Bank-Stability and Toe-Erosion Model

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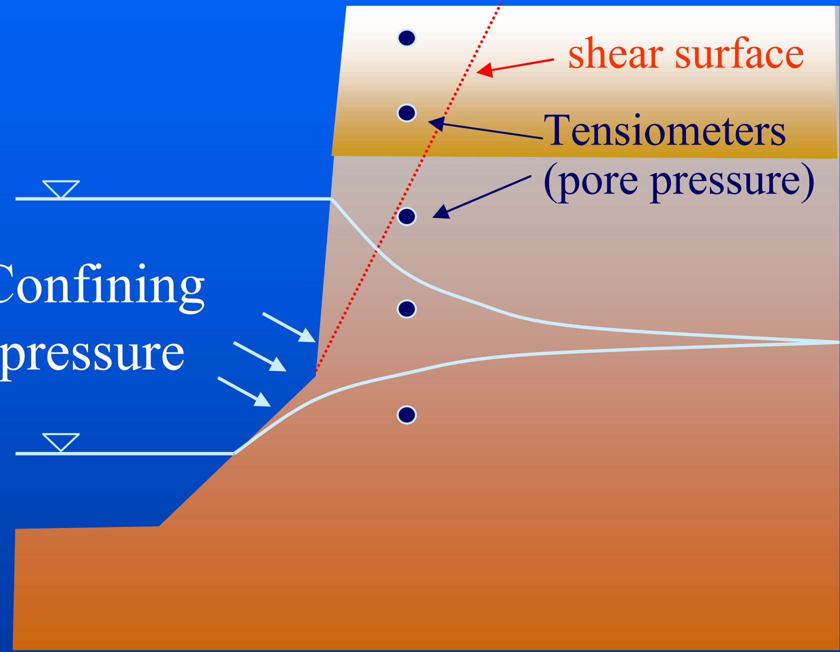
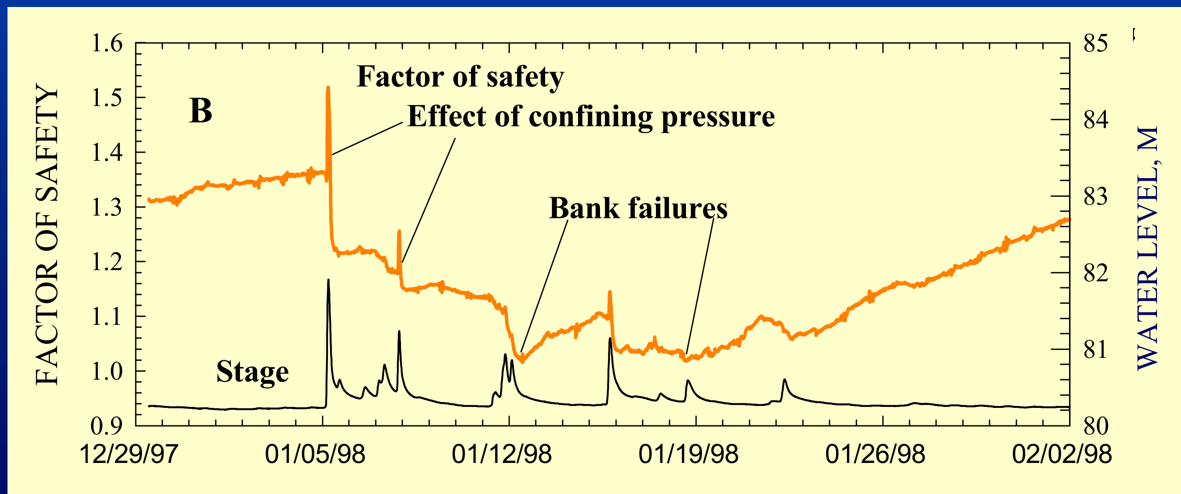
Bank-Stability Model

- 2-D wedge-failure model
- Incorporates both positive and negative pore-water pressures
- Simulates confining pressures from stage
- Incorporates layers of different strength and characteristics
- Inputs:
  γ_s, c', ϕ', ϕ^b, h, u_w





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.
- **Toe Model Step 2 page**: Enter erodibility data for bank toe and soil layers, and run shear-stress calculations.
- **Toe Model Data page**: Enter non-default values for erodibility.
- **Bank Model Step 2 page**: Enter bank-material properties (geotechnical), water table/pore-water pressure information, and obtain results.
- **Bank Model Data page**: Enter non-default values for bank-material (geotechnical) properties.

Modeling Steps

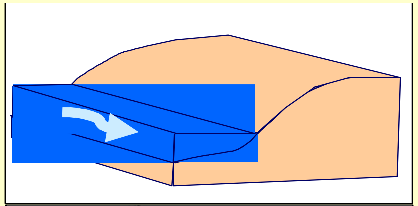
- Model the current bank profile by first evaluating the effect of hydraulic erosion at the bank toe.
- Take the resulting new profile and run this in the bank-stability model to see if the eroded bank is stable.
- Devise environmentally-sensitive schemes to protect the bank from both erosion and instability.
- Test these proposed schemes for erosion resistance and bank stability in the two models.

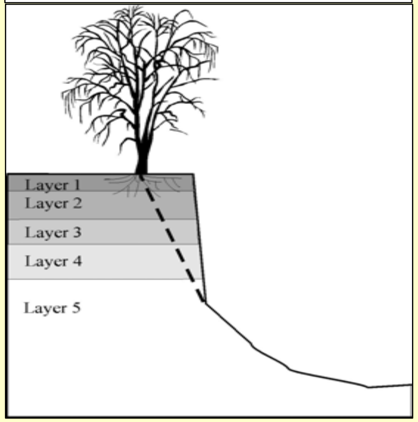
Operational Steps

1. Open Excel file “bsandtem4.1”
2. Click on “Enable Macros”…to “Introduction” sheet

Introduction Sheet

Bank Stability Model





The Channel Bank Stability Model is a wedge-based limit equilibrium model that calculates Factor of Safety (*Fs*) for multi-layer river and streambanks. It 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)) 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 Model Step 2** and **Bank Model Data)** to find the Factor of Safety.

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.

In addition to this static model there is also a dynamic version that uses a time series of pore-water pressure values to calculate *Fs*.

Bank Toe Erosion Model

The Bank Toe Erosion Model calculates erosion into the toe and bank of channels in response to applied 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 calculates boundary shear stress from channel geometry, and considers critical shear stress and erodibility of three separate zones with potentially very different materials: bed, toe and bank. The model assumes that erosion is not transport limited.

Input the bank coordinates, flow parameters and channel slope **(Input Geometry)**, then input your bed, bank and toe material types and erosion protection (if any) **(Toe Model Step 2** and **Toe Model Data)**. Next, run the shear stress macro to determine how much erosion may occur during the prescribed storm event.

Disclaimer
The model has been parameterized with literature values for variables corresponding to different vegetation and soil / sediment types. In reality these values will change from site to site and may be different from those used here.

Users are urged to check these values in the respective **Data** worksheets and, where appropriate, substitute them with their own or with conservative values. The USDA-ARS is not responsible for problems arising from the use of either model.

Operational Steps

1. Open Excel file “bsandtem4.1”
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 3 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.
You can check to ensure bank profile is correct on either **Toe Model Step 2** or **Bank Model Step 2**.

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

○ Option A

Point	Station (m)	Elevation (m)
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		

K - shear emergence

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 (°)

Either input shear surface angle;

Input shear surface angle

Or check box and have the model calculate shear surface angle from soil friction angle and bank angle

☐ Calculate shear surface angle from soil friction

Input mean soil friction angle

Need to know the shear surface angle?

Input mean bank angle
Input mean soil friction angle

0.0 **Recommended shear surface angle**

2. Bank layer thickness (m)

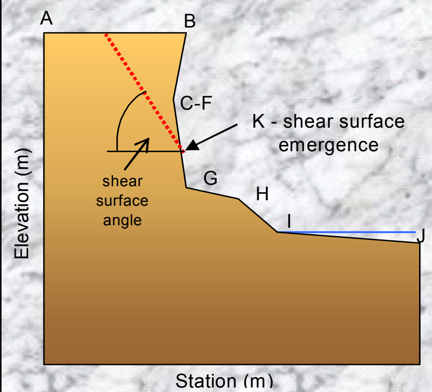
Parallel layers, starting from point B

	Bank layer thickness (m)	Elevation of layer base (m)
Layer 1 (Top Layer)		0.00
Layer 2		0.00
Layer 3		0.00
Layer 4		0.00
Layer 5 (Bottom Layer)		0.00

3. Channel flow parameters

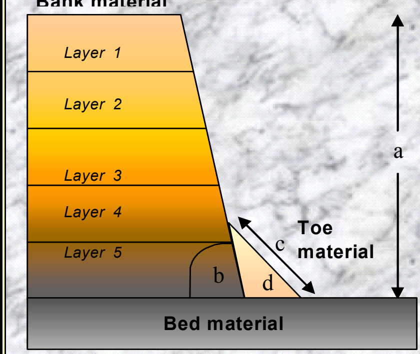
Input elevation of flow (m)
Input slope of channel (m/m)
Input duration of flow (hrs)

Definition of points used in bank profile



A - bank top: place beyond start of shear surface
B - bank edge
C-F - breaks of slope on bank (if no breaks of slope place as intermediary points)
G - top of bank toe
H - break of slope on bank toe (if no break of slope then insert as intermediary point)
I - base of bank toe
J - end point (typically mid point of channel)
K- elevation of point where shear surface emerges on the bank (anywhere between B and G)

Notes:
Shear surface must enter bank top between points A and B.
Bank profile may overhang.
Point K must not be on a horizontal section - the elevation of this point must be unique or an error message will display.



Select which component you wish to use first. You will be automatically redirected to the relevant worksheet after hitting the Run Bank Geometry Macro button

Bank Stability component ▼

Run Bank Geometry Macro

Operational Steps

1. Open Excel file “bsandtem4.1”
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 3 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.
You can check to ensure bank profile is correct on either **Toe Model Step 2** or **Bank Model Step 2**.

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

○ Option A

Point	Station (m)	Elevation (m)
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		
K - shear emergence		
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 (°)

Either input shear surface angle;
Input shear surface angle

Or check box and have the model calculate shear surface angle from soil friction angle and bank angle

☐ Calculate shear surface angle from soil friction

Input mean soil friction angle

Need to know the shear surface angle?
Input mean bank angle
Input mean soil friction angle

0.0 **Recommended shear surface angle**

2. Bank layer thickness (m)

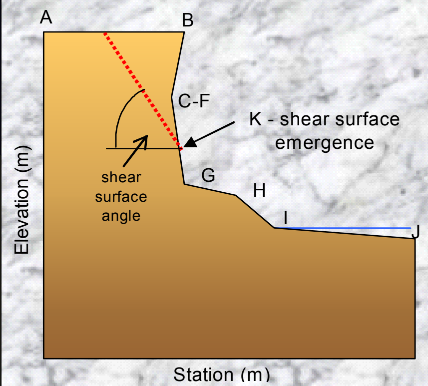
Parallel layers, starting from point B

	Bank layer thickness (m)	Elevation of layer base (m)
Layer 1 (Top Layer)		0.00
Layer 2		0.00
Layer 3		0.00
Layer 4		0.00
Layer 5 (Bottom Layer)		0.00

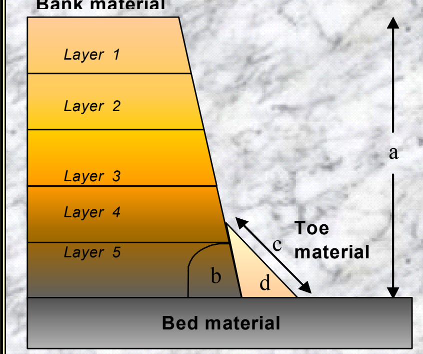
3. Channel flow parameters

Input elevation of flow (m)
Input slope of channel (m/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-F - breaks of slope on bank (if no breaks of slope place as intermediary points)
G - top of bank toe
H - break of slope on bank toe (if no break of slope then insert as intermediary point)
I - base of bank toe
J - end point (typically mid point of channel)
K- elevation of point where shear surface emerges on the bank (anywhere between B and G)



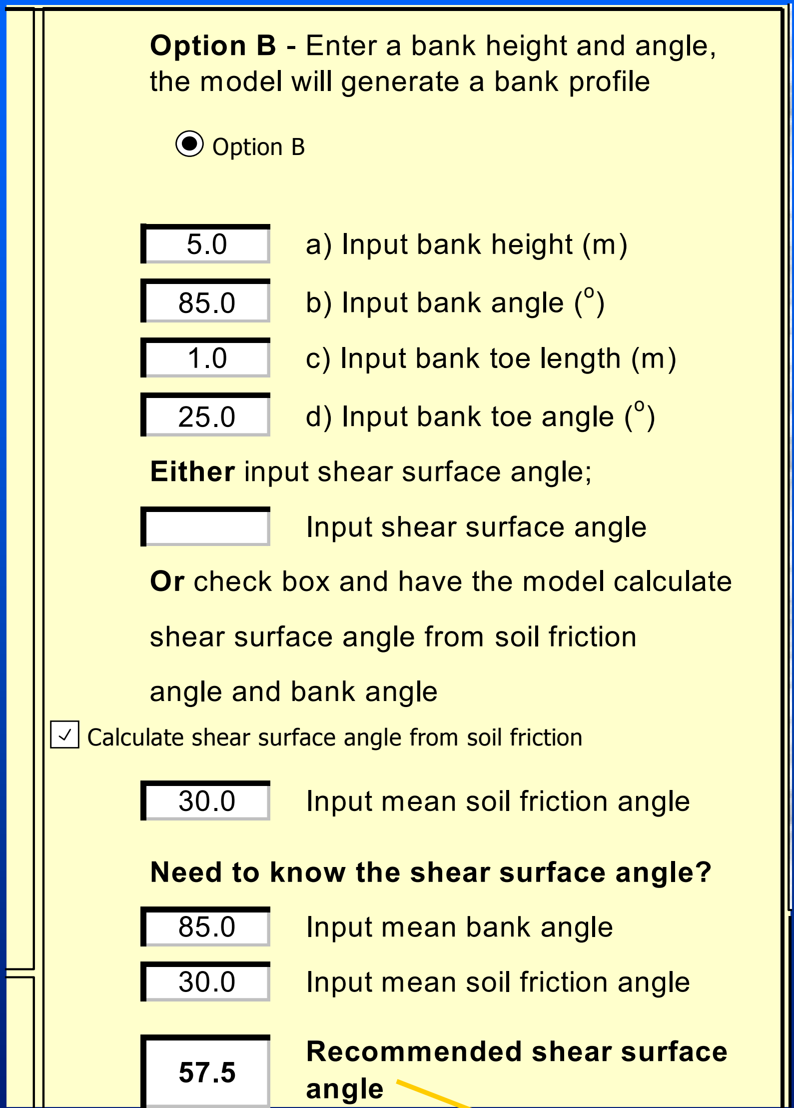
Notes:
Shear surface must enter bank top between points A and B.
Bank profile may overhang.
Point K must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

Select which component you wish to use first. You will be automatically redirected to the relevant worksheet after hitting the Run Bank Geometry Macro button

Bank Stability component ▼

Run Bank Geometry Macro

Starting with Option *B (P. Downs version)*



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 (°)

Either input shear surface angle;

[ ] Input shear surface angle

Or check box and have the model calculate shear surface angle from soil friction angle and bank angle

☑ Calculate shear surface angle from soil friction

30.0 Input mean soil friction angle

Need to know the shear surface angle?

85.0	Input mean bank angle
30.0	Input mean soil friction angle
57.5	**Recommended shear surface angle**

If you don't know failure-plane angle

Select: Option B

- 5m high bank
- 85 degree angle
- 1m toe length
- 25 degree toe angle
- Friction angle 30 degrees
- Enter shear surface angle

Operational Steps

1. Open Excel file “bsandtem4.1”
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

Input bank geometry and flow conditions

Work through all 3 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.

You can check to ensure bank profile is correct on either **Toe Model Step 2** or **Bank Model Step 2**.

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

○ Option A

Point	Station (m)	Elevation (m)
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		
K - shear emergence		
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 (°)

Either input shear surface angle;

	Input shear surface angle

Or check box and have the model calculate shear surface angle from soil friction angle and bank angle

☑ Calculate shear surface angle from soil friction

30.0	Input mean soil friction angle

Need to know the shear surface angle?

85.0	Input mean bank angle
30.0	Input mean soil friction angle
57.5	**Recommended shear surface angle**

2. Bank layer thickness (m)

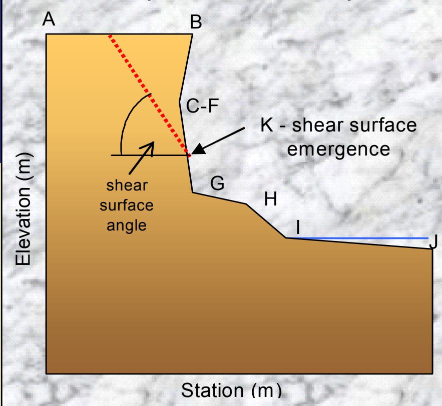
Parallel layers, starting from point B

	Bank layer 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

3. Channel flow parameters

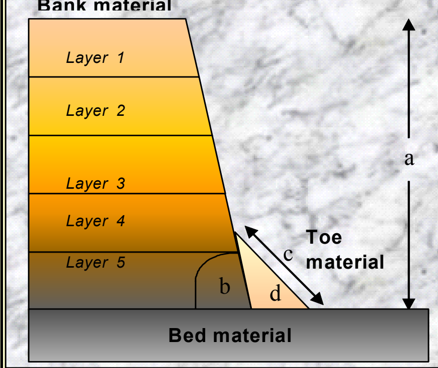
2.00	Input elevation of flow (m)
0.0035	Input slope of channel (m/m)
12	Input duration of flow (hrs)

Definition of points used in bank profile



A - bank top: place beyond start of shear surface
B - bank edge
C-F - breaks of slope on bank (if no breaks of slope place as intermediary points)
G - top of bank toe
H - break of slope on bank toe (if no break of slope then insert as intermediary point)
I - base of bank toe
J - end point (typically mid point of channel)
K- elevation of point where shear surface emerges on the bank (anywhere between B and G)

Notes:
Shear surface must enter bank top between points A and B.
Bank profile may overhang.
Point K must not be on a horizontal section - the elevation of this point must be unique or an error message will display.



Select which component you wish to use first. You will be automatically redirected to the relevant worksheet after hitting the Run Bank Geometry Macro button

Bank Stability component ▼

Run Bank Geometry Macro

Enter Bank Layer Thickness: Detail

2. Bank layer thickness (m)

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

Parallel layers, starting from point B

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

If the bank is all one material it helps to divide it into several layers.

Layer 5 must 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 I (base of bank toe) if option A is selected, or 0 (zero) if option B is selected

Operational Steps

1. Open Excel file “bsandtem4.1”
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-flow parameters

Flow Parameters for Toe-Erosion Model

Input bank geometry and flow conditions

Work through all 3 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.
You can check to ensure bank profile is correct on either **Toe Model Step 2** or **Bank Model Step 2**.

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

○ Option A

Point	Station (m)	Elevation (m)
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		
K - shear emergence		
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 (°)

Either input shear surface angle;

	Input shear surface angle

Or check box and have the model calculate shear surface angle from soil friction angle and bank angle

☑ Calculate shear surface angle from soil friction

30.0	Input mean soil friction angle

Need to know the shear surface angle?

85.0	Input mean bank angle
30.0	Input mean soil friction angle
57.5	**Recommended shear surface angle**

2. Bank layer thickness (m)

	Bank 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

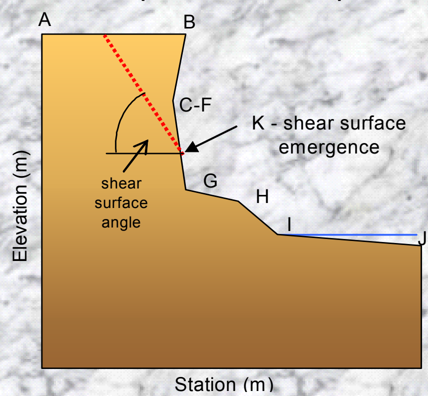
Top Layer → Bottom Layer

Parallel layers, starting from point B

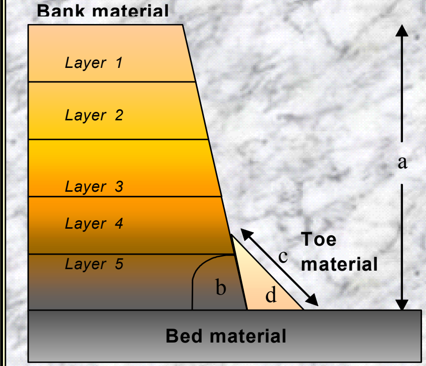
3. Channel flow parameters

2.00	Input elevation of flow (m)
0.0035	Input slope of channel (m/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-F - breaks of slope on bank (if no breaks of slope place as intermediary points)
G - top of bank toe
H - break of slope on bank toe (if no break of slope then insert as intermediary point)
I - base of bank toe
J - end point (typically mid point of channel)
K- elevation of point where shear surface emerges on the bank (anywhere between B and G)



Notes:
Shear surface must enter bank top between points A and B.
Bank profile may overhang.
Point K must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

Select which component you wish to use first. You will be automatically redirected to the relevant worksheet after hitting the Run Bank Geometry Macro button

Bank Stability component ▼

Run Bank Geometry Macro

Flow Parameters for Toe-Erosion Model

3. Channel flow parameters

2.00	Input elevation of flow (m)
0.0035	Input slope of channel (m/m)
12	Input duration of flow (hrs)

Input the above values for this example

Operational Steps

1. Open Excel file “bsandtem4.1”
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-flow parameters
7. Select model component: <u>Toe Erosion</u> and click “Run Bank Geometry Macro” - You are directed to the appropriate “Material Types” worksheet.

Select the Component to Model

Input bank geometry and flow conditions

Work through all 3 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.
You can check to ensure bank profile is correct on either **Toe Model Step 2** or **Bank Model Step 2**.

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

○ Option A

Point	Station (m)	Elevation (m)
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		
K - shear emergence		
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 (°)

Either input shear surface angle;

	Input shear surface angle

Or check box and have the model calculate shear surface angle from soil friction angle and bank angle

☑ Calculate shear surface angle from soil friction

30.0	Input mean soil friction angle

Need to know the shear surface angle?

85.0	Input mean bank angle
30.0	Input mean soil friction angle
57.5	**Recommended shear surface angle**

2. Bank layer thickness (m)

	Bank 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

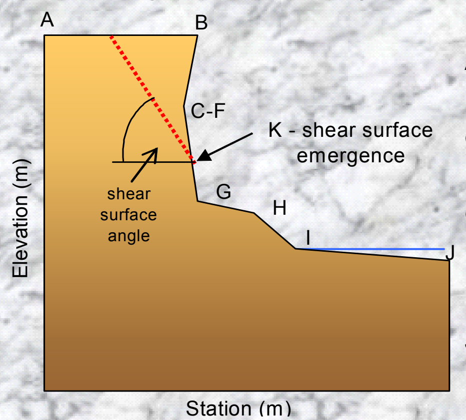
Top Layer → Bottom Layer

Parallel layers, starting from point B

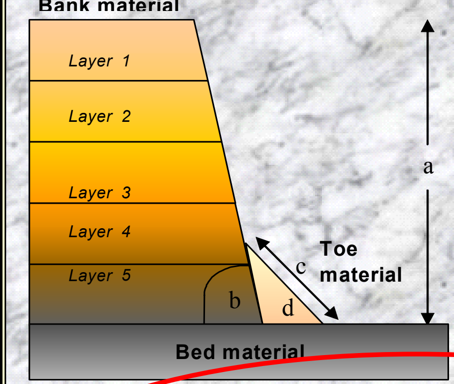
3. Channel flow parameters

2.00	Input elevation of flow (m)
0.0035	Input slope of channel (m/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-F - breaks of slope on bank (if no breaks of slope place as intermediary points)
G - top of bank toe
H - break of slope on bank toe (if no break of slope then insert as intermediary point)
I - base of bank toe
J - end point (typically mid point of channel)
K- elevation of point where shear surface emerges on the bank (anywhere between B and G)



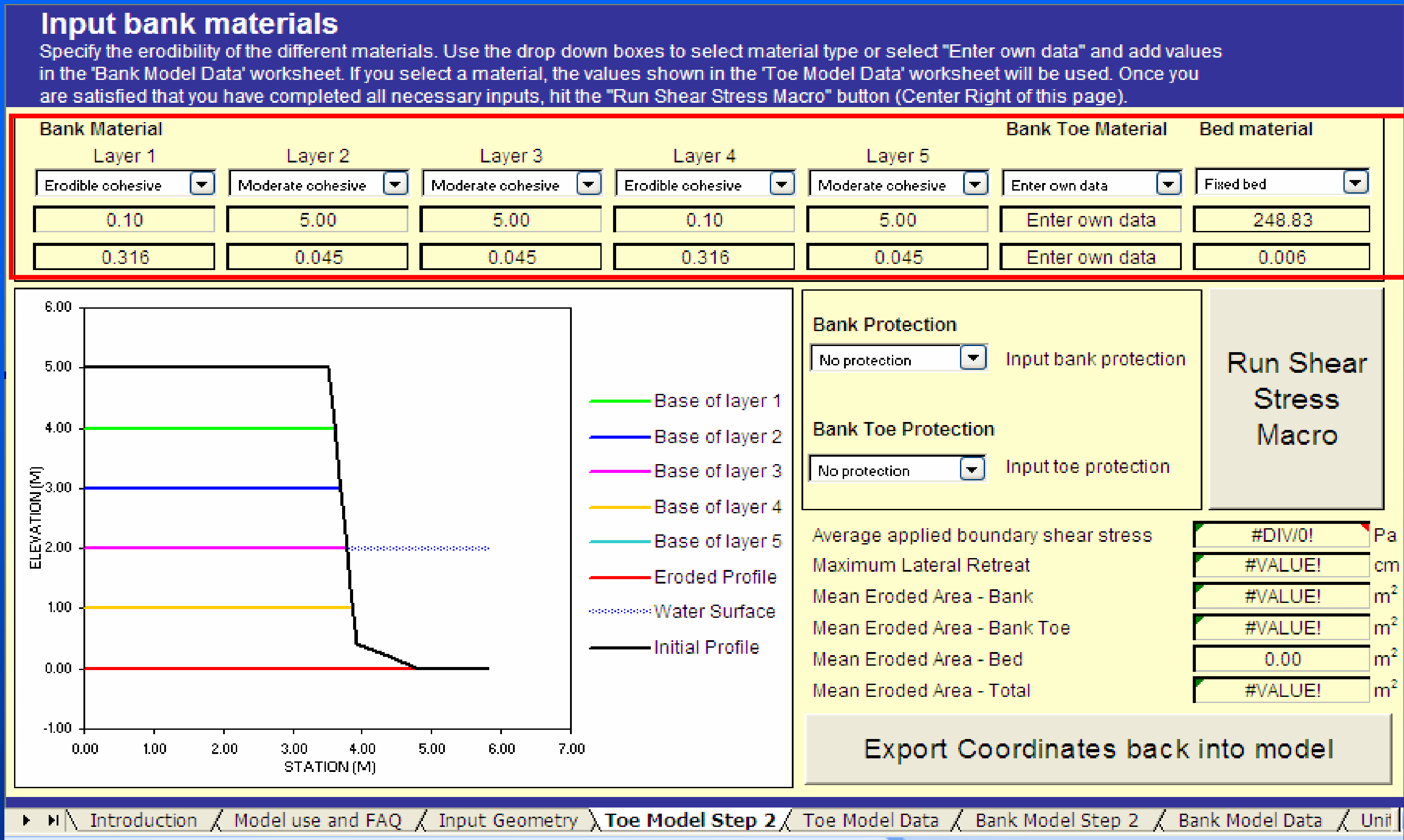
Notes:
Shear surface must enter bank top between points A and B.
Bank profile may overhang.
Point K must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

Select which component you wish to use first. You will be automatically redirected to the relevant worksheet after hitting the Run Bank Geometry Macro button

Bank Stability component ▼

Run Bank Geometry Macro

Toe Erosion: Input Bank Materials



Select bank layer materials shown below from drop down boxes :

Layer 1 = Erodible cohesive, **Layer 2** = Moderate cohesive,

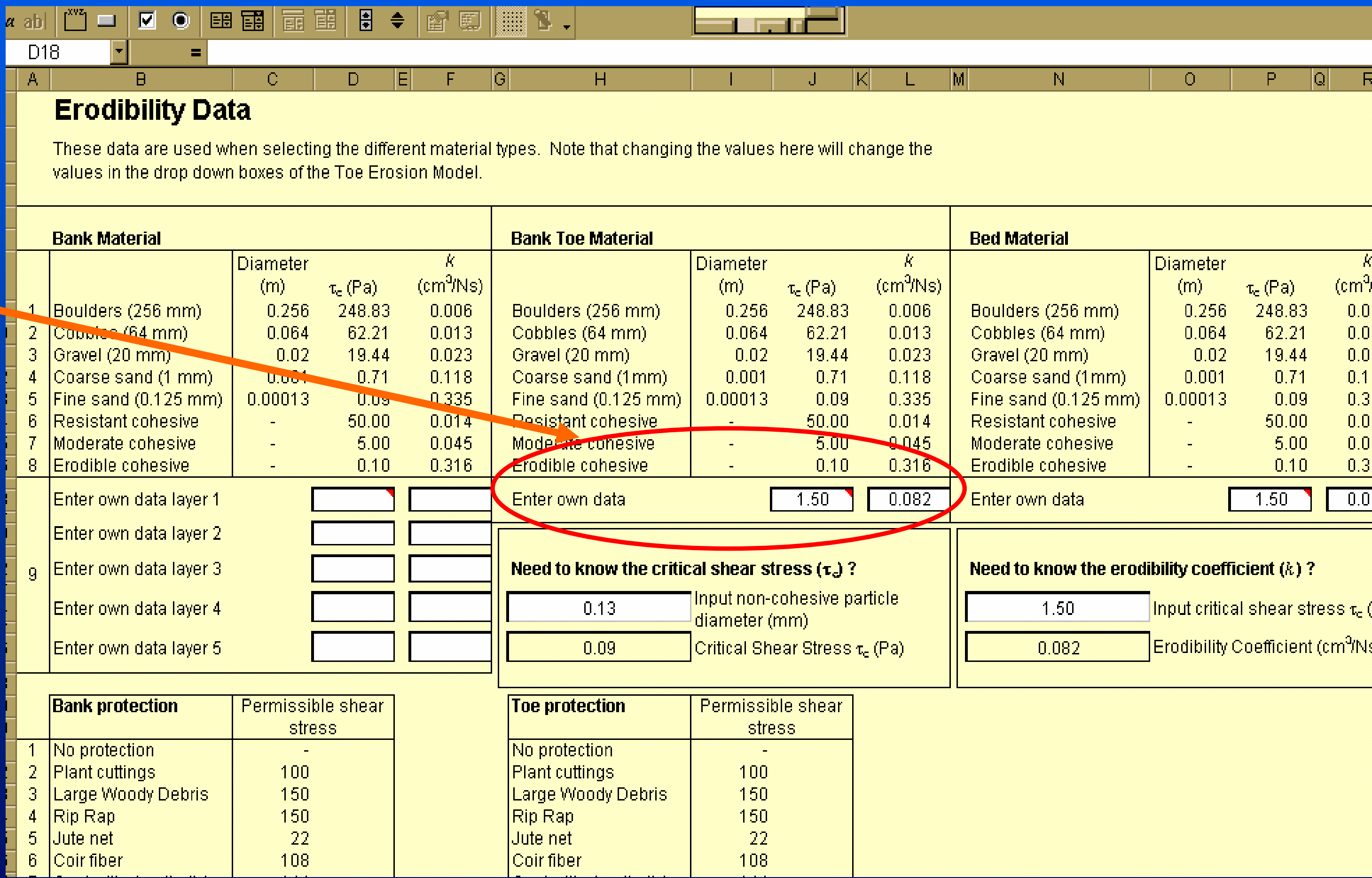
Layer 3 = Moderate cohesive, **Layer 4** = Erodible cohesive,

Layer 5 = Moderate cohesive, **Bank Toe Material** = own data

Toe Erosion: Input Bank Materials

•Click on the “Toe model data” sheet to enter your own data for the bank toe.

For this example, enter values of τ_c = 1.5 k = 0.082 for toe material

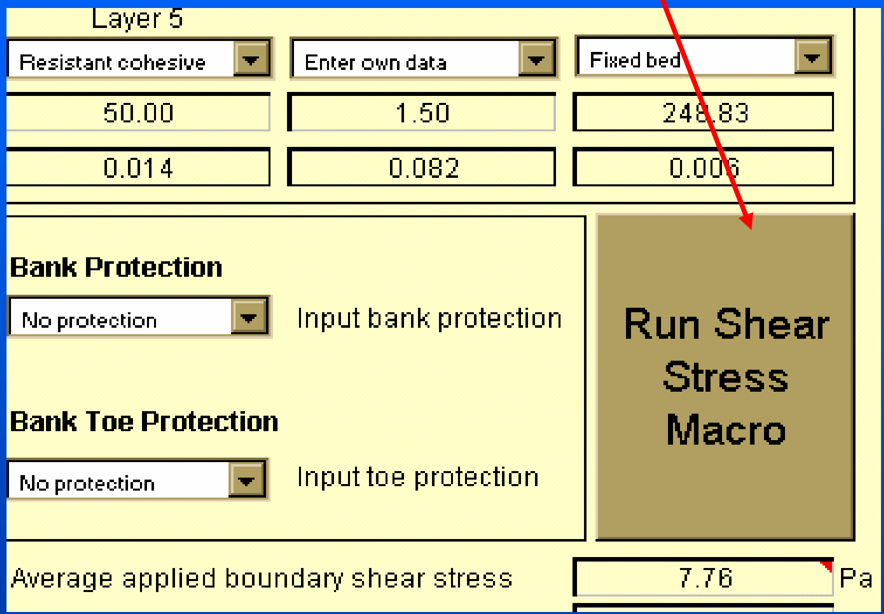


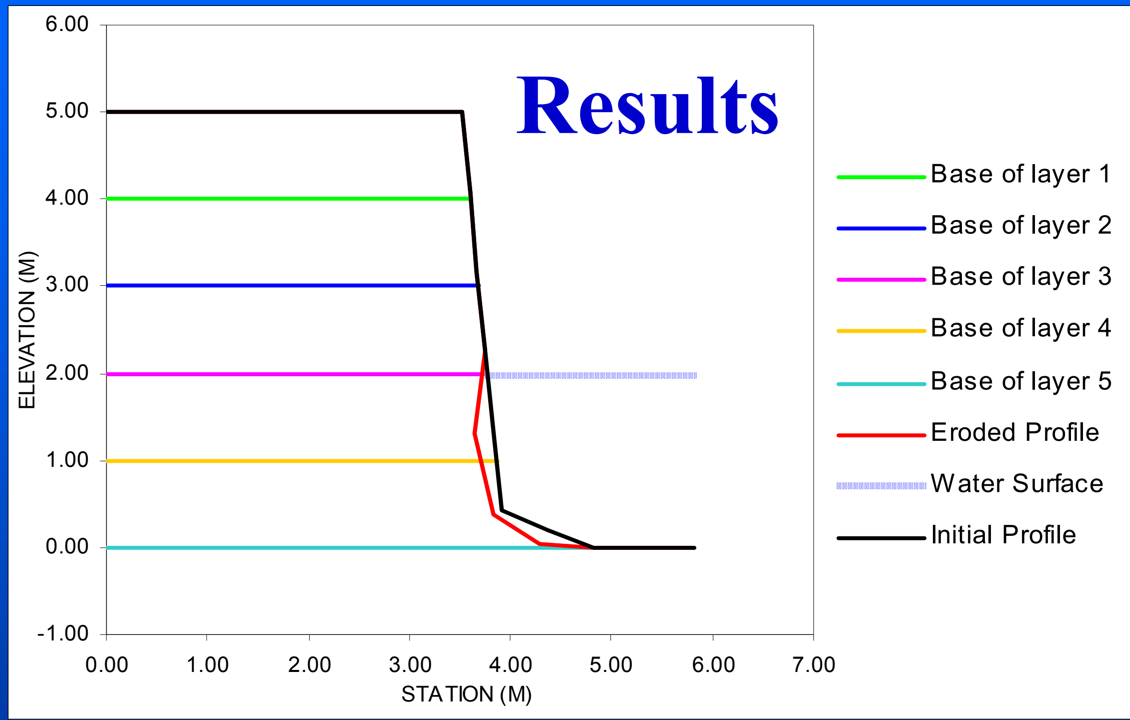
Operational Steps

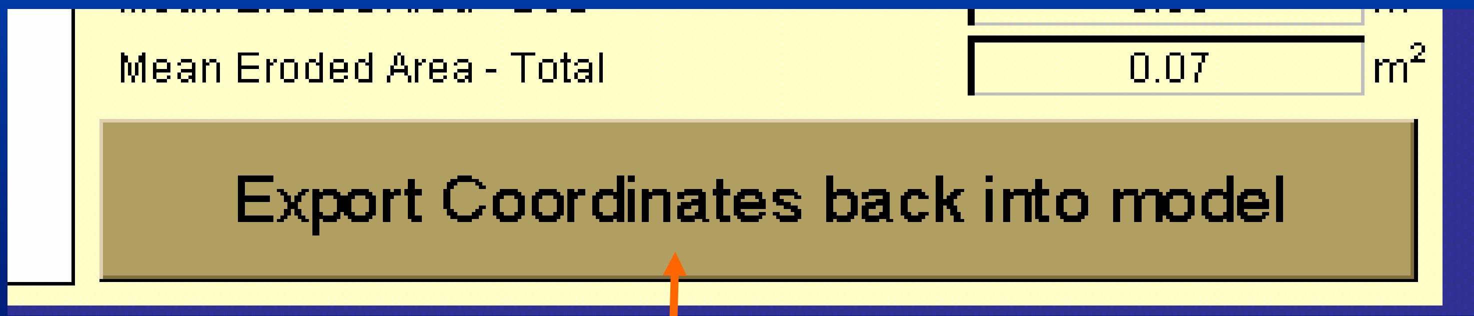
1. Open Excel file “bsandtem4.1”
2. Click on “Enable Macros”…to “Introduction” sheet
3. Click on “Input Geometry” sheet
4. Select EITHER Option *A* or Option *B* to input bank geometry
5. Enter Bank-layer Thickness
6. Enter channel-flow parameters
7. Select model component: Toe Erosion and click “Run Bank Geometry Macro” - You are directed to the appropriate “Material Types” worksheet.
8. Return to “Toe Erosion Model Step 2” worksheet. Click on “Run Shear Stress Macro”. Note undercutting. Click on “Export coordinates back into model”

Toe Erosion

'Toe Erosion Step 2' worksheet







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)
A	0.00	5.00
B	3.52	5.00
C	3.60	4.08
D	3.68	3.17
E	3.76	2.25
F	3.64	1.32
G	3.84	0.39
H	4.29	0.04
I	4.82	0.00
J	5.82	0.00
K - shear emergence		
Shear surface angle		

Use 1.0 and 57.5

Model redirects you back to the "Input geometry" sheet. You can run another flow event or run the Bank-Stability model.

We will choose to run the Bank-Stability model.

To run Bank-Stability Component you must first select elevation of shear-surface emergence and shear-surface angle.

Operational Steps

1. Open Excel file "bsandtem4.1"
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-flow parameters
7. Select model component: Toe Erosion and click "Run Bank Geometry Macro" - You are directed to the appropriate "Material Types" worksheet.
8. Click on "Run Shear Stress Macro" then click on "Export coordinates back into model"
9. Enter shear-plane emergence elevation and angle, then click on "Bank Model Step 2" worksheet

Material Types: Stability Model

Select material types, vegetation cover and water table depth below bank top

(or select "own data" and add values in 'Bank Model Data' worksheet)

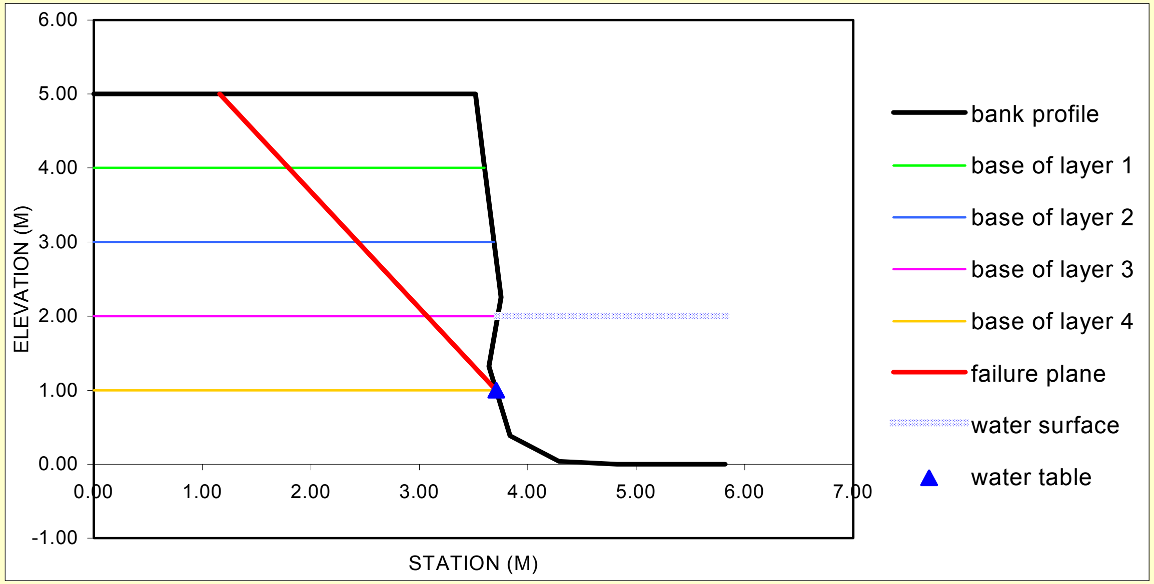
Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Gravel	Gravel	Gravel	Gravel	Gravel
Angular sand	Angular sand	Angular sand	Angular sand	Angular sand
Rounded sand	Rounded sand	Rounded sand	Rounded sand	Rounded sand
Silt	Silt	Silt	Silt	Silt
Stiff clay	Stiff clay	Stiff clay	Stiff clay	Stiff clay

Bank top vegetation cover (age): None

Vegetation safety margin: 50

Reach Length (m): 100

Constituent concentration (kg/kg): 0.001



Water table depth (m) below bank top: 4.00

- Use water table (selected)
- Input own pore pressures (kPa)

Own Pore Pressures	kPa	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

57.5 Shear surface angle used

Export Coordinates back into model

Factor of Safety

1.09 Conditionally stable

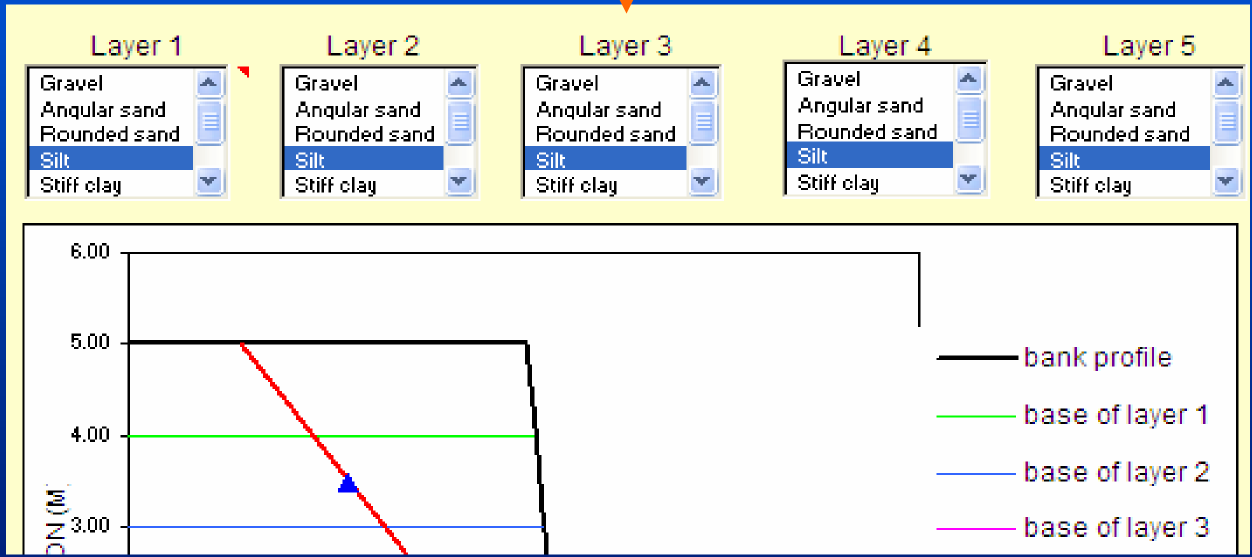
Failure width	2.35	m
Failure volume	487	m^3
Sediment loading	814176	kg
Constituent load	814	kg

Operational Steps

5. Enter Bank-layer Thickness
6. Enter channel-flow parameters
7. Select model component: Toe Erosion and click "Run Bank Geometry Macro" - You are directed to the appropriate "Material Types" worksheet.
8. Click on "Run Shear Stress Macro" then click on "Export coordinates back into model"
9. Enter shear-plane emergence elevation and angle, then click on "Bank Model Step 2" worksheet
10. Select bank-material types to assign geotechnical values

Bank material properties

- In this example start by selecting 'silt' for all five soil layers, from the drop down boxes



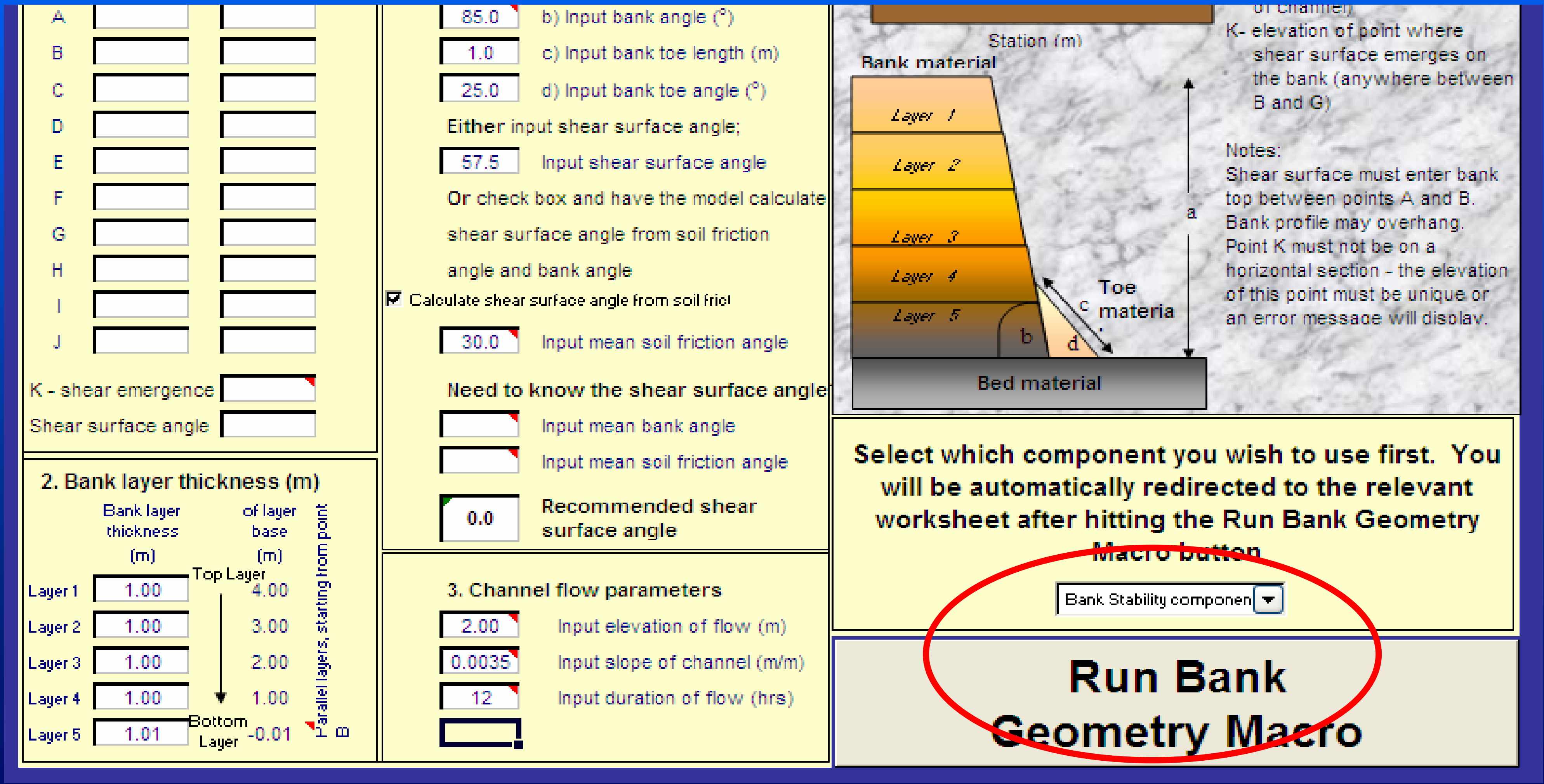
Bank-Material Properties (cont'd)

If you wanted to add your own geotechnical data you could select "own data" from the drop down boxes and go to "Bank Model data" sheet to enter your own values

Bank material type	Description	Friction angle ϕ'	Cohesion c' (kPa)	Saturated unit weight (kN/m^3)	ϕb (degrees)
1	Gravel	36	0	20	5
2	Angular sand	36	0	18	15
3	Rounded sand	27.0	0.0	18	15
4	Silt	25.0	5.0	18	15
5	Stiff clay	10.0	15.0	18	15
6	Soft clay	30	10	16	15
7	Own data layer 1	27.0	0.4	21.4	15.0
	Own data layer 2	0.0	79.0	21.6	15.0
	Own data layer 3	35.0	0.0	21.6	15.0
	Own data layer 4	15.0	10.0	16.0	12.0
	Own data layer 5	15.0	10.0	16.0	12.0

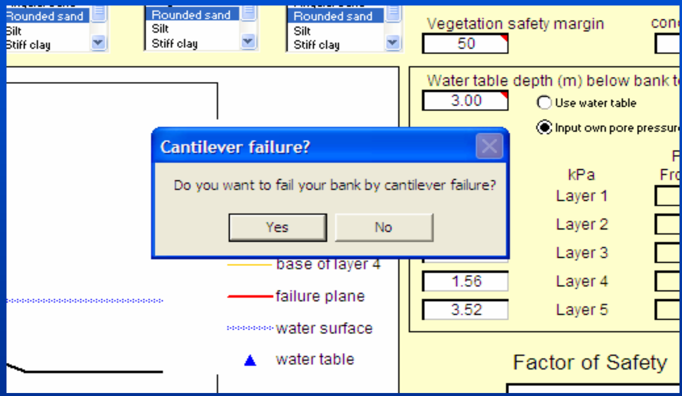
Again, For this example choose silt for all layers

Go back to "Input Geometry" worksheet. Select 'Bank Stability Component' and then click on "Run Bank Geometry Macro" button



Running bank stability macro…

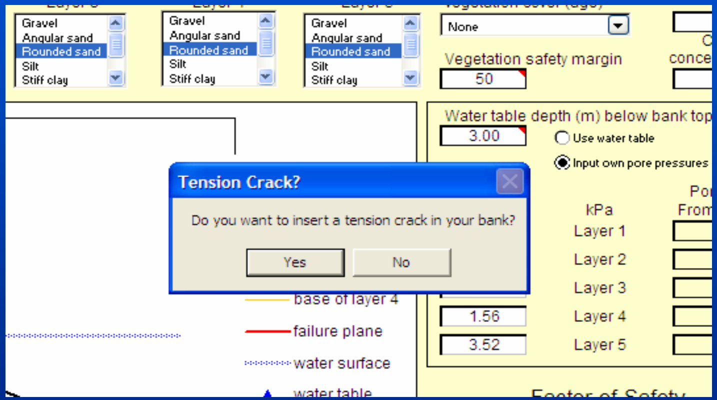
First you are asked if you want to select a cantilever failure:



For this example, select "No"

Running bank stability macro…

If you choose not to select a cantilever failure, as in this case, another message box will appear, asking if you want to insert a tension crack.



Again, for this first example select "No" (we will use this feature in a later example)

Operational Steps

5. Enter Bank-layer Thickness
6. Enter channel-flow parameters
7. Select model component: Toe Erosion and click “Run Bank Geometry Macro” - You are directed to the appropriate “Material Types” worksheet.
8. Click on “Run Shear Stress Macro” then click on “Export coordinates back into model”
9. Enter shear-plane emergence elevation and angle, then select Bank-Stability model and click on “Run bank geometry macro”. Model redirects you to “Select material types”
10. Select bank-material types to assign geotechnical values or select “enter own data”
11. Select type of pore-water pressure data (water-table elevation or measured values).

Data for Pore-Water Pressure

In "Bank Model Step 2" worksheet

Water table depth (m) below bank top

4.00

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

Or

Own Pore Pressures	kPa	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

In this case select option to use water table depth, and enter a value of 4.0m below the bank top

Results: Factor of Safety

Factor of Safety

1.09	Conditionally stable	
Failure width	2.35	m
Failure volume	487	m^3
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)

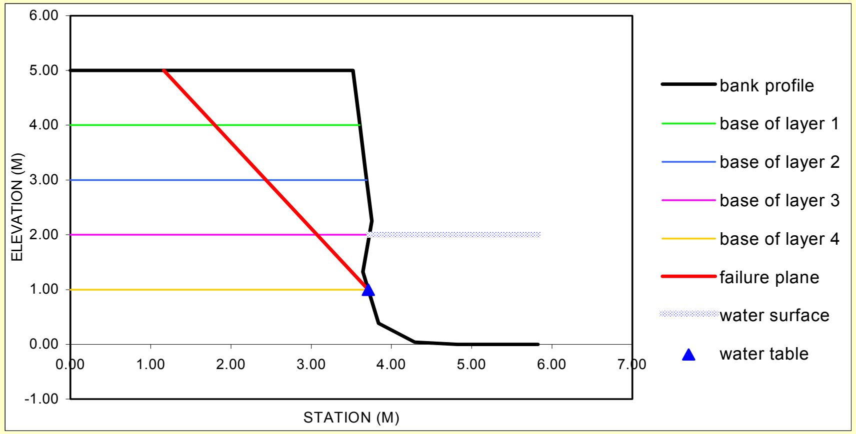
Layer 1	Layer 2	Layer 3	Layer 4	Layer 5
Gravel / Angular sand / Rounded sand / Silt / Stiff clay	Gravel / Angular sand / Rounded sand / Silt / Stiff clay	Gravel / Angular sand / Rounded sand / Silt / Stiff clay	Gravel / Angular sand / Rounded sand / Silt / Stiff clay	Gravel / Angular sand / Rounded sand / Silt / Stiff clay

Bank top vegetation cover (age): None

Vegetation safety margin: 50

Reach Length (m): 100

Constituent concentration (kg/kg): 0.001



Water table depth (m) below bank top: 4.00

- (•) Use water table
- ( ) Input own pore pressures (kPa)

Own Pore Pressures	kPa	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

57.5 Shear surface angle used

Export Coordinates back into model

Factor of Safety

1.09	Conditionally stable	
Failure width	2.35	m
Failure volume	487	m^3
Sediment loading	814176	kg
Constituent load	814	kg

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

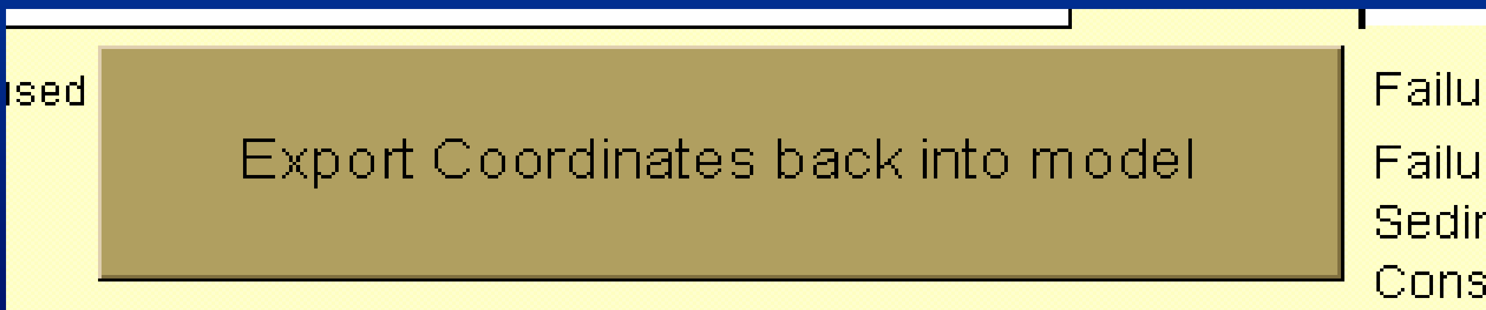
Try experimenting with the following parameters to get a feel for the model:

- Water surface elevation (Input Geometry Sheet)
- Shear angle (Input Geometry Sheet)
- Water table height (Bank Model Step 2 sheet)
- Bank material types (Bank Model Step 2 sheet)
- Vegetation component (Bank Model Step 2 sheet)

Further Simulations…

Once stability has been determined, the coordinates may be exported back into the model ("Initial Geometry" sheet) IF the modeller deems that the bank has failed. This is done by clicking the "Export Coordinates back into model" button.

IF the bank remains stable, return to the "Initial Geometry" sheet to simulate another flow event or another pore-water pressure condition.



Example 2

Go back to “input geometry” worksheet

Make sure Option A is still selected.

We are going to enter a new bank profile. Enter the coordinates opposite

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

Option A

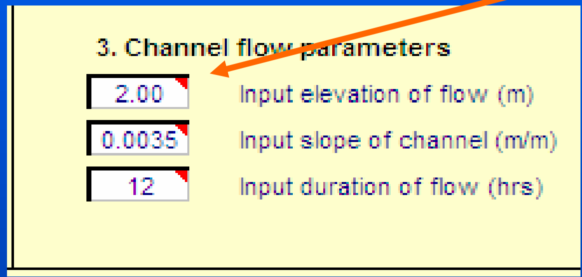
Point	Station (m)	Elevation (m)
A	0.00	5.00
B	3.76	5.00
C	3.76	4.08
D	3.76	3.17
E	3.76	2.25
F	3.20	1.32
G	3.84	0.39
H	4.29	0.04
I	4.82	0.00
J	5.82	0.00

K - shear emergence: 1.32

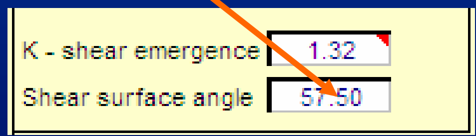
Shear surface angle: 57.50

Example 2

- Set your water surface elevation to 2m



Set your shear emergence elevation to 1.32 and failure surface angle to 57.5 :



Run bank stability macro again…

Input bank geometry and flow conditions

Work through all 3 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.

You can check to ensure bank profile is correct on either **Toe Model Step 2** or **Bank Model Step 2**.

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

○ Option A

Point	Station (m)	Elevation (m)
A		
B		
C		
D		
E		
F		
G		
H		
I		
J		

K - shear emergence:

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})

Either input shear surface angle;

[ ] Input shear surface angle

Or check box and have the model calculate shear surface angle from soil friction angle and bank angle

☑ Calculate shear surface angle from soil friction

30.0 Input mean soil friction angle

Need to know the shear surface angle?

85.0 Input mean bank angle

30.0 Input mean soil friction angle

57.5 **Recommended shear surface angle**

2. Bank layer thickness (m)

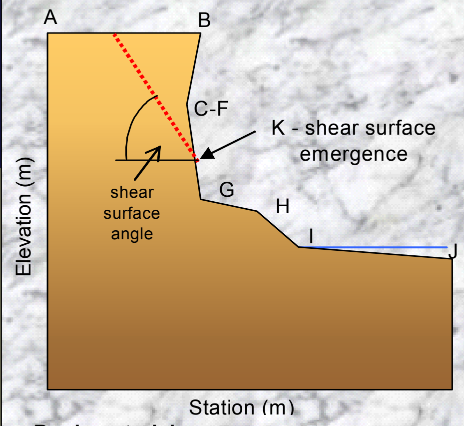
Parallel layers, starting from point B

	Bank layer 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

3. Channel flow parameters

2.00	Input elevation of flow (m)
0.0035	Input slope of channel (m/m)
12	Input duration of flow (hrs)

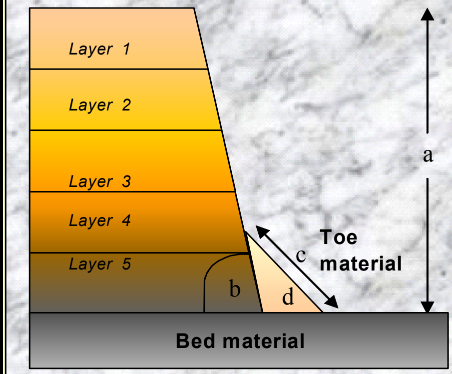
Definition of points used in bank profile



A - bank top: place beyond start of shear surface
B - bank edge
C-F - breaks of slope on bank (if no breaks of slope place as intermediary points)
G - top of bank toe
H - break of slope on bank toe (if no break of slope then insert as intermediary point)
I - base of bank toe
J - end point (typically mid point of channel)
K- elevation of point where shear surface emerges on the bank (anywhere between B and G)

Notes:
Shear surface must enter bank top between points A and B.
Bank profile may overhang.
Point K must not be on a horizontal section - the elevation of this point must be unique or an error message will display.

Bank material

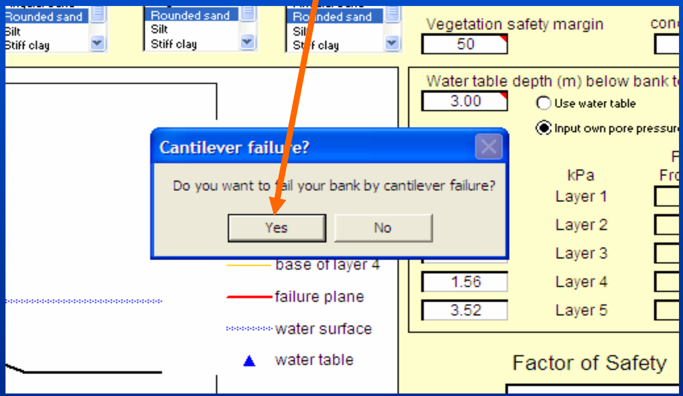


Select which component you wish to use first. You will be automatically redirected to the relevant worksheet after hitting the Run Bank Geometry Macro button

Bank Stability component ▼

Run bank stability macro…

- This time select “Yes” to run a cantilever failure



Enter data for Pore-Water Pressure…

"Bank Model Step 2" worksheet – initially select a value of 4.0 m below bank top for this example

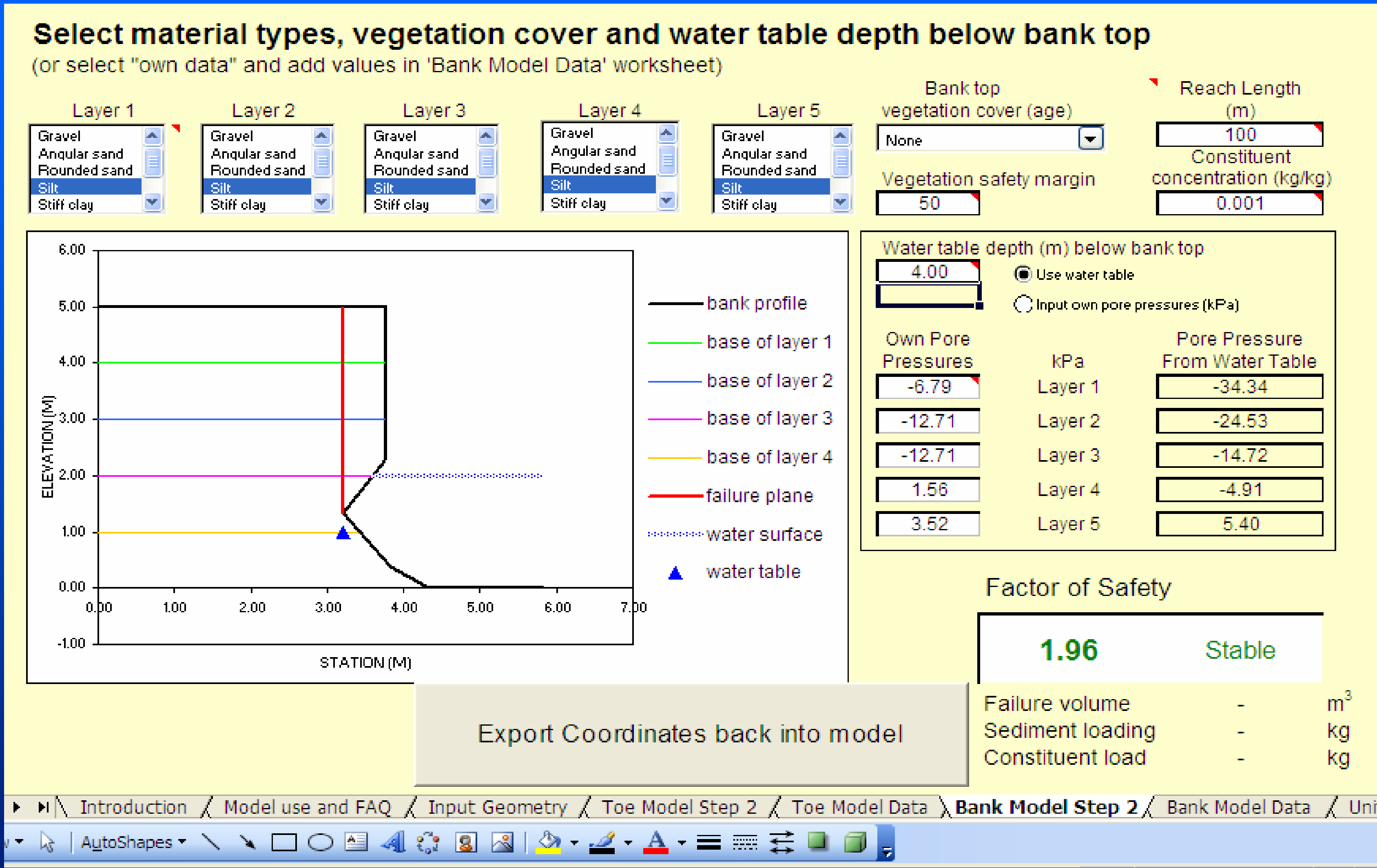
Water table depth (m) below bank top

4.00

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

Own Pore Pressures	kPa	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

Example 2 results…

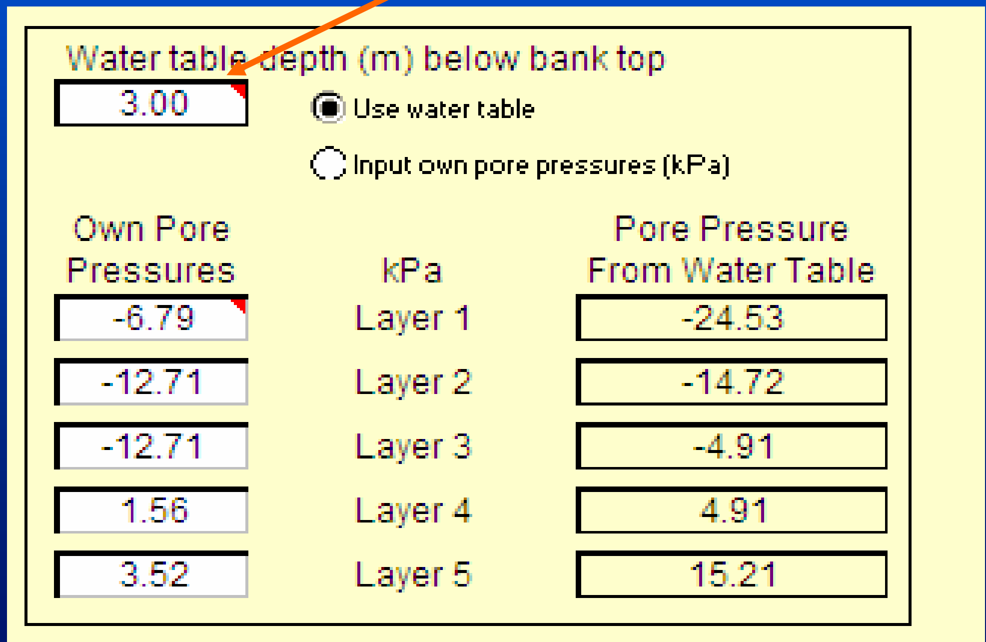


Under these conditions the bank is stable

What happens if……

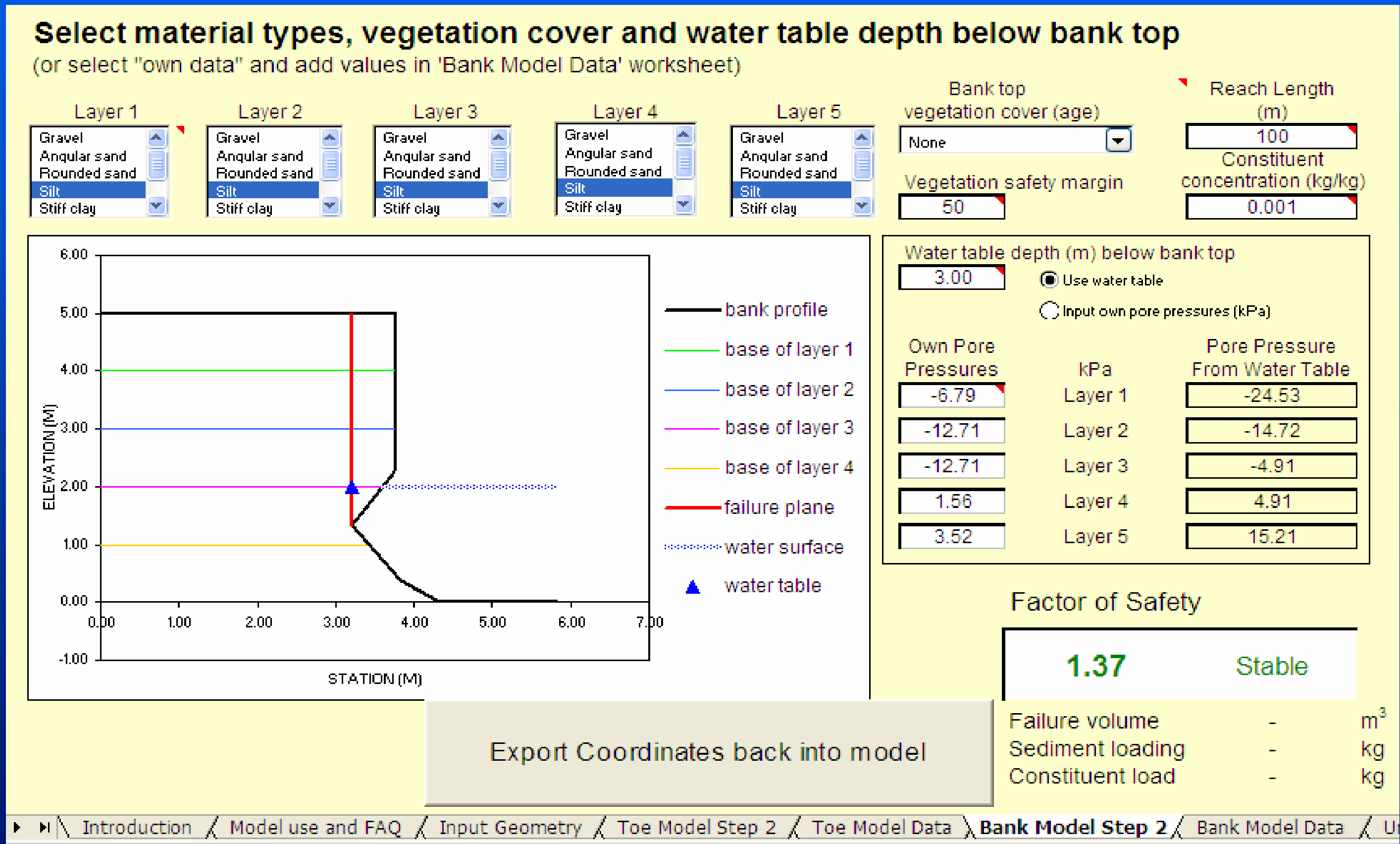
You increase the height of the water table (and hence, pore-water pressures) in the bank?

Increase water table height to 3m below surface



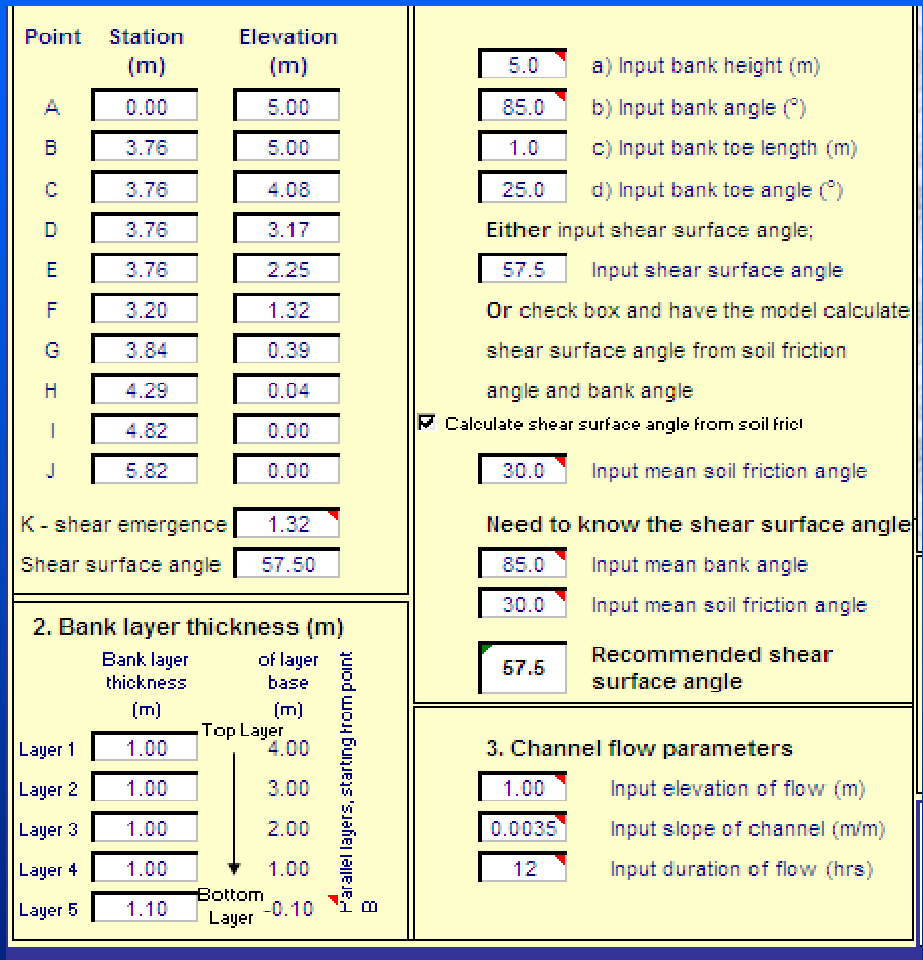
Example 2….

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



Example 2

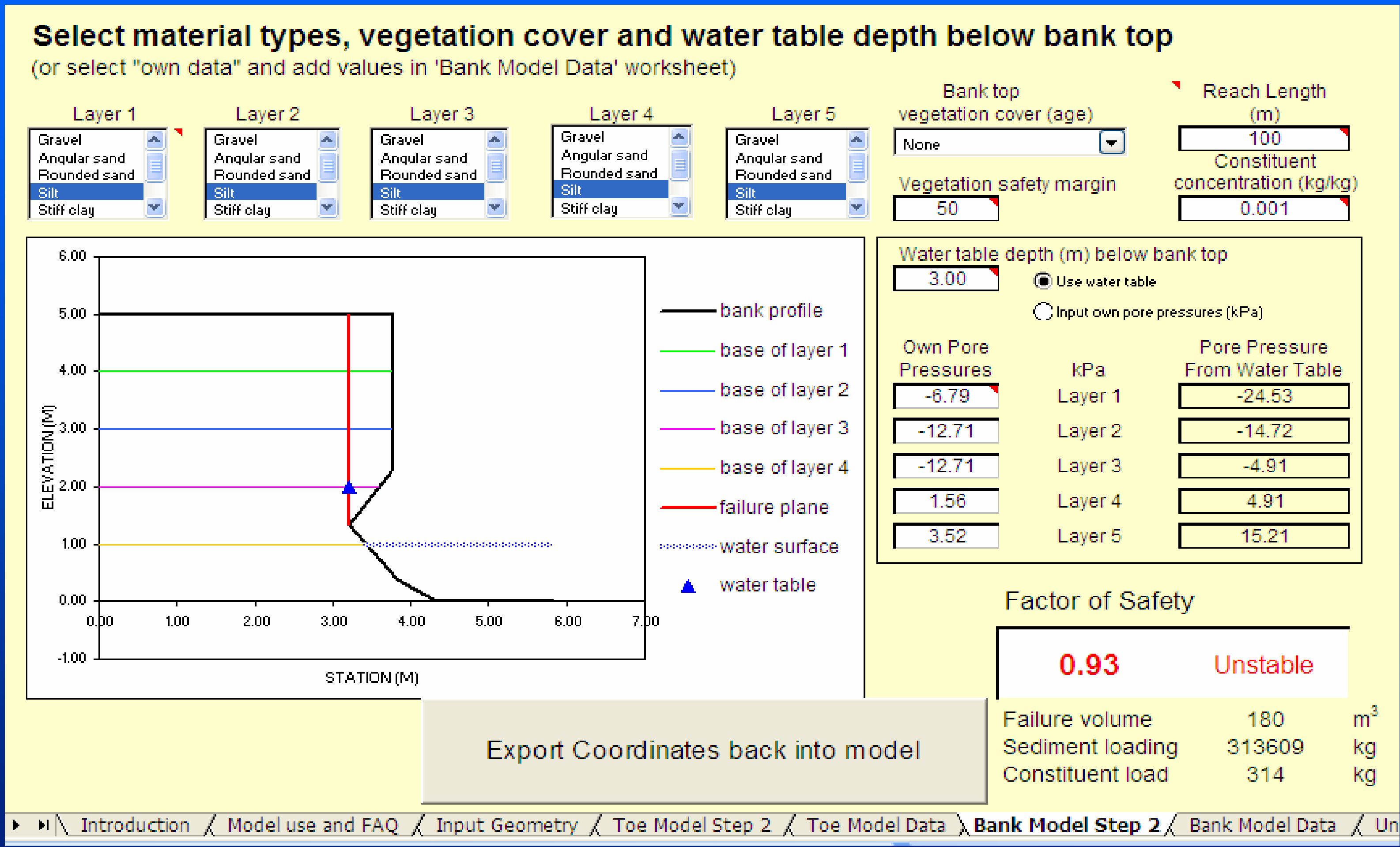
- Now assume that the flow level recedes to 1m.



This is the "typical" drawdown case and often represents the most critical condition

Example 2…

- Bank is now unstable ($F_s = 0.93$)



Example 2…

Again, try adjusting variables, for example:

- Bank materials
- Width of undercut block
- Water table height (what is the critical water table height for a given water surface elevation?)
- Vegetation component

Example 3…

- This time we are going to look at a bank with a tension crack…
- Set up the following bank and shear profiles in Option A:

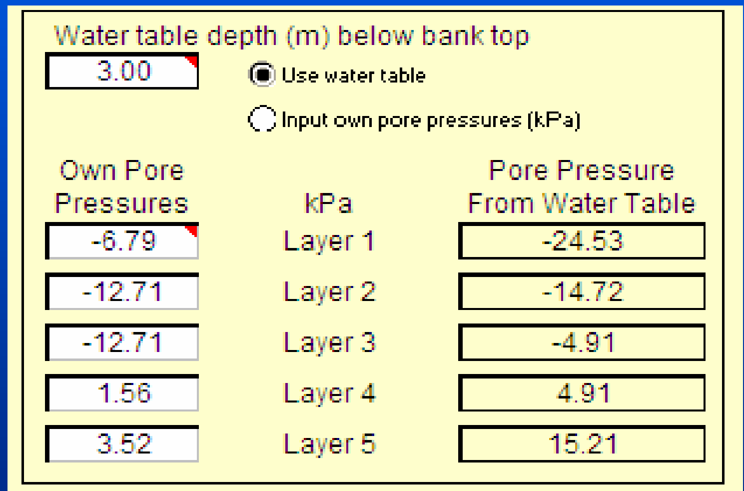
Option A

Point	Station (m)	Elevation (m)
A	0.00	5.00
B	3.50	5.00
C	3.75	4.08
D	3.75	3.17
E	3.75	2.25
F	4.00	1.32
G	4.00	1.00
H	4.65	0.04
I	4.82	0.00
J	5.82	0.00

K - shear emergence	2.25
Shear surface angle	55.00

Example 3…

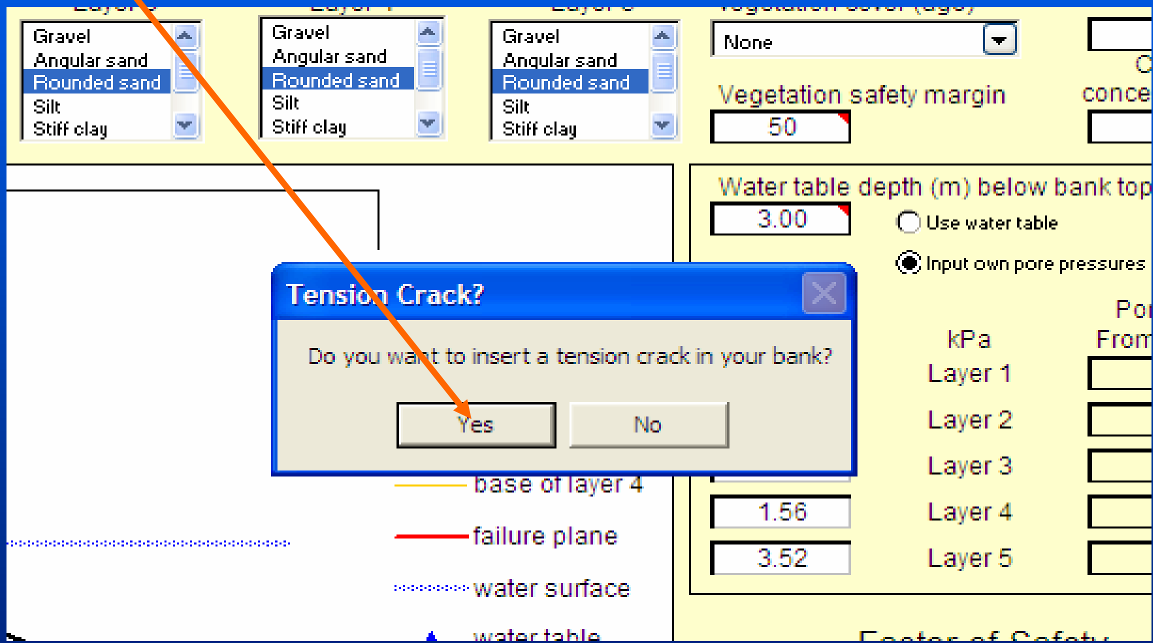
- Next go to the "Bank model step 2" worksheet and select a water table depth 3m below the bank surface



- Return to "Input Geometry" and run bank stability macro.

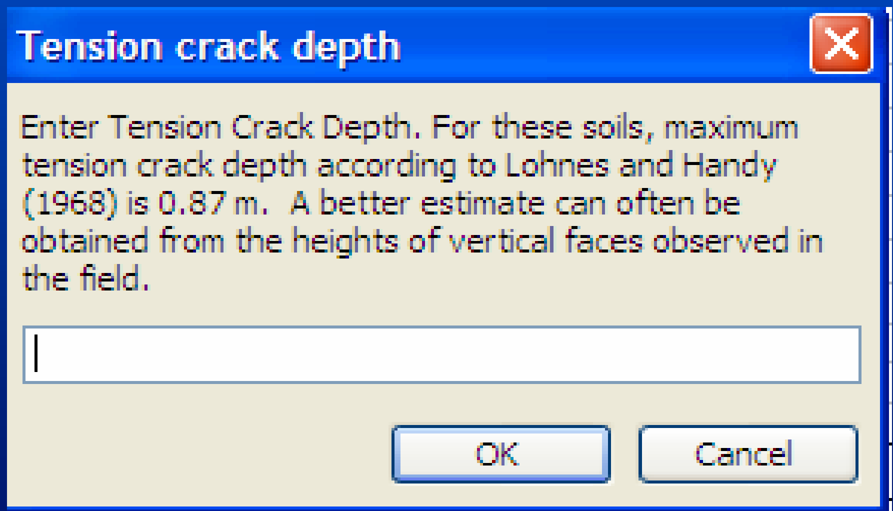
Example 3…

- This time select "No" for cantilever failure, and "Yes" to insert a tension crack



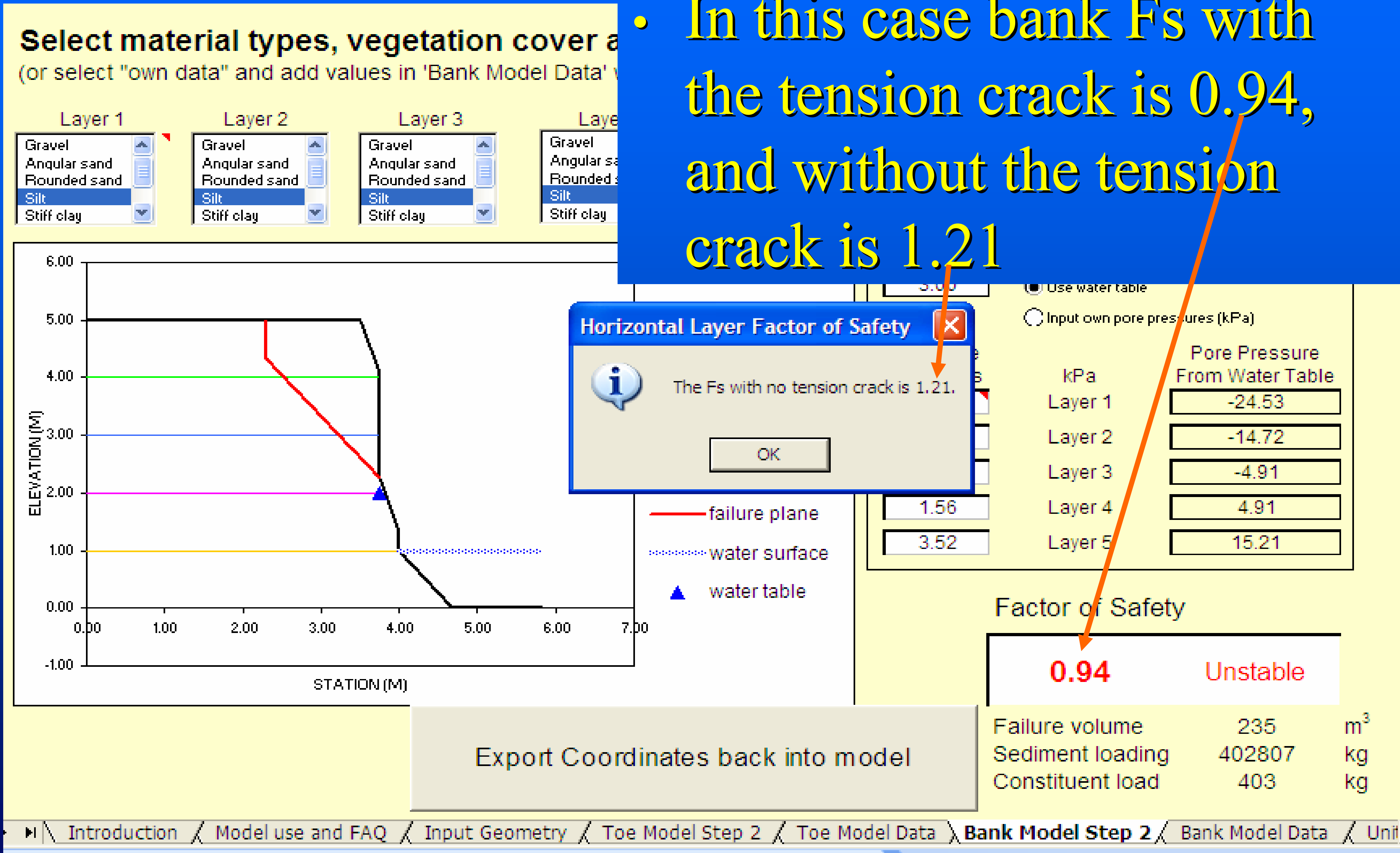
Example 3…

- You are now prompted to add a tension crack depth (maximum and minimum estimated values are indicated in the prompt box). For this example type in the largest suggested value: 0.87m, and click ‘OK’



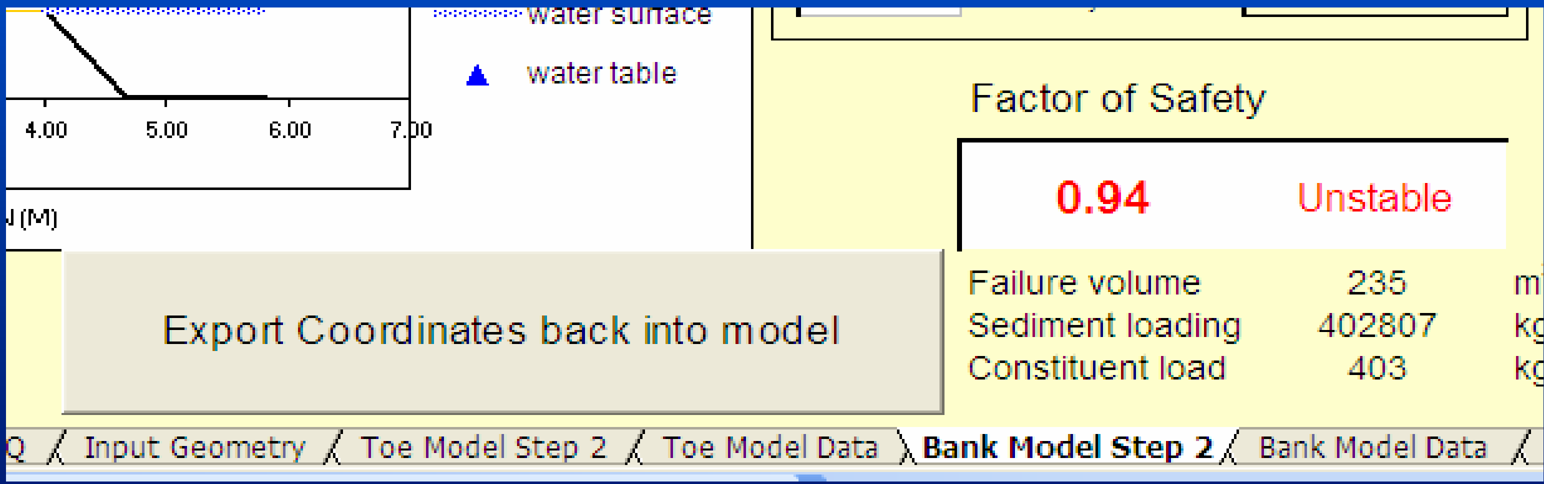
Example 3…

- In this case bank Fs with the tension crack is 0.94, and without the tension crack is 1.21



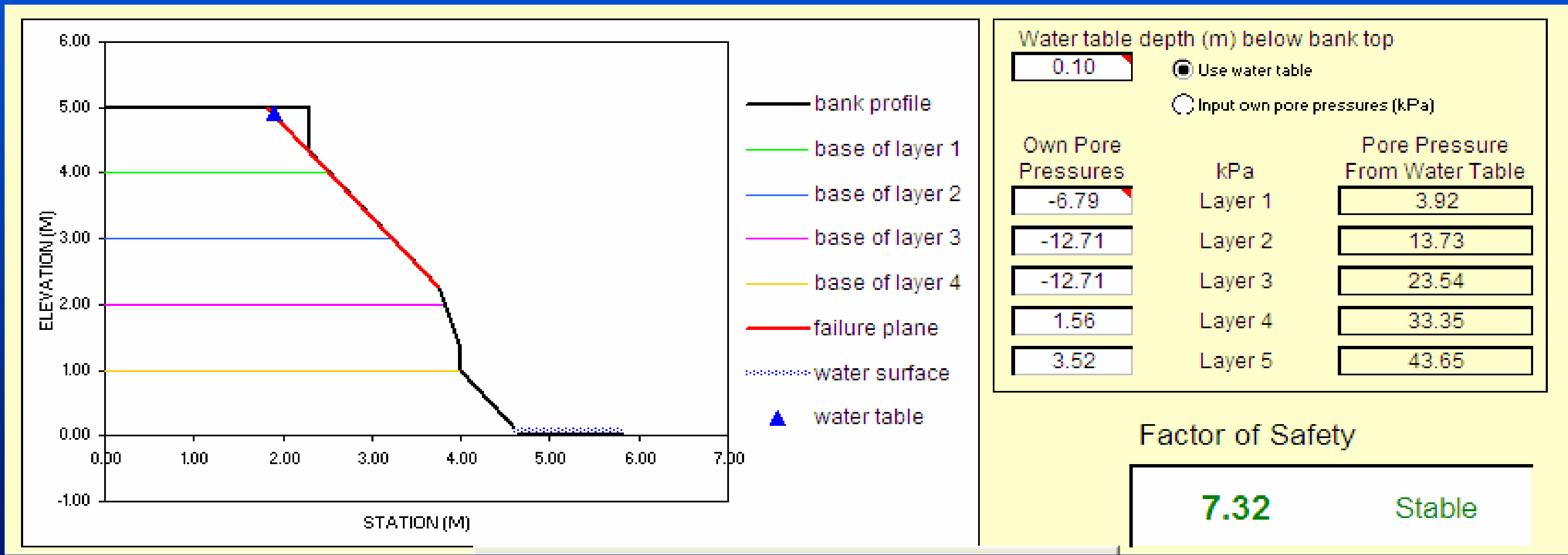
Example 3…

- As the F_s with the tension crack is <1, and is considered unstable, click on the button to ‘Export coordinates back into model’



Example 3…

- Rerun the bank stability macro again….. This time your bank should be stable with a failure angle of 55 degrees, even under worst case conditions (fully saturated bank, with low flow to provide confining force)



Testing for Bank Stabilization

- Now, try creating your own bank profiles and experimenting with bank stabilization by adjusting input parameters in the toe erosion and bank stability macros.

Hydraulic vs. Geotechnical Processes

Distinguish Between Hydraulic and Geotechnical Bank Protection

- Toe armoring
  rock, LWD, live vegetation, fiberschines
- Bank face armoring
  mattresses, vertical bundles, geotextiles

Hydraulic Protection

- Bank reinforcement
  pole and post plantings, bank top vegetation, brush layers, drainage

Geotechnical Protection

Distinguish Between Hydraulic and Geotechnical Bank Protection

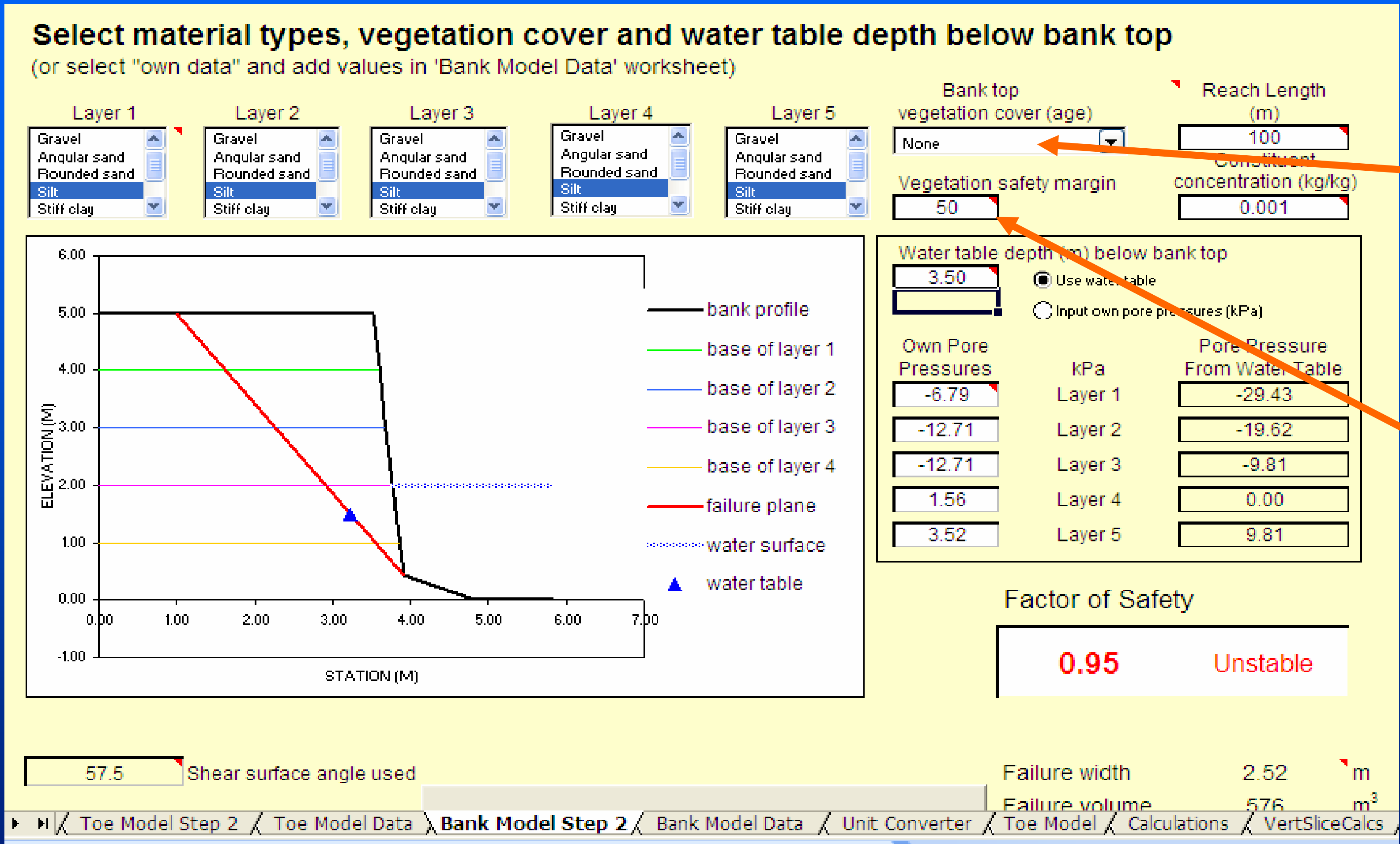
- Hydraulic protection reduces the available boundary hydraulic shear stress, and increases the shear resistance to particle detachment

Hydraulic Protection

- Geotechnical protection increases soil shear strength and decreases driving forces

Geotechnical Protection

Adding vegetation effects

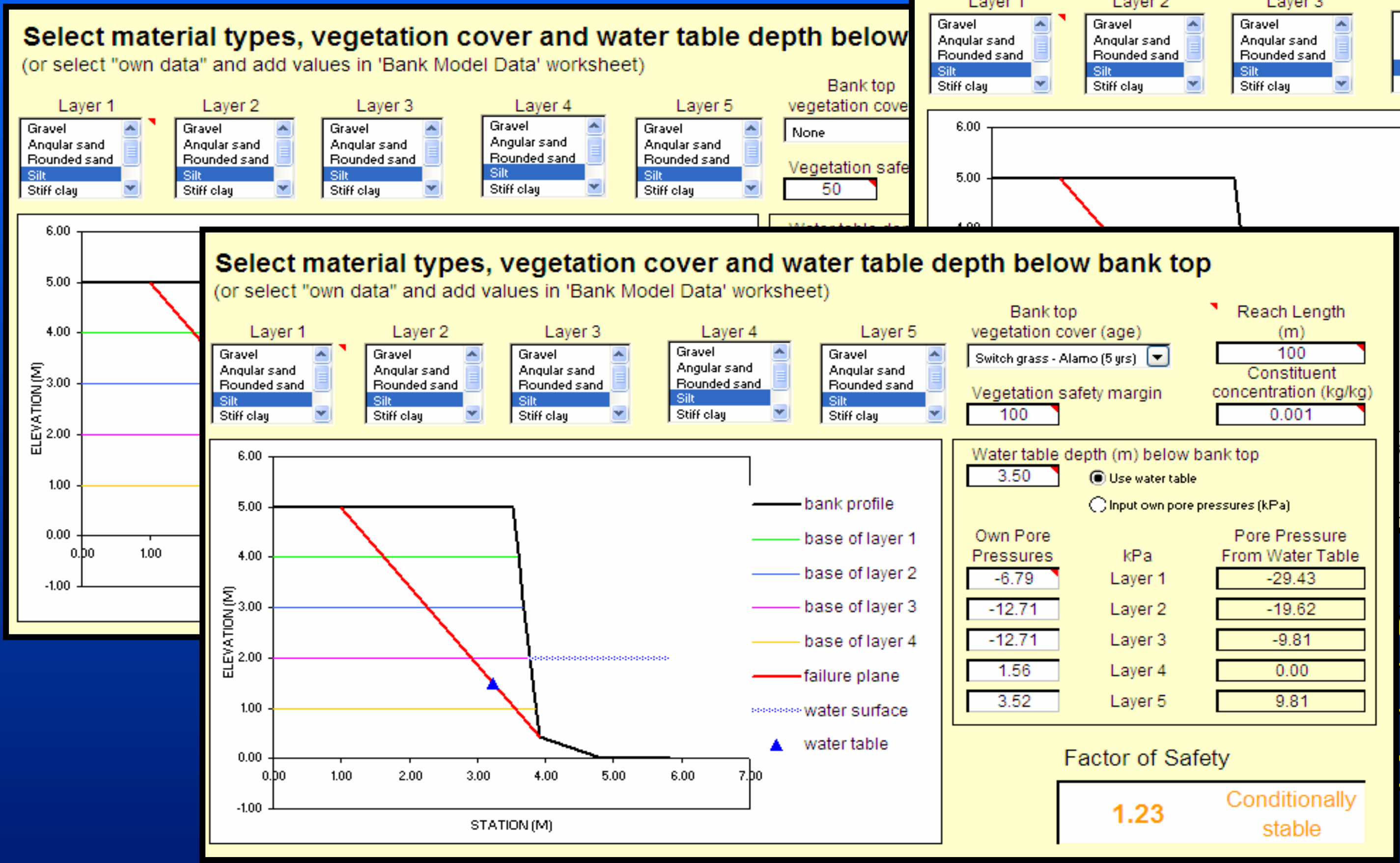


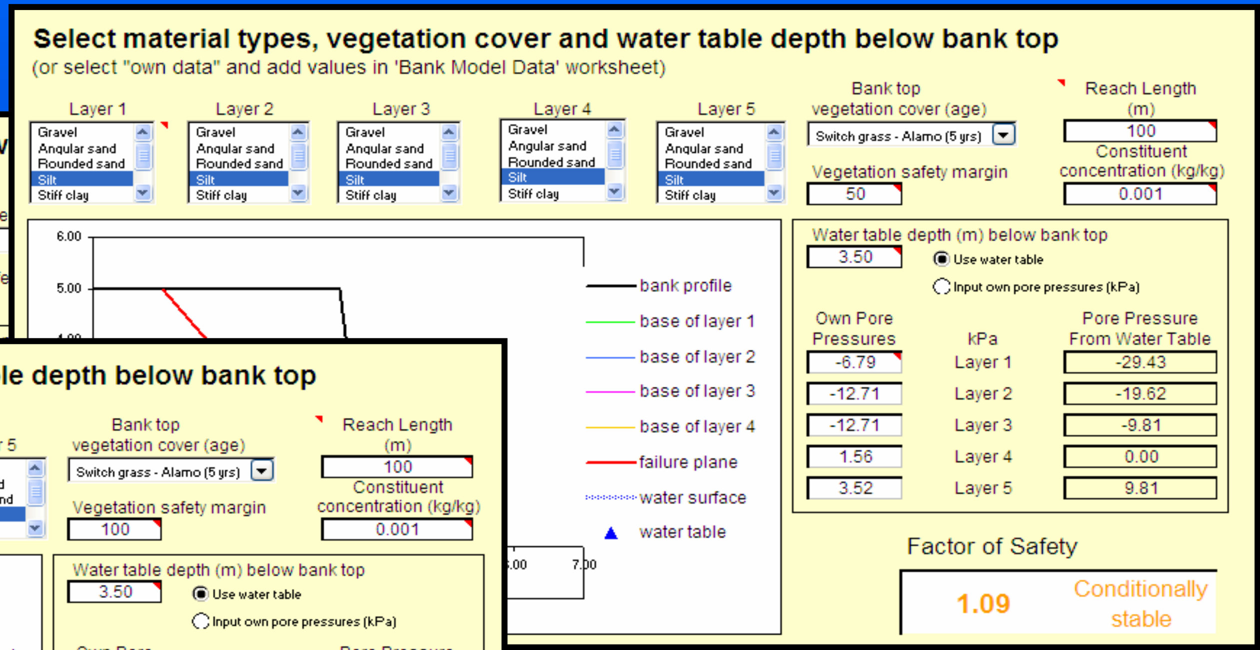
Select type/age of vegetation from drop down box

Select vegetation safety margin (0 – 100 %)

Adding vegetation effects…. An example

- No vegetation – unstable



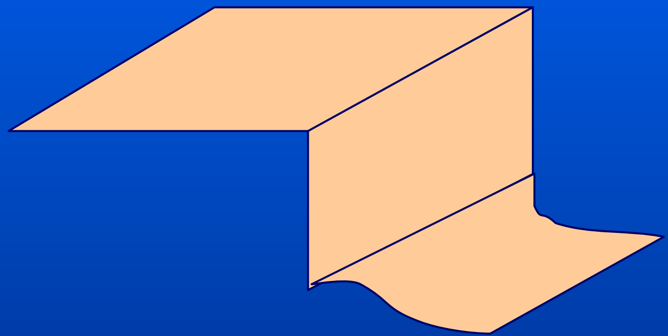


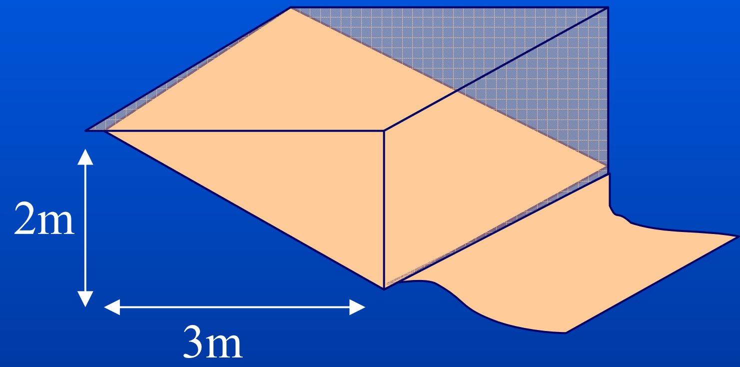
- witchgrass (5 years-old @ 0% safety margin) – nditionally stable

- Switchgrass (5 years-old @ 100 % safety margin)

Comparing Bio-engineering With Hard Engineering

Excavated material 3 m^3/m





2m high vertical silt bank

F_s bare = 0.31 worst case

F_s regraded to 1 in 1.5 = 1.33

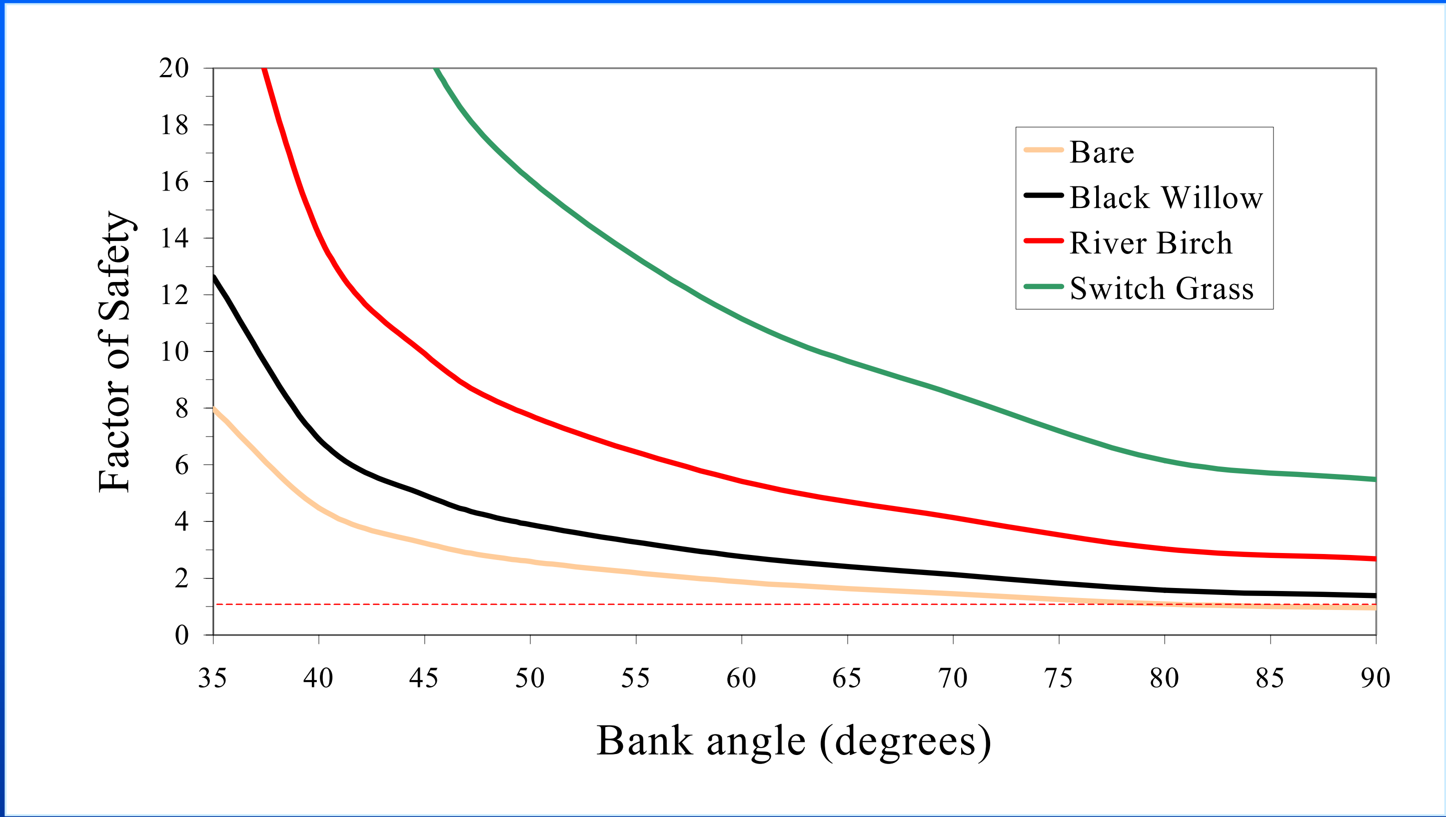
F_s with cottonwood = 1.33

Costs:

Regrading - 3 m^3 per m channel plus cost of land

Bioengineering – plant materials plus maintenance

Factor of Safety v. Bank Angle



Planting vegetation on a 90°, 1m high silt bank is the equivalent of cutting back a bare slope to;

5 yr old Black willow ≈ 72°

7 yr old River birch ≈ 48°

5 yr old Switch grass ≈ 38°

Bank Stabilization Techniques

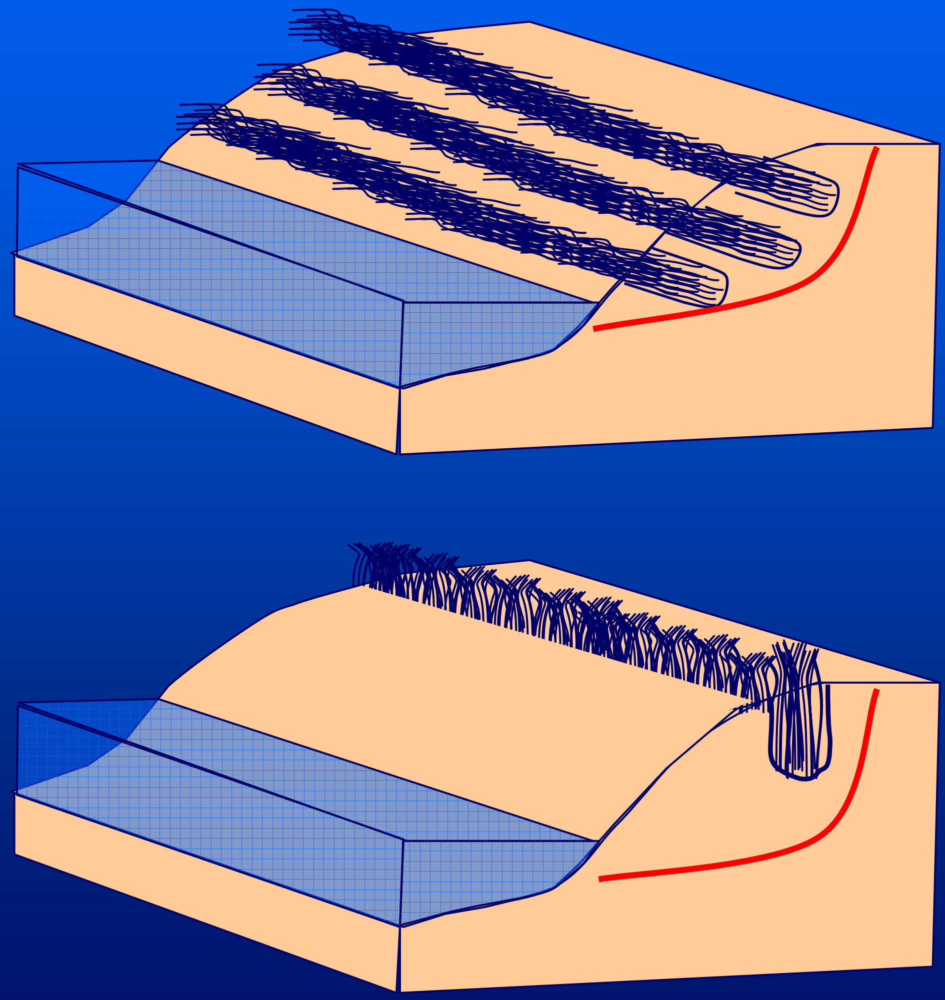
Plant bundles of willow cuttings in trenches on bank face or top. Brush layer reinforces bank face, and reduces scour and surface erosion.

Design question:

How much do the brush layers increase bank Factor of Safety?

How deep/far back do the layers need to go in order to stabilize the bank?

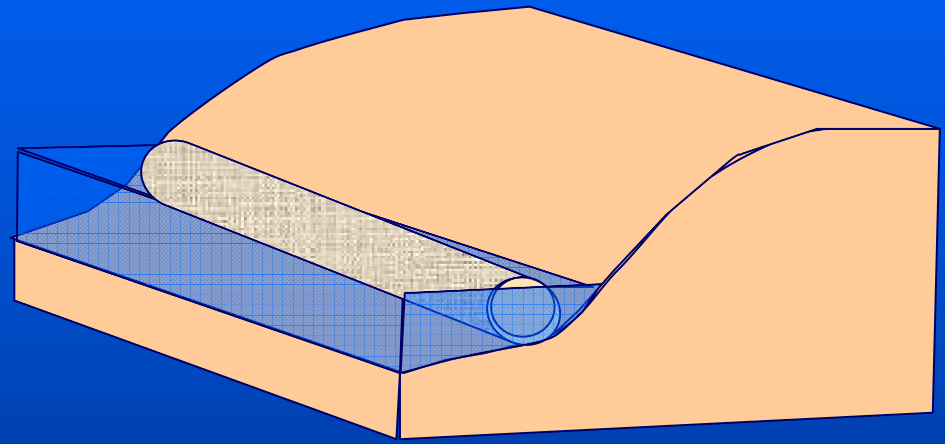
Brush layer and brush trench



Bank Toe Protection

Fiberschines and large woody debris (LWD)

Attach fiber roll or tree stumps and root wads to bank toe and fill in behind with soil and willows



Design question:

How much effect will the LWD have on bank toe erosion rates?