)
- Water table height (Bank Model Output sheet)
- Bank material types (Bank Model Output sheet)

**We'll work with the effects of vegetation later…**

# Operational Steps

1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)
10. Run “Bank Geometry Macro” and Click on “Bank Model Output” sheet; Set water-table depth and Click “Run Bank Stability Model”
11. Save file under different name
12. Open file and Click on “Bank Vegetation and Protection” sheet

# Incorporating Vegetation Effects and other Protection

## 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).

RipRoot requires the user to first select either a species from a drop-down box, which then activates root tensile strength- diameter curves measured by USDA-ARS-NSL scientists, or the user may enter their own root tensile strength- diameter relation. The user must then decide whether to use growth curves that use the age of the plant to predict the total number of roots and root diameter histograms derived separately for woody vegetation and grasses or to enter their own root-diameter data. Finally, the user needs to enter the percentage of the study reach that is composed of the selected species.

After it has run, the model outputs a tab-delimited list of the species entered by the user, a tab-delimited list of the percent contribution of each of those species to the assemblage and the estimated increase in cohesion afforded by the roots associated with the assemblage.

**Run Root-Reinforcement Model**

**Root-Reinforcement Model Output**

**List of Species**
**Percent of Assemblage**

**Added cohesion due to roots, $c_r$** [ ]

## Select bank and bank-toe protection (or select "own data" and add values below)

**Protection**

| Bank Protection | Bank Toe Protection |
|---|---|
| No protection | No protection |

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

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 box.

**Bank and Bank-Toe Protection Descriptors**

| *Protection type* | *Description* | *Permissible shear stress (Pa)* |
|---|---|---|
| 1 | No protection | - |
| 2 | Coir fiber | 108 |
| 3 | Geotextile (synthetic) | 144 |
| 4 | Jute net | 22 |
| 5 | Large Woody Debris | 192 |
| 6 | Live fascine | 100 |
| 7 | Plant cuttings | 17 |
| 8 | Rip Rap ($D_{50}$ 0.256 m) | 204 |
| 9 | - | |
| 10 | - | |
| 11 | - | |
| 12 | - | |
| 13 | Own Data | [ ] |

# Root Reinforcement: RipRoot

*(from measured data)*

# Bank and Toe Protection

*(from literature values)*

# Operational Steps

1. Open Excel file “BSTEM-5.0”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on “Bank Material” sheet
8. Select “Toe Model Output” sheet and Click on “Run Toe-Erosion Model”
9. Export Coordinates to Model (Returned to “Input Geometry” sheet)
10. Run “Bank Geometry Macro” and Click on “Bank Model Output” sheet; Set water-table depth and Click “Run Bank Stability Model”
11. Save file under different name
12. Open file and Click on “Bank Vegetation and Protection” sheet
13. Click “Run Root-Reinforcement Model”

# 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).

RipRoot requires the user to first select either a species from a drop-down box, which then activates root tensile strength- diameter curves measured by USDA-ARS-NSL scientists, or the user may enter their own root tensile strength- diameter relation. The user must then decide whether to use growth curves that use the age of the plant to predict the total number of roots and root diameter histograms derived separately for woody vegetation and grasses or to enter their own root-diameter data. Finally, the user needs to enter the percentage of the study reach that is composed of the selected species.

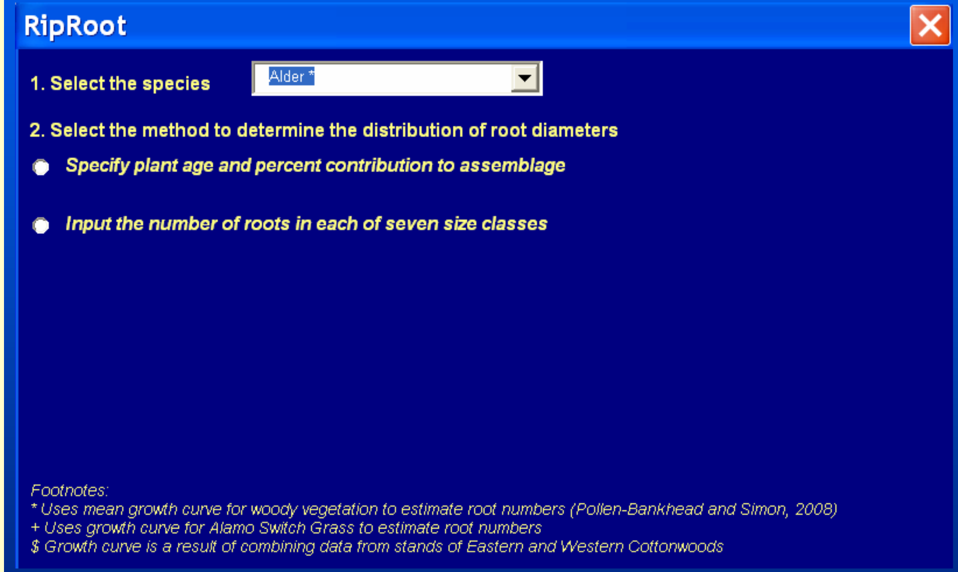
After it has run, the model outputs a tab-delimited list of the species entered by the user, a tab-delimited list of the percent contribution of each of those species to the assemblage and the estimated increase in cohesion afforded by the roots associated with the assemblage.

**Run Root-Reinforcement Model**

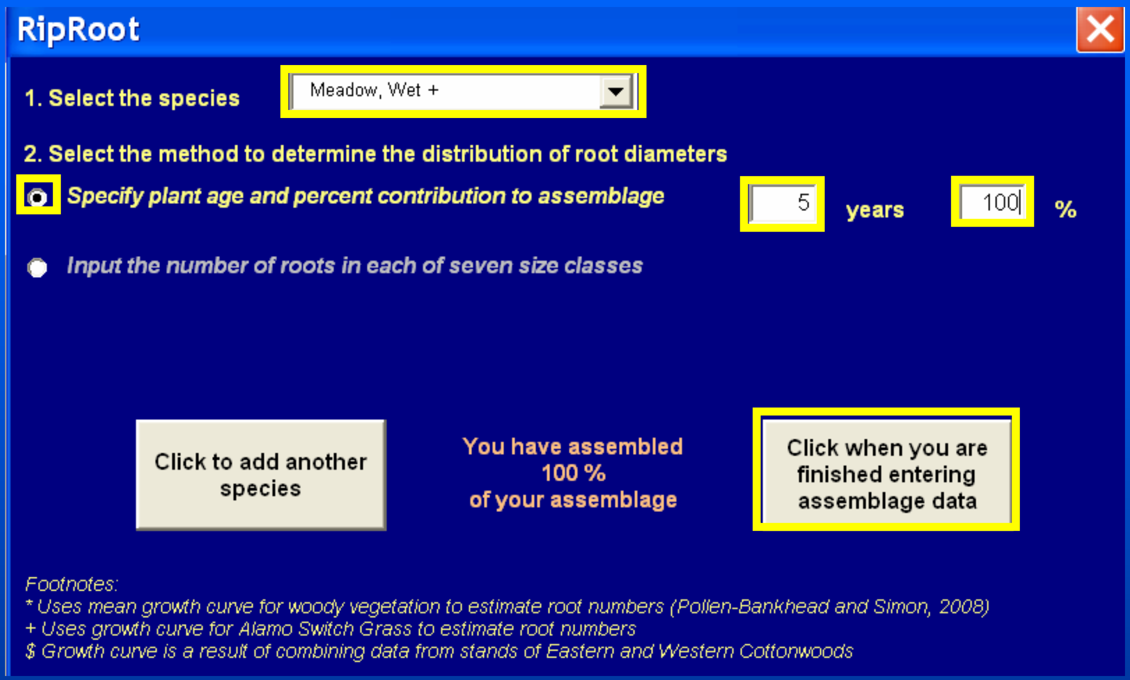
**Root-Reinforcement Model Output**

**List of Species**
**Percent of Assemblage**

**Added cohesion due to roots, $c_r$**



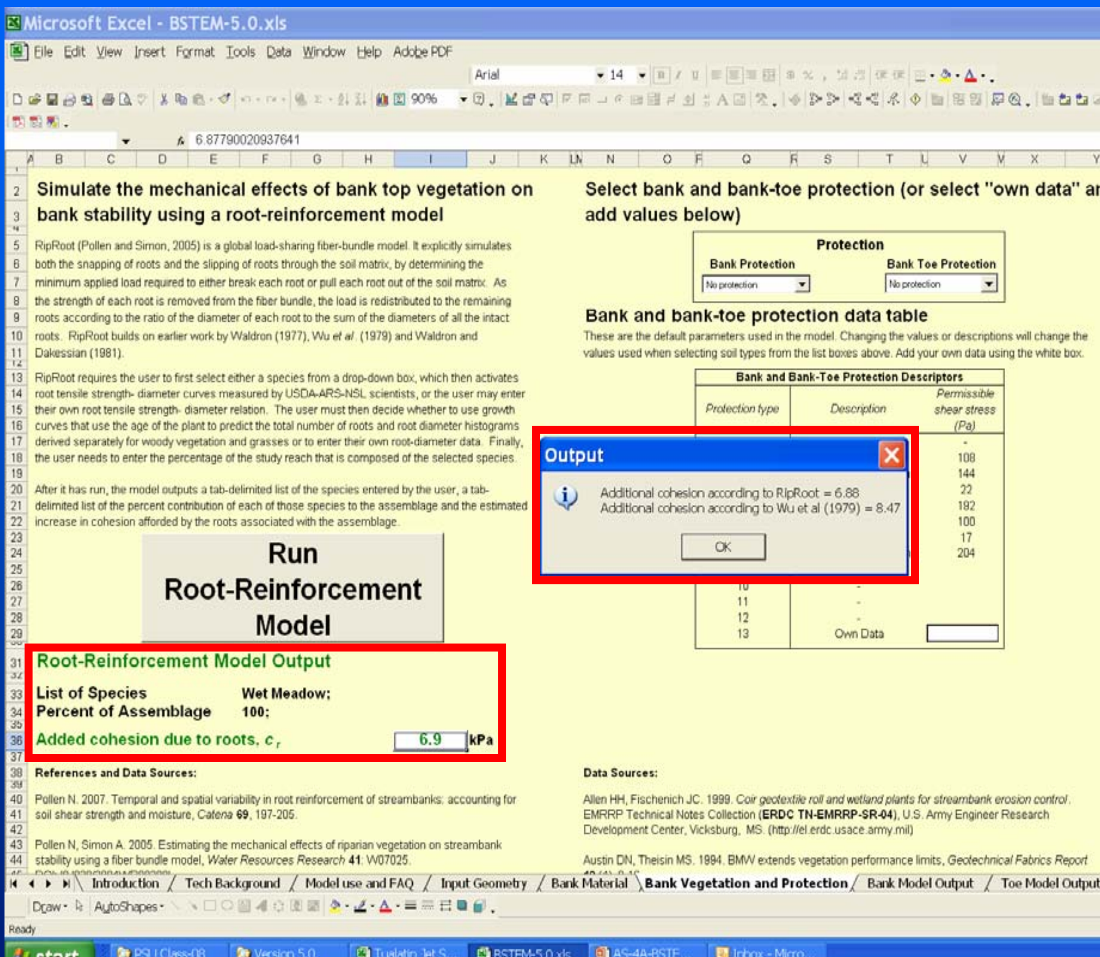
# Root Reinforcement using RipRoot

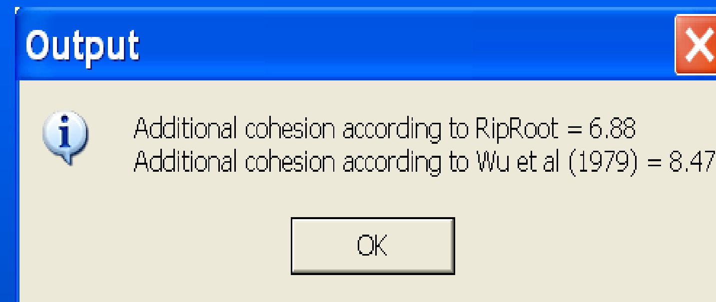


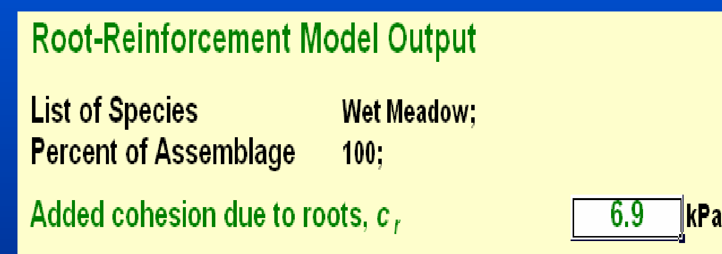

## Simple Case: 1 species

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

# RipRoot: Results



# Operational Steps

1. Open Excel file "BSTEM-5.0"
2. Click on "Enable Macros"…to "Introduction" sheet
3. Click on "Input Geometry" sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel and flow parameters
7. Enter Bank-material Properties: Click on "Bank Material" sheet
8. Select "Toe Model Output" sheet and Click on "Run Toe-Erosion Model"
9. Export Coordinates to Model (Returned to "Input Geometry" sheet)
10. Run "Bank Geometry Macro" and Click on "Bank Model Output" sheet; Set water-table depth and Click "Run Bank Stability Model"
11. Save file under different name
12. Open file and Click on "Bank Vegetation and Protection" sheet
13. Click "Run Root-Reinforcement Model"
14. Return to "Bank Model Output" sheet

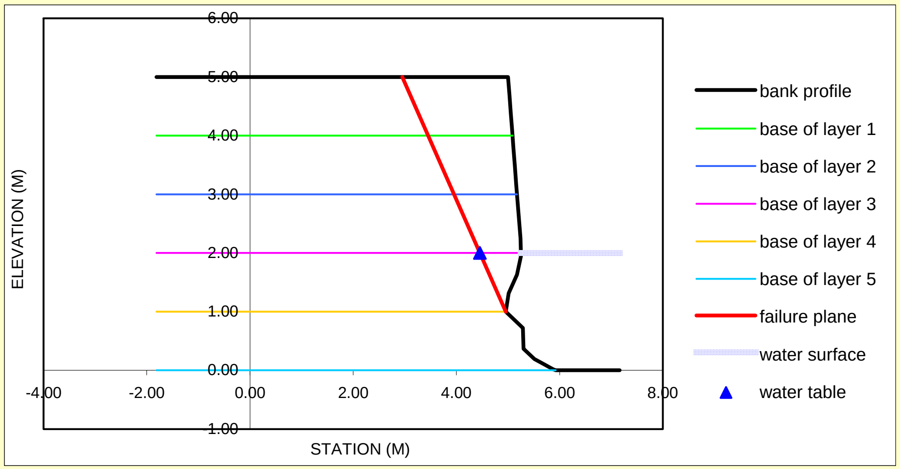
# Still Unstable with Vegetation

## 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.

**Bank Material Properties**

| Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 |
|---|---|---|---|---|
| Soft Clay | Soft Clay | Silt | Silt | Silt |




Water table depth (m) below bank top

3.00

◉ Use water table

○ Input own pore pressures (kPa)

| Own Pore Pressures | kPa | Pore Pressure From Water Table |
|---|---|---|
| | Layer 1 | -24.52 |
| | Layer 2 | -14.71 |
| | Layer 3 | -4.90 |
| | Layer 4 | 4.90 |
| | Layer 5 | 14.71 |

Factor of Safety

**0.99** Unstable

**Run Bank-Stability Model**

**Revised strength and $F_s$ calculated automatically**

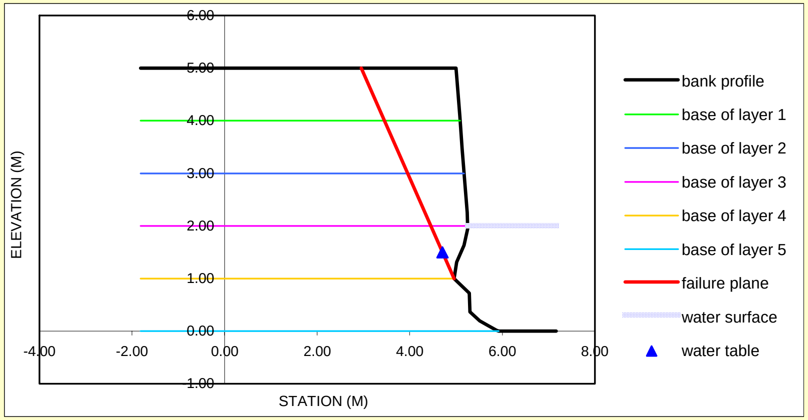
# Conditionally Stable with Lower Water Table

**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.

**Bank Material Properties**

| Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 |
|---|---|---|---|---|
| Soft Clay | Soft Clay | Silt | Silt | Silt |




Water table depth (m) below bank top

3.50

- (●) Use water table
- (○) Input own pore pressures (kPa)

| Own Pore Pressures | kPa | Pore Pressure From Water Table |
|---|---|---|
| | Layer 1 | -29.42 |
| | Layer 2 | -19.61 |
| | Layer 3 | -9.81 |
| | Layer 4 | 0.00 |
| | Layer 5 | 9.81 |

Factor of Safety

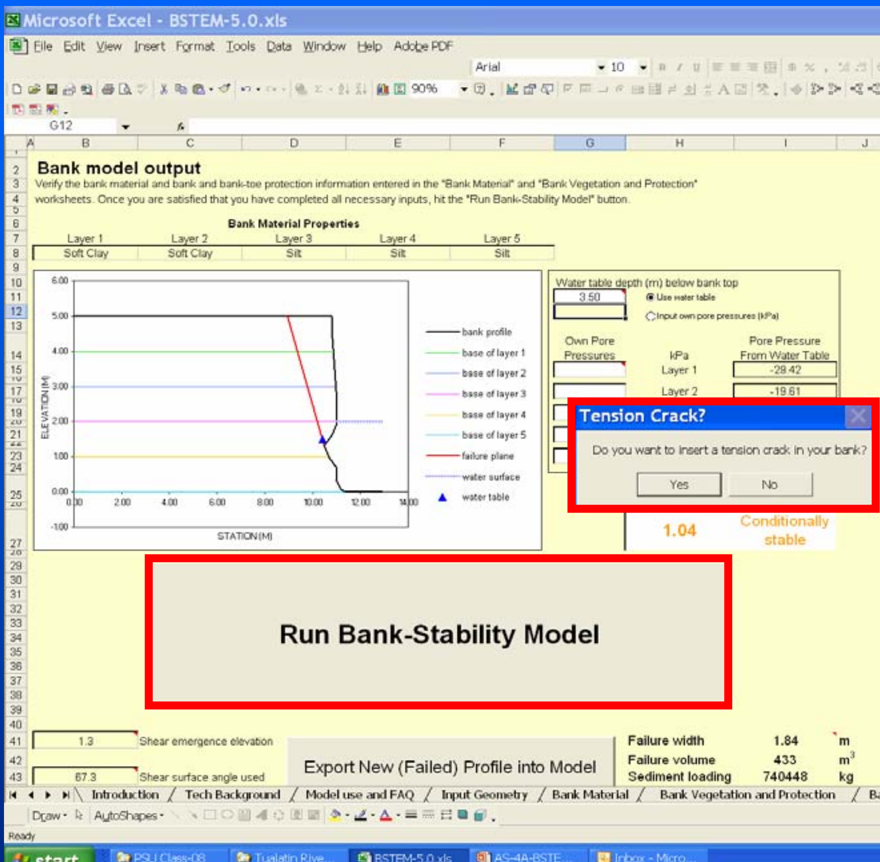
**1.11** Conditionally stable

**Run Bank-Stability Model**

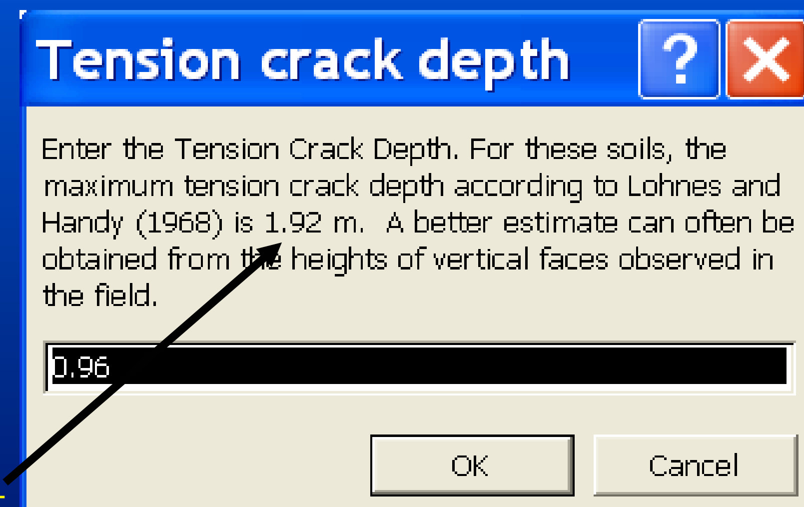
Change water-table depth to 3.5 m

Revised pore-water pressures and $F_s$ calculated automatically

# Further Simulations…Tension Cracks



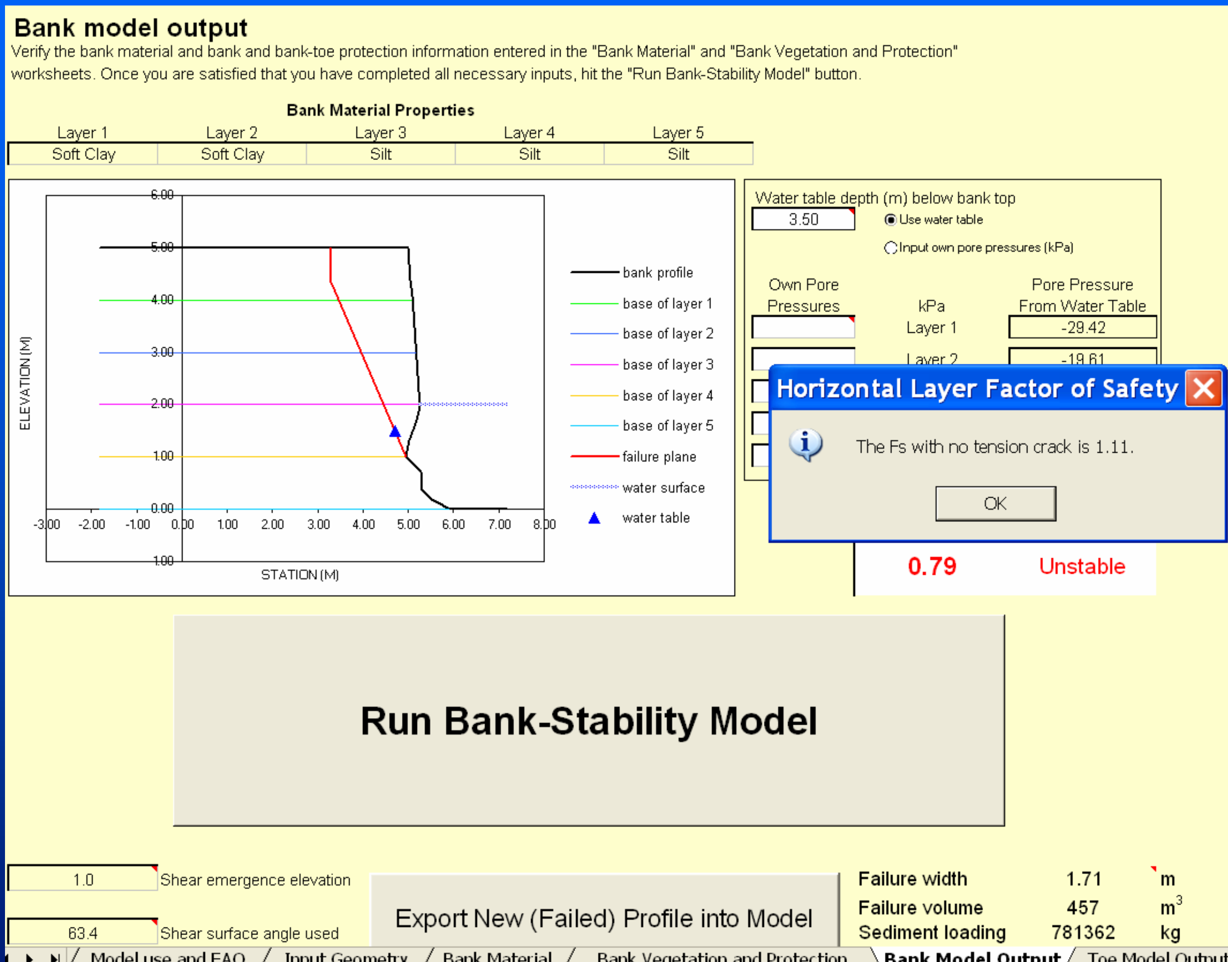

1. Click "Run-Bank Stability Model"
2. Click "Yes" for tension crack
3. Enter depth of tension crack




**Maximum based on cohesion and unit weight**

**We often use ½ the value or observed vertical-face heights**

# Results with Tension Crack

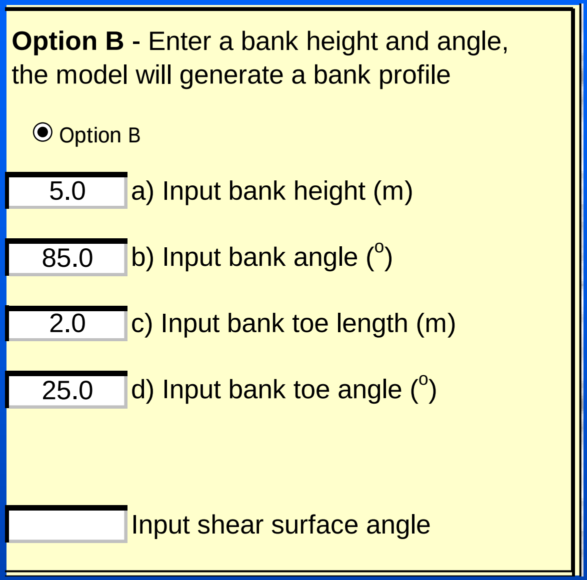



$F_s = 0.79$

**Bank is unstable again due to loss of strength along upper part of failure plane.**

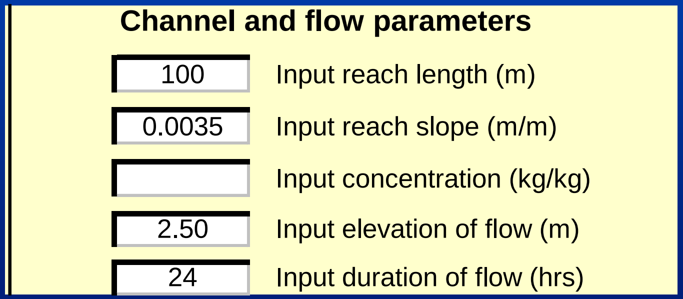
# Bank-Toe Protection

1. Re-open BSTEM-5.0.xls
2. Select “Input Geometry sheet”
3. Select Option B
4. Input these values:
5. Input channel and flow parameters
6. Click “Run Bank Geometry Macro”
7. Open “Bank Material” sheet
8. Select “Moderate silt” for all layers
9. Select “Toe Model Output” sheet
10. Click “Run Toe-Erosion Model”


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

◉ Option B

| | |
|---|---|
| 5.0 | a) Input bank height (m) |
| 85.0 | b) Input bank angle ($^o$) |
| 2.0 | c) Input bank toe length (m) |
| 25.0 | d) Input bank toe angle ($^o$) |
| | Input shear surface angle |


**Channel and flow parameters**

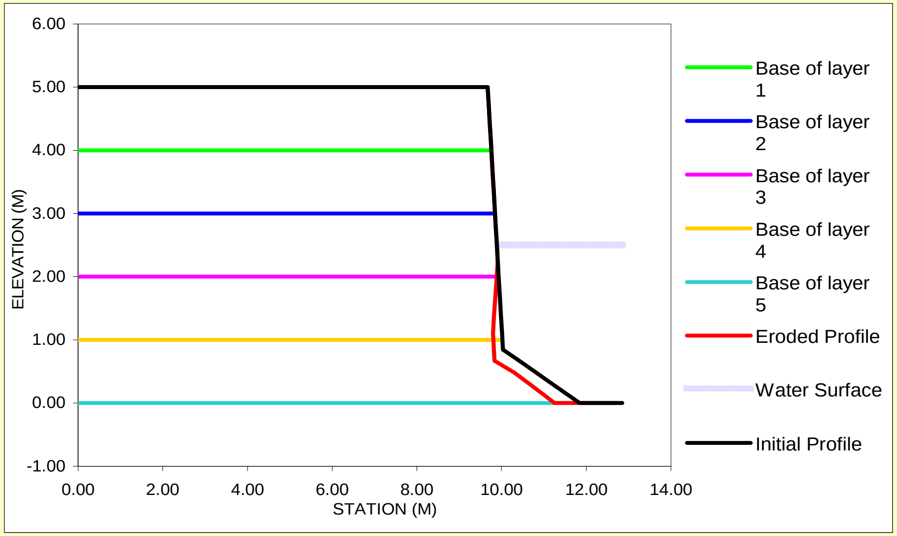
| | |
|---|---|
| 100 | Input reach length (m) |
| 0.0035 | Input reach slope (m/m) |
| | Input concentration (kg/kg) |
| 2.50 | Input elevation of flow (m) |
| 24 | Input duration of flow (hrs) |

# Toe Erosion without 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).

| | Bank Material | | | | | Bank Toe Material |
|---|---|---|---|---|---|---|
| | Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 | |
| **Material** | Moderate cohesive | Moderate cohesive | Moderate cohesive | Moderate cohesive | Moderate cohesive | Moderate cohesive |
| **Critical shear stress (Pa)** | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| **Erodibility Coefficient (cm3/Ns)** | 0.045 | 0.045 | 0.045 | 0.045 | 0.045 | 0.045 |




**Run Toe-Erosion Model**

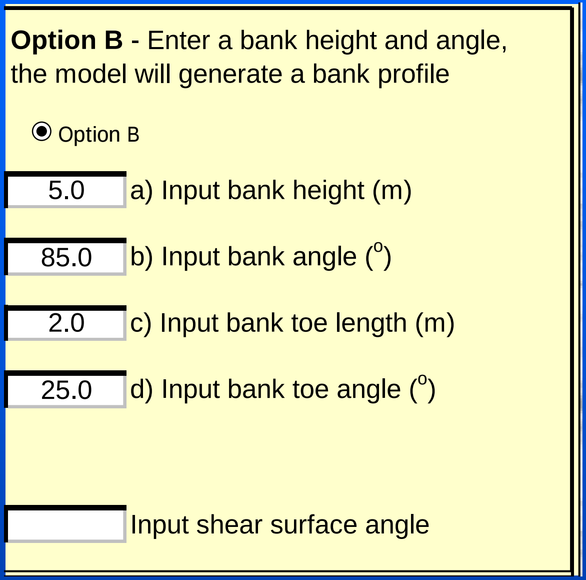
| | | |
|---|---|---|
| Average applied boundary shear stress | 52.200 | Pa |
| Maximum Lateral Retreat | 0.000 | cm |
| Eroded Area - Bank | 0.202 | $m^2$ |
| Eroded Area - Bank Toe | 0.421 | $m^2$ |
| Eroded Area - Bed | 0.000 | $m^2$ |
| Eroded Area - Total | 0.622 | $m^2$ |

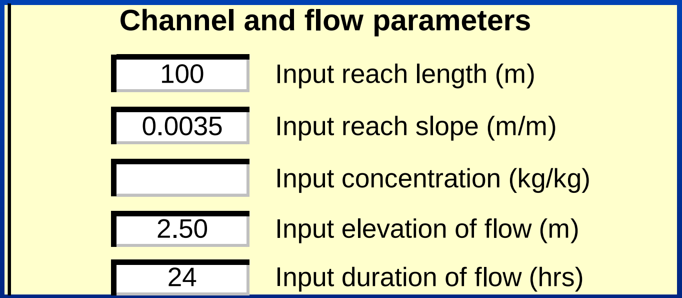
Export New (Eroded) Profile into Model

**Toe Erosion = 0.62 $m^2$**

# Bank-Toe Protection

1. Re-open BSTEM-5.0.xls
2. Select "Input Geometry sheet"
3. Select Option B
4. Input these values:
5. Input channel and flow parameters
6. Click "Run Bank Geometry Macro"
7. Open "Bank Material" sheet
8. Select "Moderate silt" for all layers
9. Select "Toe Model Output" sheet
10. Click "Run Toe-Erosion Model" and notate



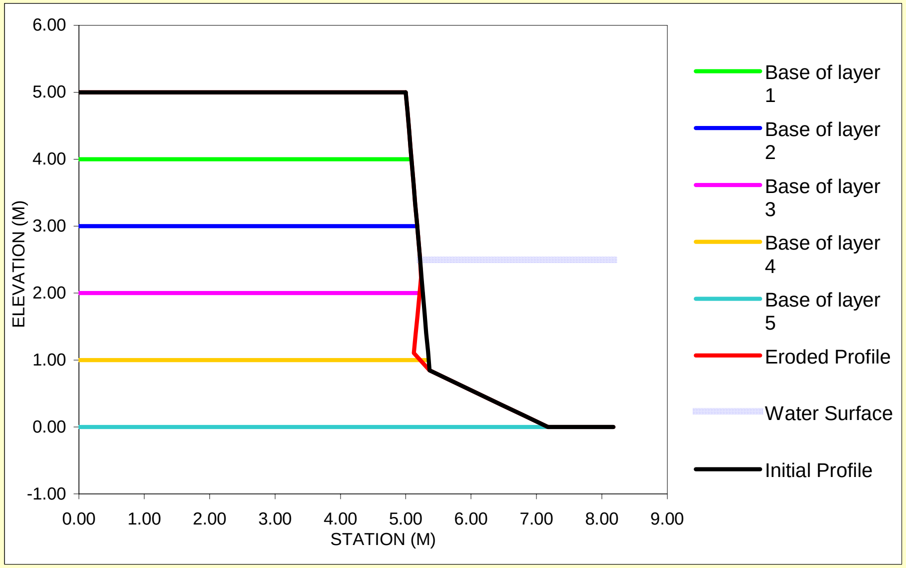

11. Select "Bank Material" sheet and select boulders for layer 5 and toe material
12. Select "Toe Model Output" sheet and click "Run Toe-Erosion Model"

# Toe Erosion with 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).

| Bank Material | | | | Bank Toe Material | | |
|---|---|---|---|---|---|---|
| Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5 | | |
| Moderate cohesive | Moderate cohesive | Moderate cohesive | Moderate cohesive | Boulders | Boulders | **Material** |
| 5.00 | 5.00 | 5.00 | 5.00 | 497.66 | 497.66 | **Critical shear stress (Pa)** |
| 0.045 | 0.045 | 0.045 | 0.045 | 0.004 | 0.004 | **Erodibility Coefficient (cm3/Ns)** |




**Run Toe-Erosion Model**

| | | |
|---|---|---|
| Average applied boundary shear stress | 52.200 | Pa |
| Maximum Lateral Retreat | 0.000 | cm |
| Eroded Area - Bank | 0.154 | $m^2$ |
| Eroded Area - Bank Toe | 0.000 | $m^2$ |
| Eroded Area - Bed | 0.000 | $m^2$ |
| Eroded Area - Total | 0.154 | $m^2$ |

Export New (Eroded) Profile into Model

**Toe Erosion = 0.15 $m^2$**

# Distinguish Between Hydraulic and Geotechnical Bank Protection

| | |
|---|---|
| • Toe armoring<br>rock, LWD, live vegetation, fiberschines<br>• Bank face armoring<br>mattresses, vertical bundles, geotextiles | Hydraulic Protection |
| • Bank reinforcement<br>pole and post plantings, bank top vegetation, brush layers, drainage | Geotechnical Protection |

# Distinguish Between Hydraulic and Geotechnical Bank Protection

- Hydraulic protection reduces the available boundary hydraulic shear stress and increases the shear resistance to particle detachment

**Hydraulic Protection**

- Geotechnical protection increases soil shear strength and decreases driving forces

**Geotechnical Protection**