Tidal Inlet Reservoir Model

for Calculating Sand Bypassing and Change in Volume of Morphologic Features

Nicholas.C.Kraus.erdc.usace.army.mil

U.S. Army Engineer Research and Development Center

Coastal and Hydraulics Laboratory

Calculating Long-Term Inlet Morphology Change and Sand Bypassing – the Reservoir Model

Bay Center (Willapa Bay, WA)

I. Modeling Assumptions

Modeling assumptions

II. Analytical solution (ebb shoal)

Blind tests

Validation – Ocean City, MD

III. Numerical extension of model

Ebb & flood shoal, channel, adjacent beach

Generalization of equations

Application to Shinnecock Inlet, NY

IV. Beta Version of Interface

Application of the Reservoir Model

Reservoir Model
Assumptions

1. Mass (volume) is conserved.

2. Identifiable morphological forms and sediment pathways among them can be identified.

3. Morphologic forms evolve while preserving identity

4. Dynamic equilibrium occurs about an ideal stable equilibrium

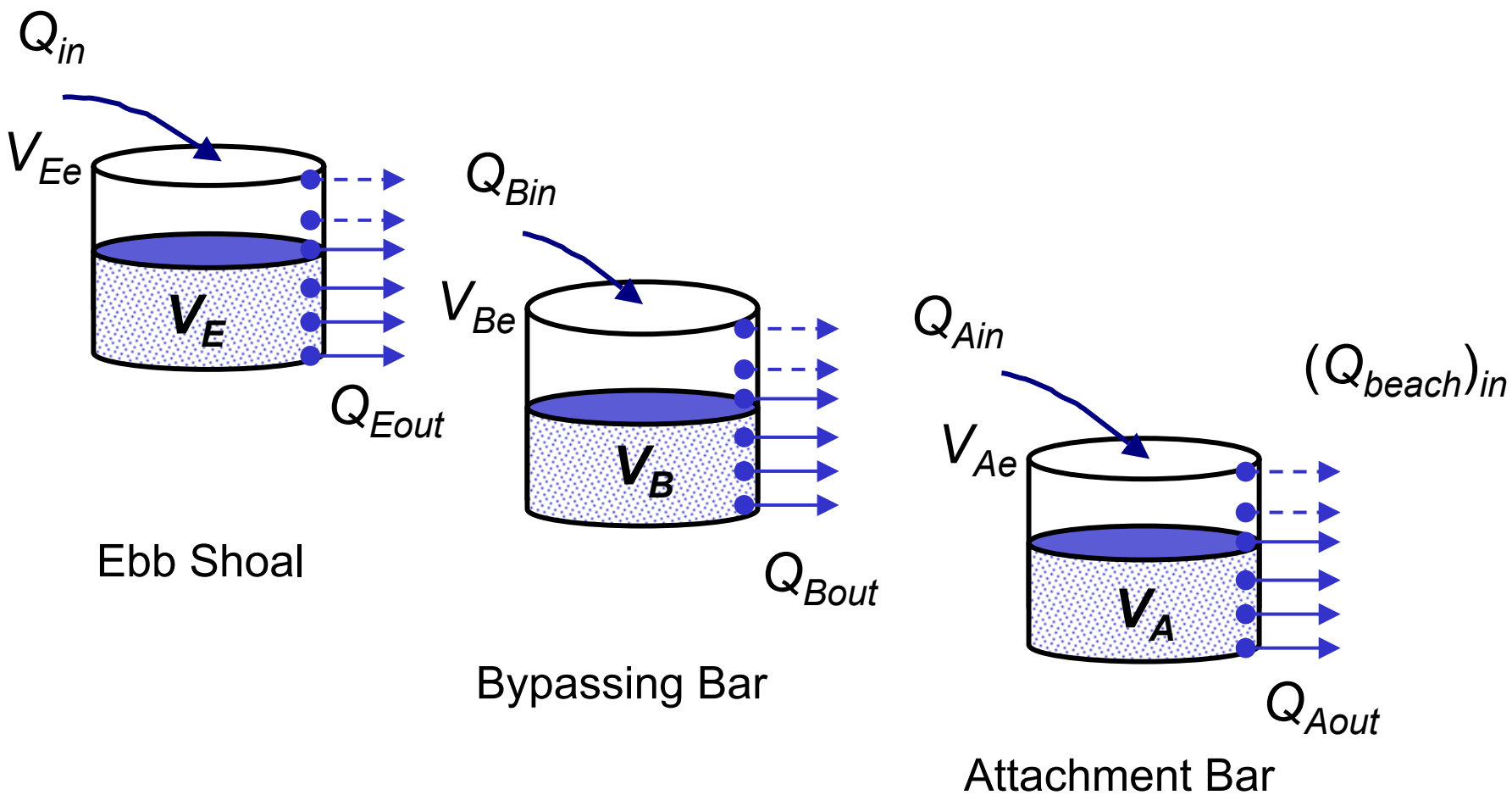
5. Change in morphology is smooth (trends & derivatives exist)

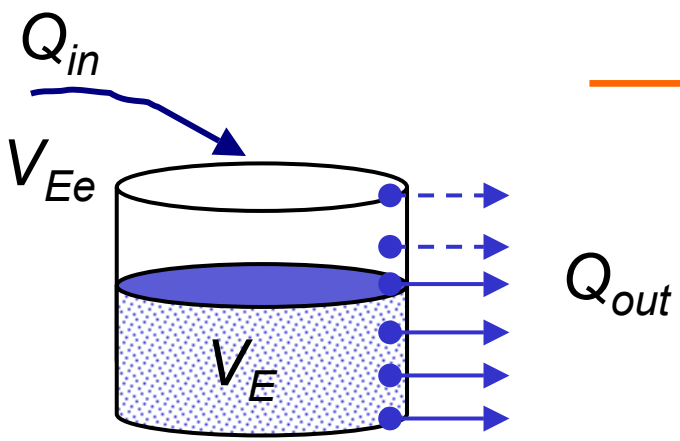
6. Rate of material leaving a form is proportional to the product of its volume and rate of material input to the form

Motivation: Inferred Sediment Pathways at Ebb-Tidal Shoal

Shinnecock Inlet, Long Island, NY
April 1997

Reservoir Model Model Concept





$$\frac{dV_E}{dt} = Q_{in} - Q_{out} \quad , V_E < V_{Ee}$$

$$= 0 \quad , V_E = V_{Ee}$$

<u>where</u>

$Q_{in} =$ arbitrary, *e.g.*, Q_R

$$Q_{out} = \frac{V_E}{V_{Ee}} Q_{in} \; , \Rightarrow \alpha \equiv \frac{Q_{in}}{V_{Ee}}$$

<u>Yields</u>

$$V_{Eout} = (Q_{in})t - V_E$$

$$V_E = V_{Ee}\left(1 - e^{-\alpha t}\right)$$

$$\alpha = \frac{Q_{in}}{V_{Ee}}$$

$$Q_{Eout} = \frac{d(V_E)_{out}}{dt} = Q_{in} - \alpha V_{Ee} e^{-\alpha t}$$

$$= Q_{in}\left(1 - e^{-\alpha t}\right) = \frac{V_E}{V_{Ee}} Q_{in}$$

Continuing, find:

$$V_E = V_{Ee}\left(1 - e^{-\alpha t}\right), \quad \alpha = \frac{Q_{in}}{V_{Ee}}$$

$$V_B = V_{Be}\left(1 - e^{-\beta t'}\right), \quad \beta = \frac{Q_{in}}{V_{Be}}, \quad t' = t - \frac{V_E}{Q_{in}}$$

$$V_A = V_{Ae}\left(1 - e^{-\gamma t''}\right), \quad \gamma = \frac{Q_{in}}{V_{Ae}}, \quad t'' = t' - \frac{V_B}{Q_{in}}$$

Time lagged

$$(Q_E)_{out} = \frac{V_E}{V_{Ee}} Q_{in} \qquad = (Q_B)_{in}$$

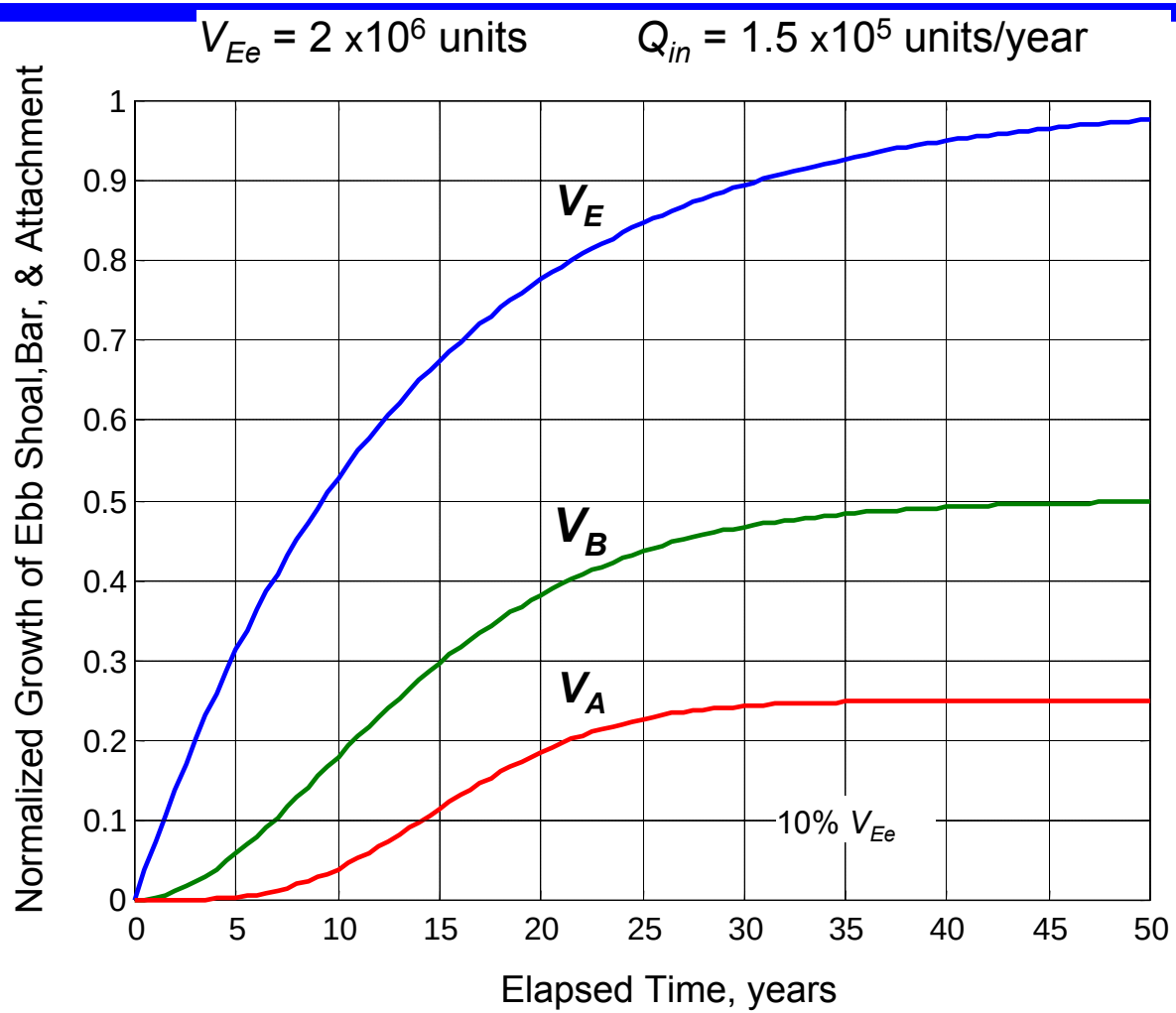
$$(Q_B)_{out} = \frac{V_E}{V_{Ee}} \frac{V_B}{V_{Be}} Q_{in} \qquad = (Q_A)_{in}$$

$$(Q_A)_{out} = \frac{V_E}{V_{Ee}} \frac{V_B}{V_{Be}} \frac{V_A}{V_{Ae}} Q_{in} \qquad = (Q_{Beach})_{in}$$

Bypassing rate to the beach

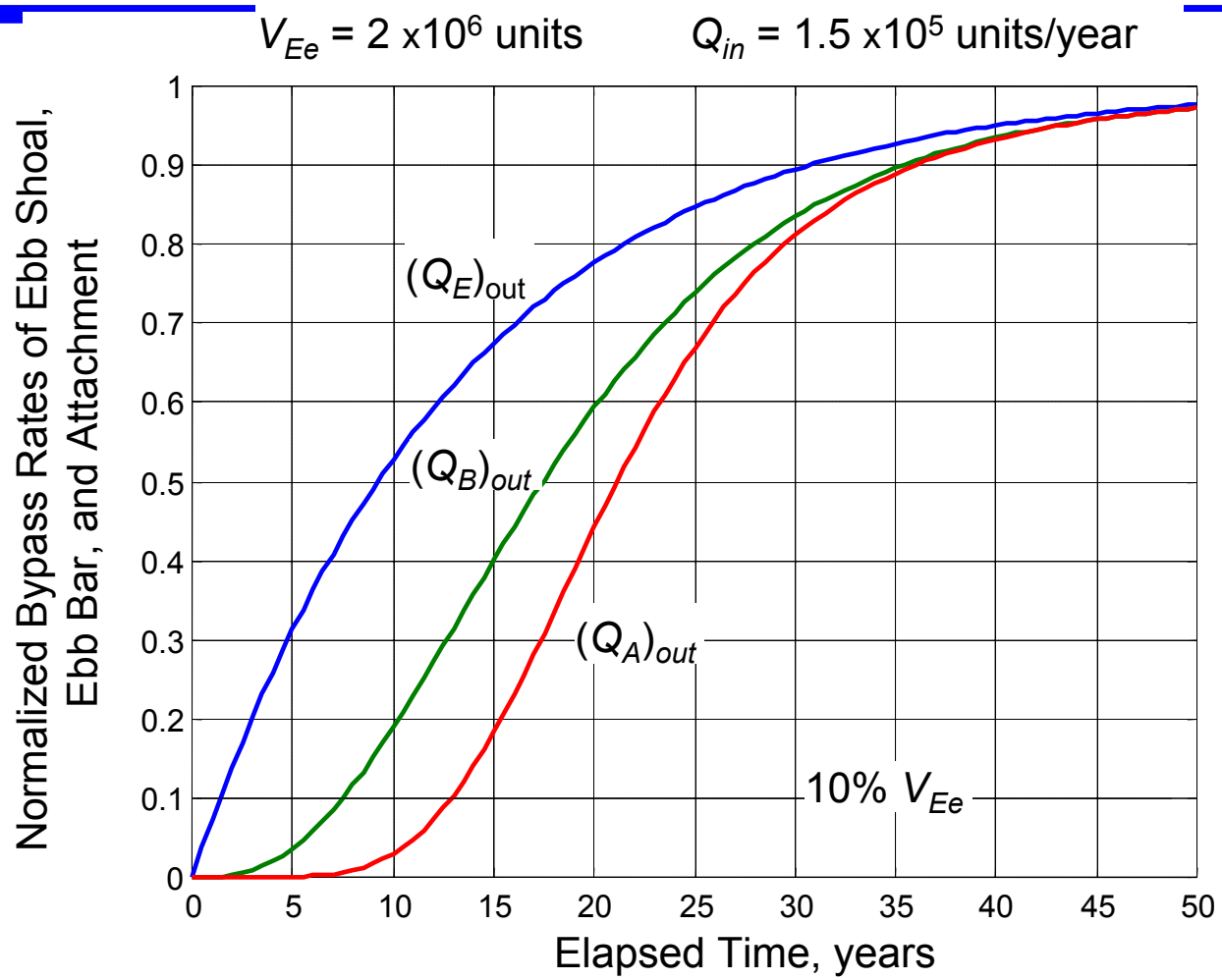
Example Analytical Solution -- unidirectional transport

Growth of Ebb Shoal, Bypassing Bar, Attachment Bar

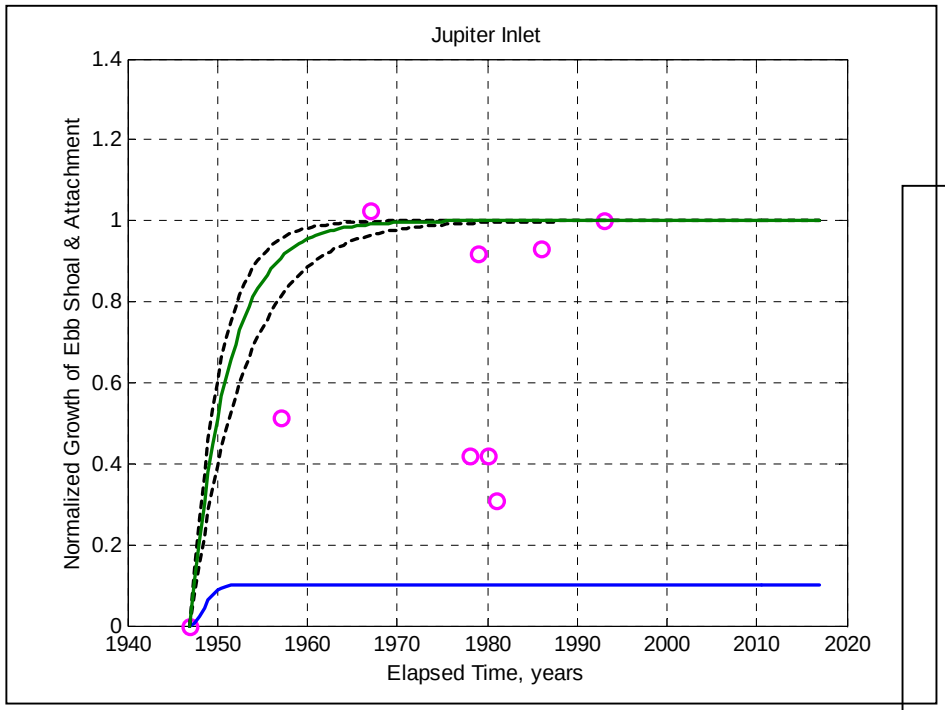


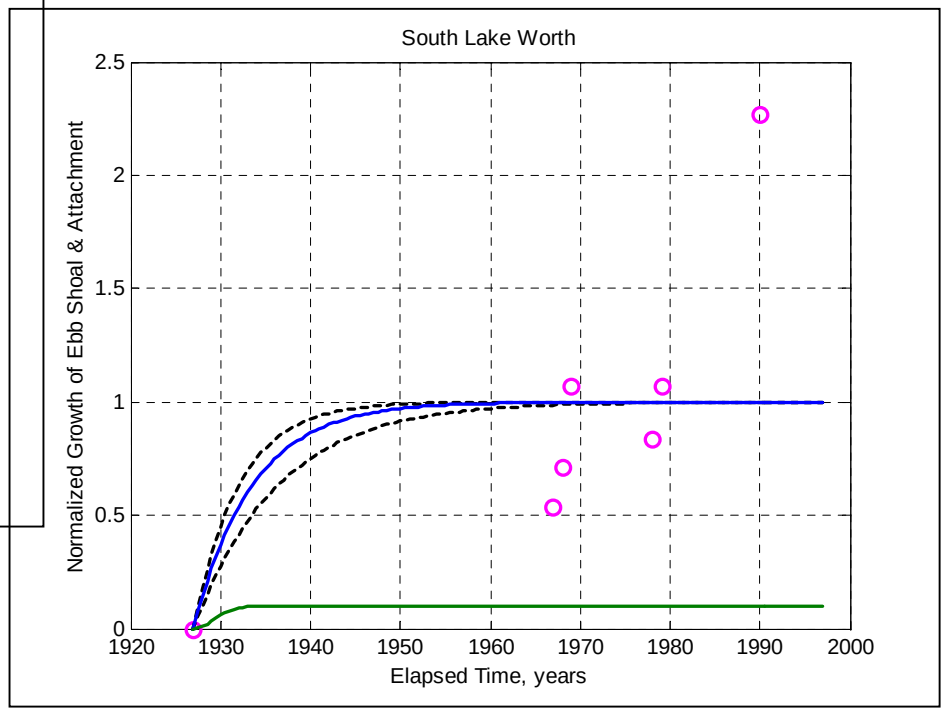
Example Analytical Solution -- unidirectional transport

Bypassing Rates



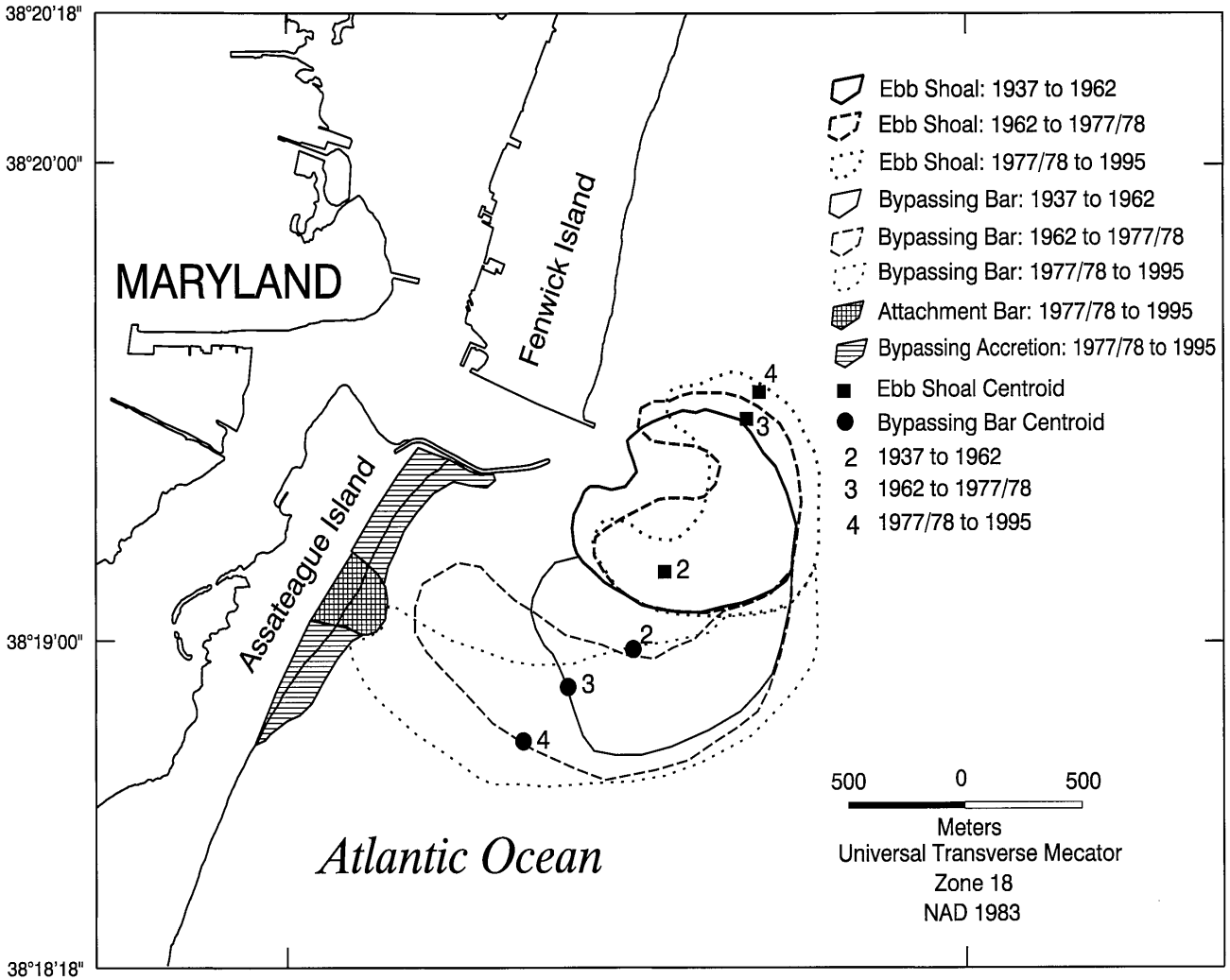
Blind Tests – Courtesy of Erica Carr
Modeling of Ebb-Shoal Complex (2 of 8 available)





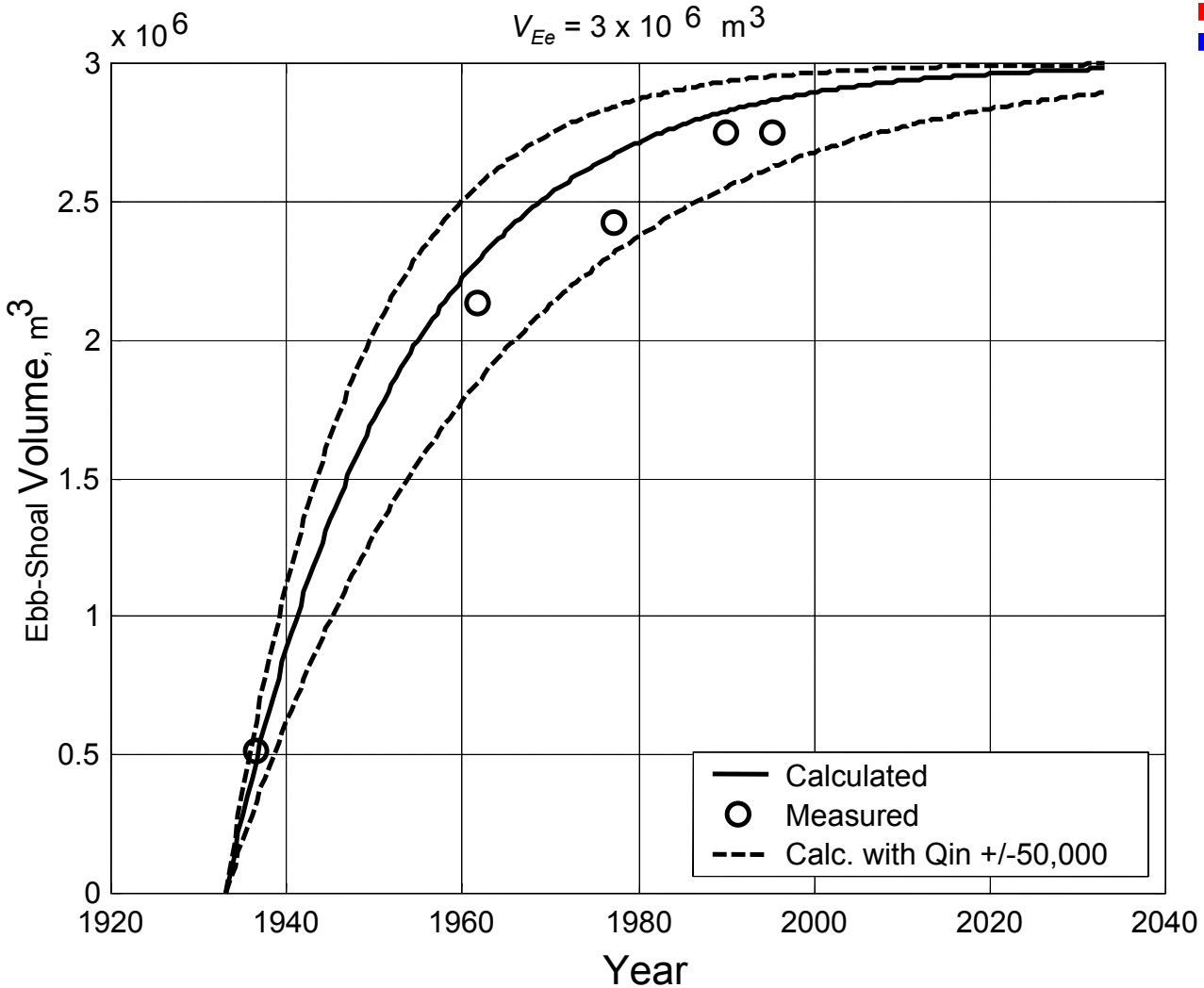
Ocean City, Maryland
(opened by hurricane, August 1933)

Ocean City Inlet, 1933-1937, 1937-1962
1962-1977/78, 1977/78-1995



Ocean City Inlet -- Growth of Ebb Shoal

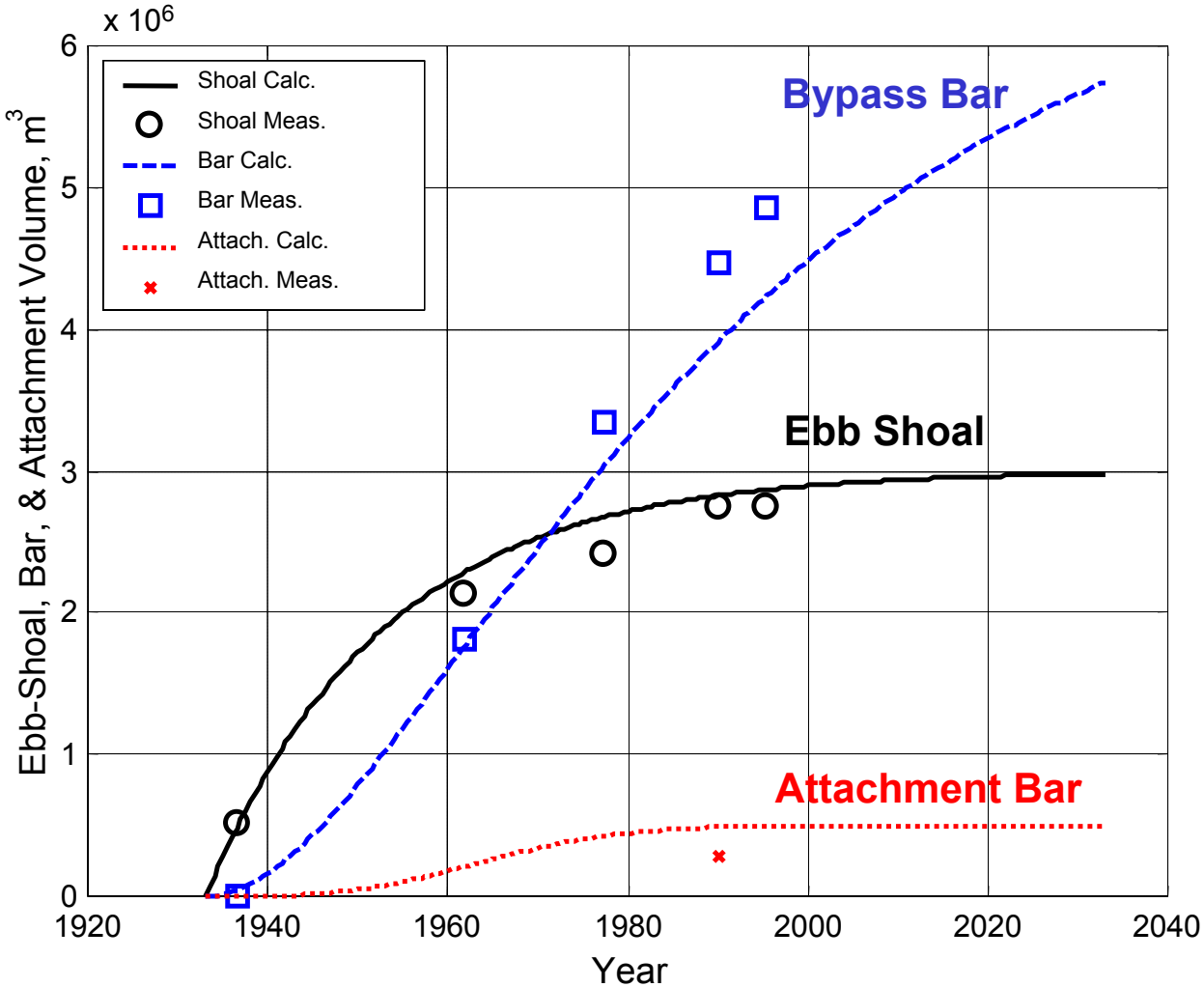
Q_{in} = 150,000 m³/year; V_{Ee} = 3 x 10⁶ m³



Growth of Ebb Shoal, Bypassing Bar, & Attachment Bar

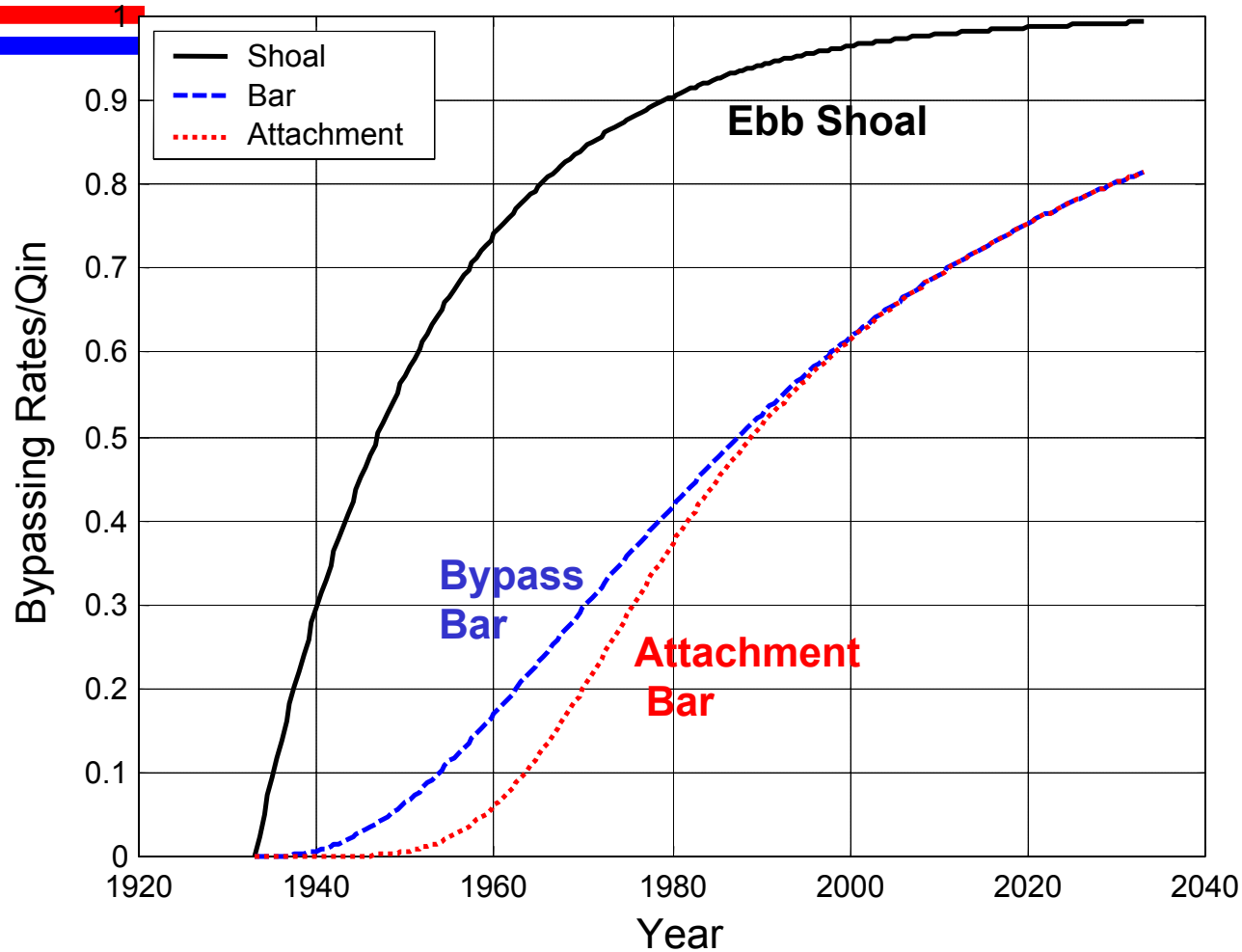
Q_{in} = 150,000 m³/year; V_{Ee} = 3 x 10⁶ m³

V_{Be} = 7 x 10⁶ m³; V_{Ae} = 0.5 x 10⁶ m³

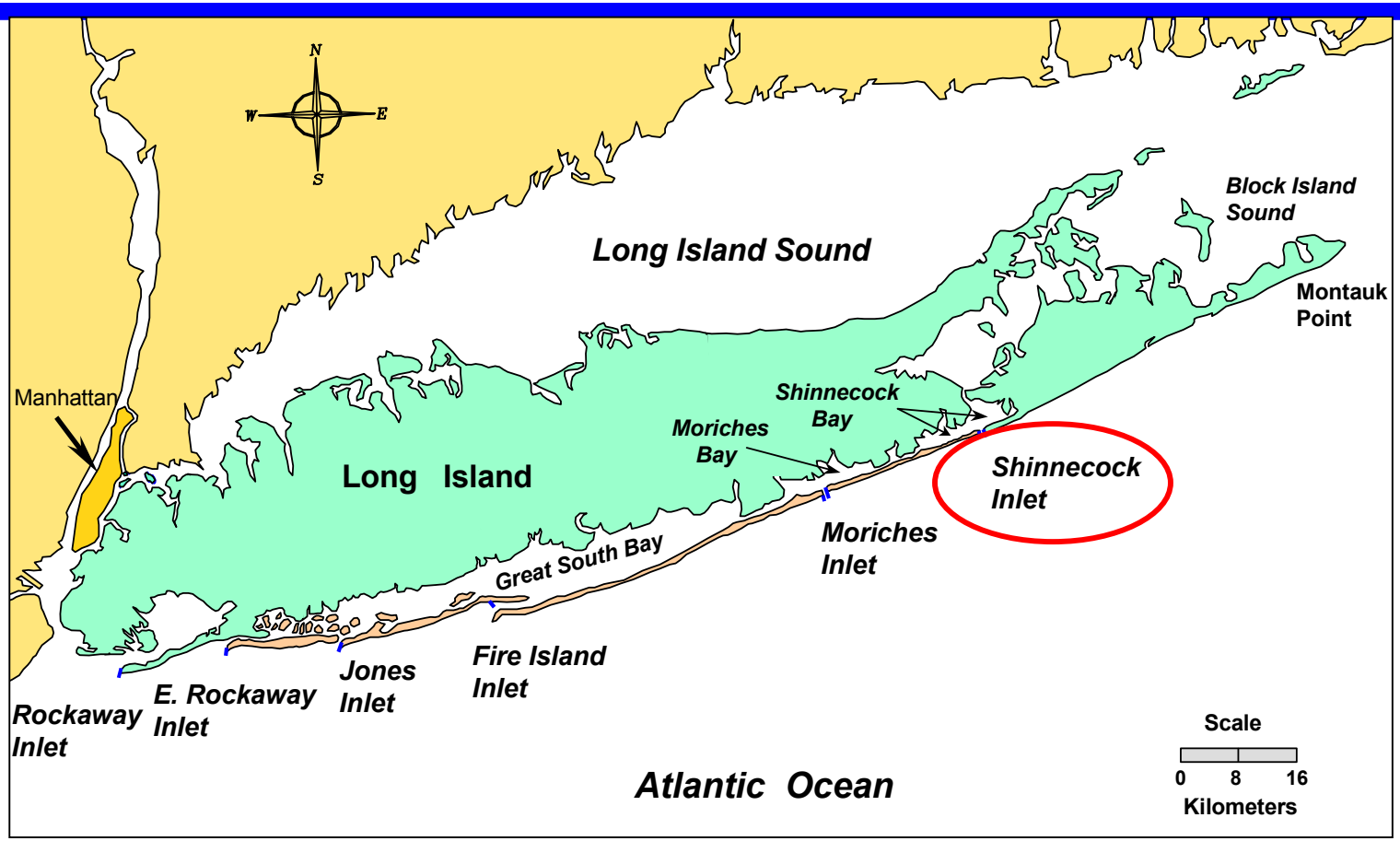


Bypassing Rates

Q_{in} = 150,000 m^3/year; V_{Fe} = 3 x 10^6 m^3

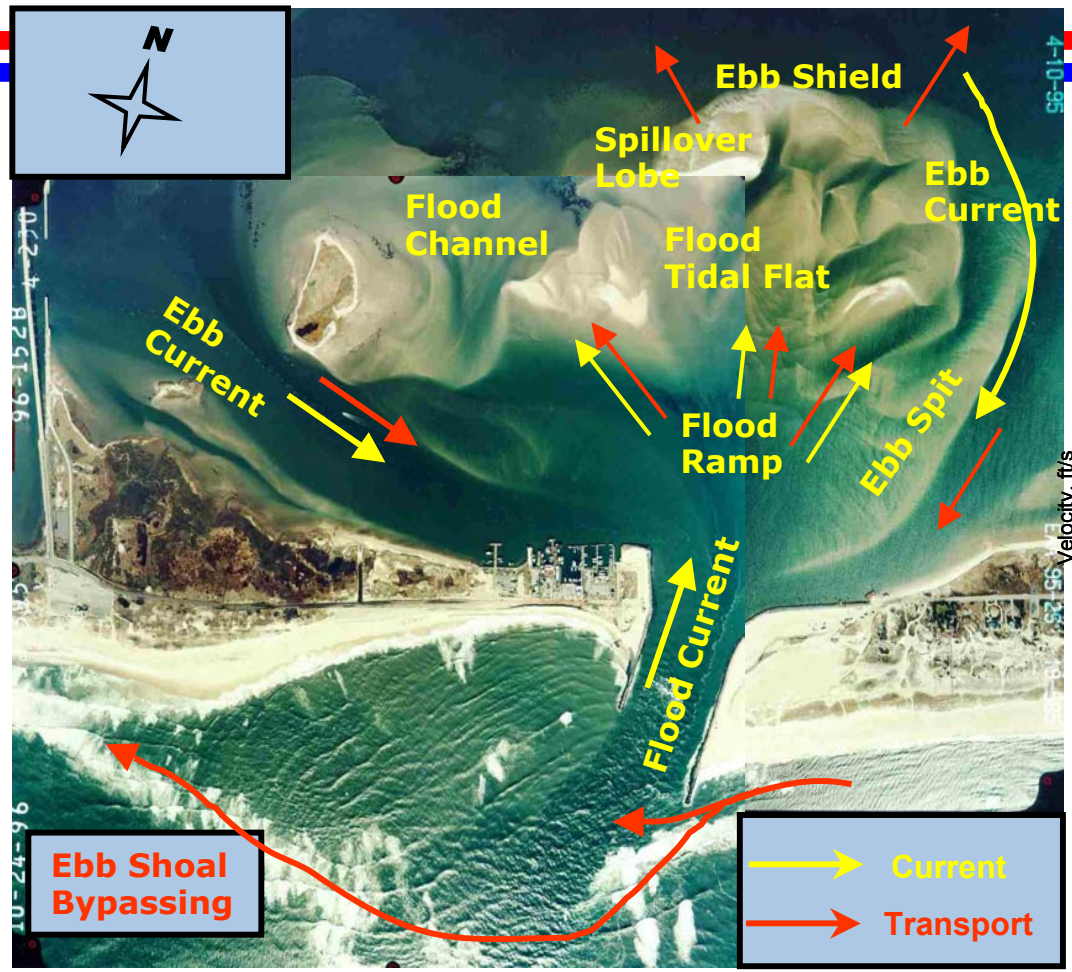


Shinnecock Inlet, Long Island, NY



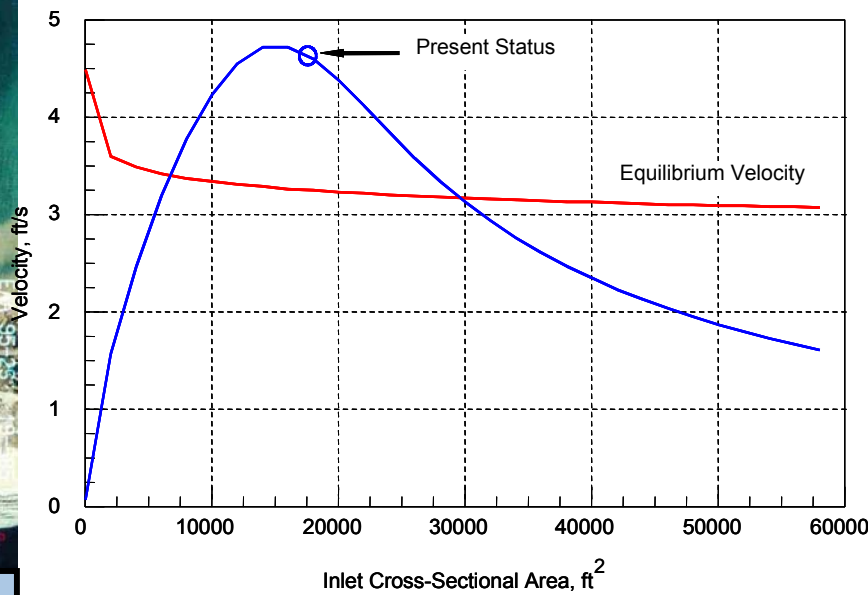
Shinnecock Inlet

(Opened by hurricane, September 1938)



(composite Apr 1995 – Oct 1996)

Escoffier stability diagram



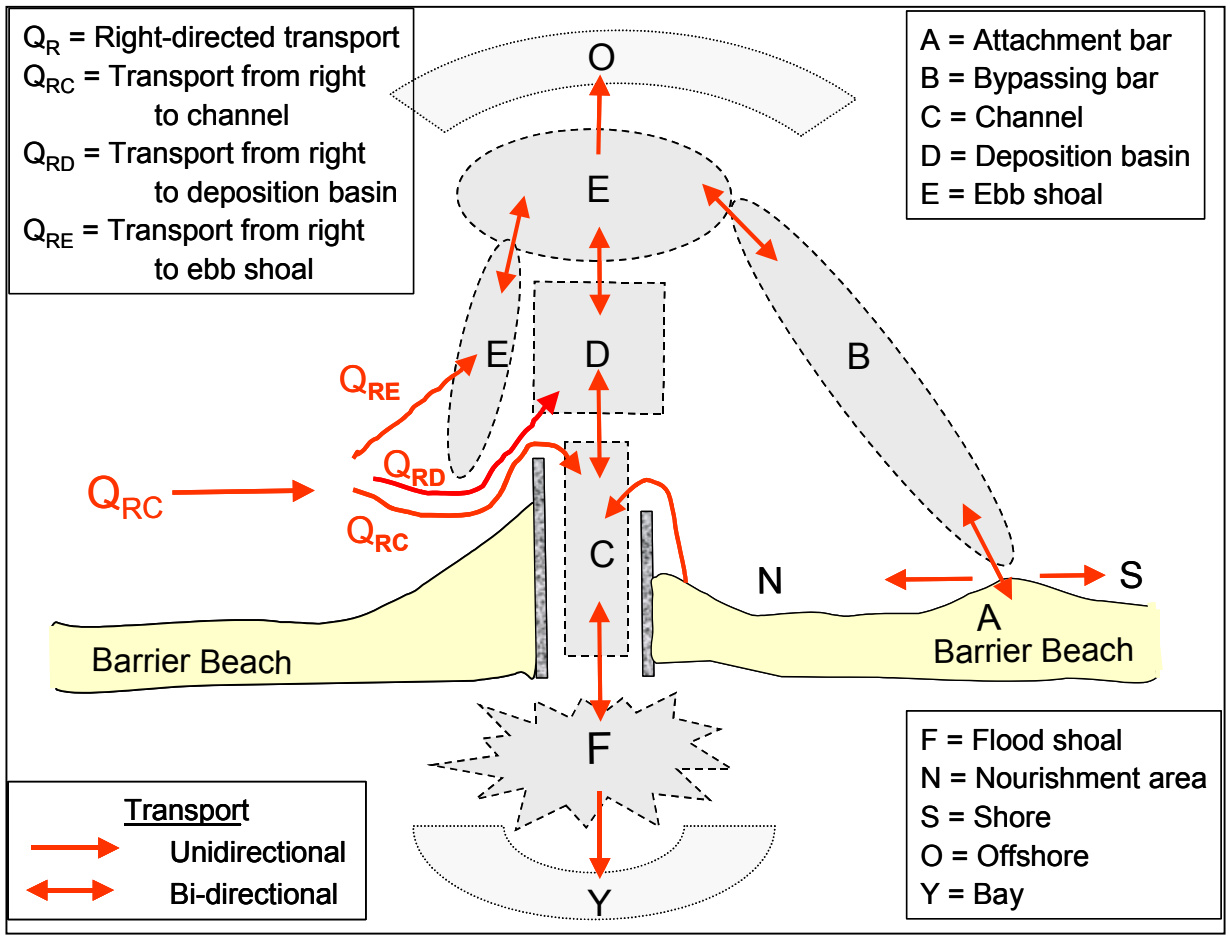
Shinnecock Inlet
Flood Shoal

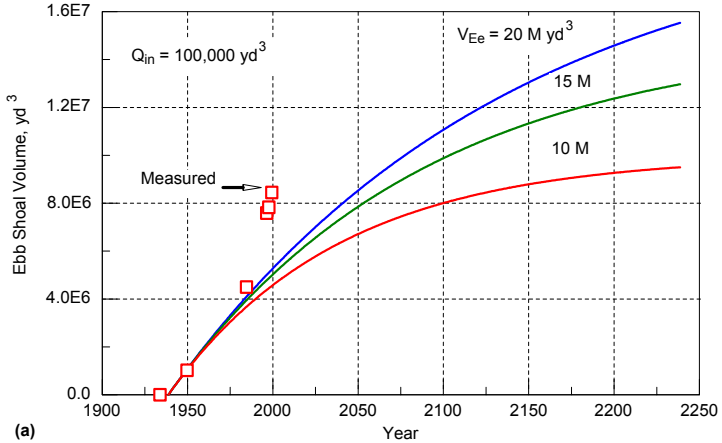
Shinnecock Inlet
Flood shoal growing --

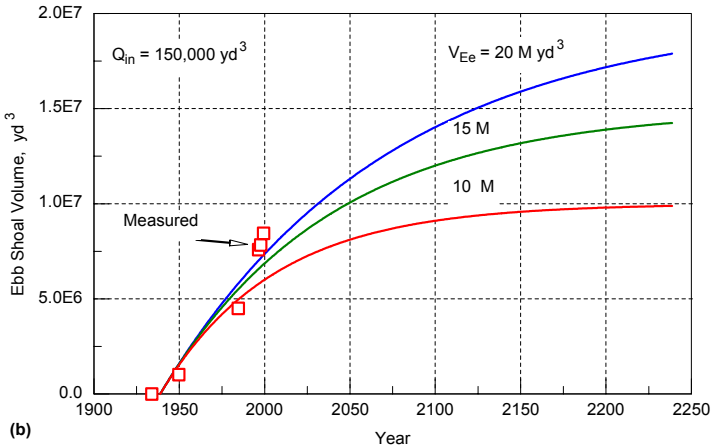
- constricting channel
- removing sand from beach
- potential borrow source

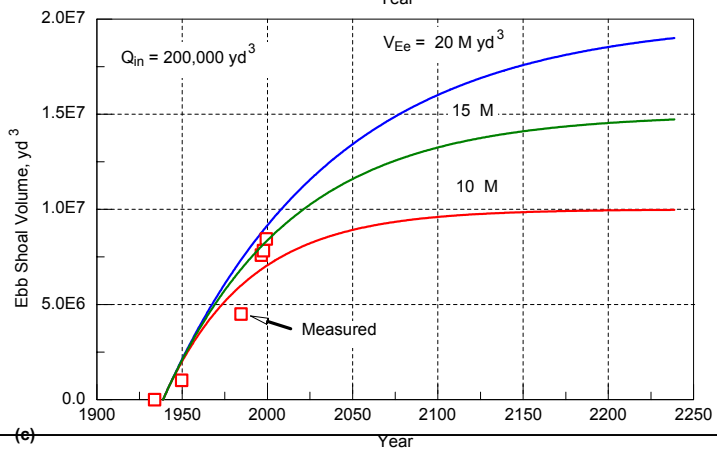
Flood shoal is part of an inter-connected geomorphologic system

Shinnecock Inlet
Conceptualization of sediment pathways



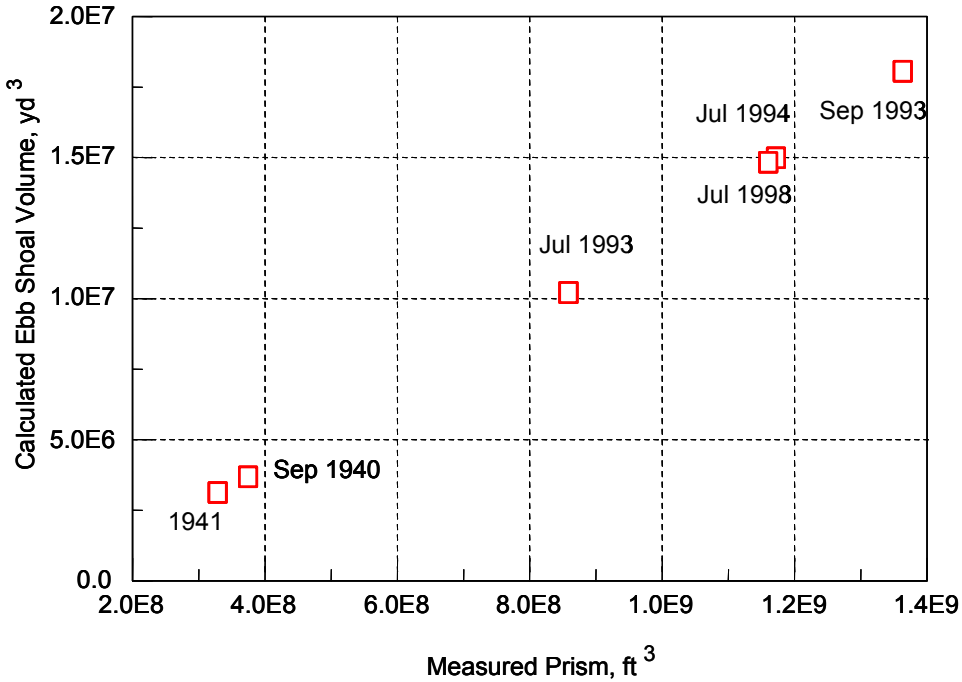






Sensitivity tests with reservoir model to estimate:

- ***input longshore transport rate***
- ***equilibrium ebb-shoal volume***



"Coupling Coefficients" for Shinnecock Inlet (generalized reservoir model)

Short-hand notation

$Q_R = Q_{RC} + Q_{RD} + Q_{RE}$

D → C, E

E → C, D, B, O (to C prior to October 1990)

F → C, Y

B → A, E

A → N, S, B

N → A, C

Example 2

$D \rightarrow C, E$

$$a_{DC} + a_{DE} = 1$$

The *a*'s must be given as data or calculated -- as from a process-based model

⇨ Opportunity to insert physics

Example 1

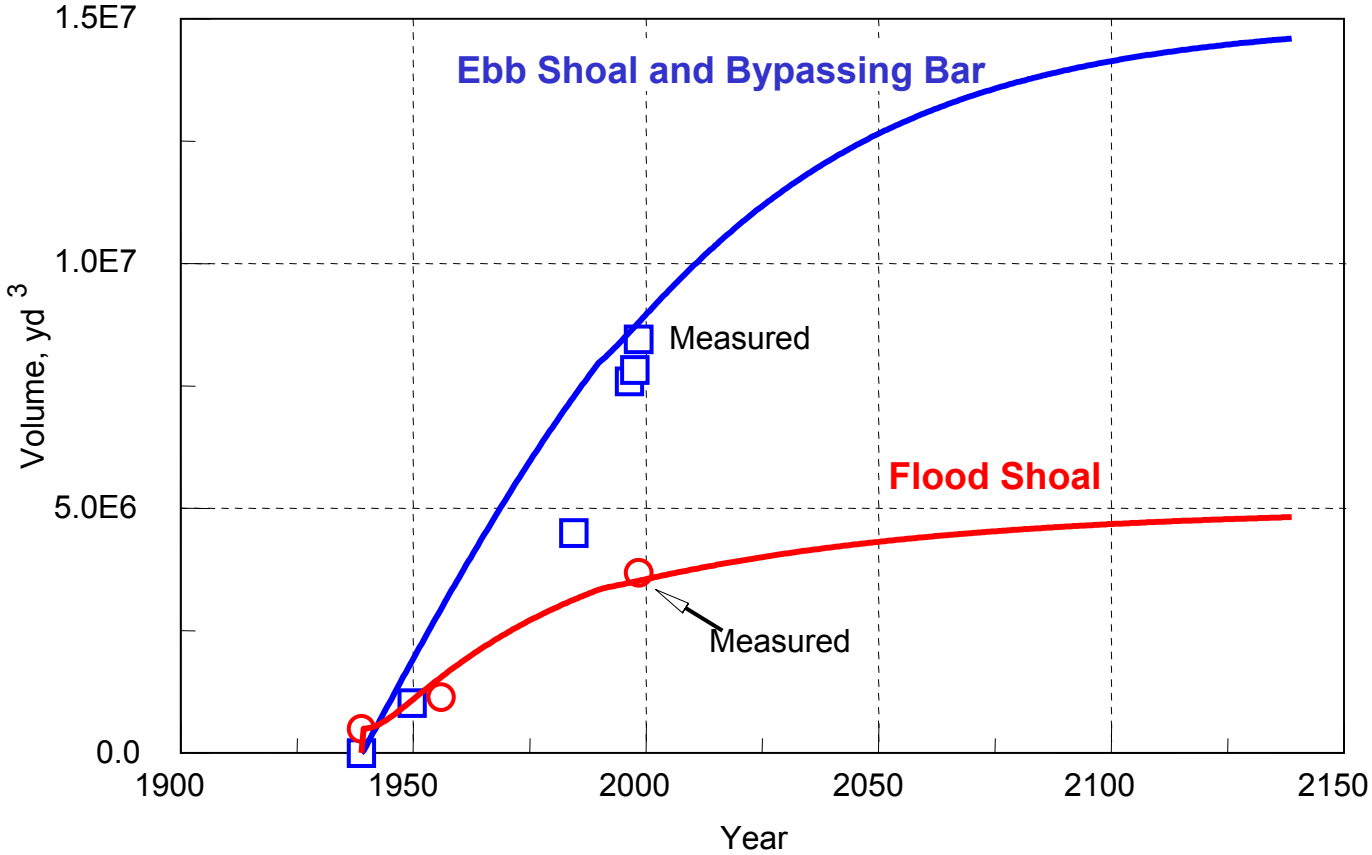
$$Q_R = \left(a_{RC} + a_{RD} + a_{RE}\right) Q_R$$

$$Q_{RC} \triangleq a_{RC} Q_R, \quad Q_{RD} \triangleq a_{RD} Q_R, \text{ and } Q_{RE} \triangleq a_{RE} Q_R$$

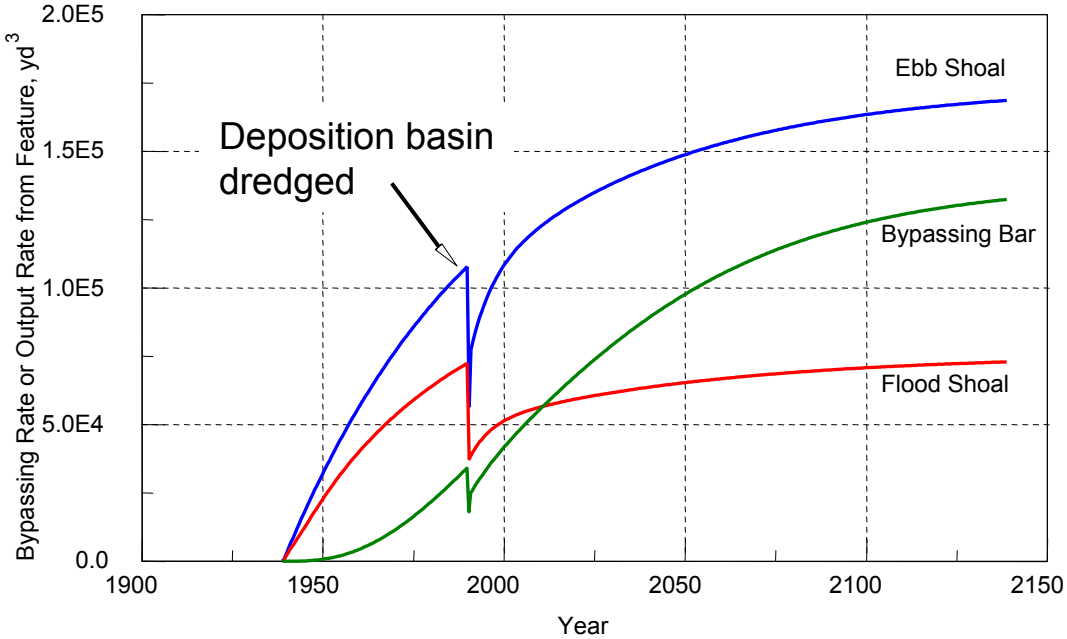
$$a_{RC} + a_{RD} + a_{RE} = 1$$

Shinnecock Inlet
(generalized reservoir model)

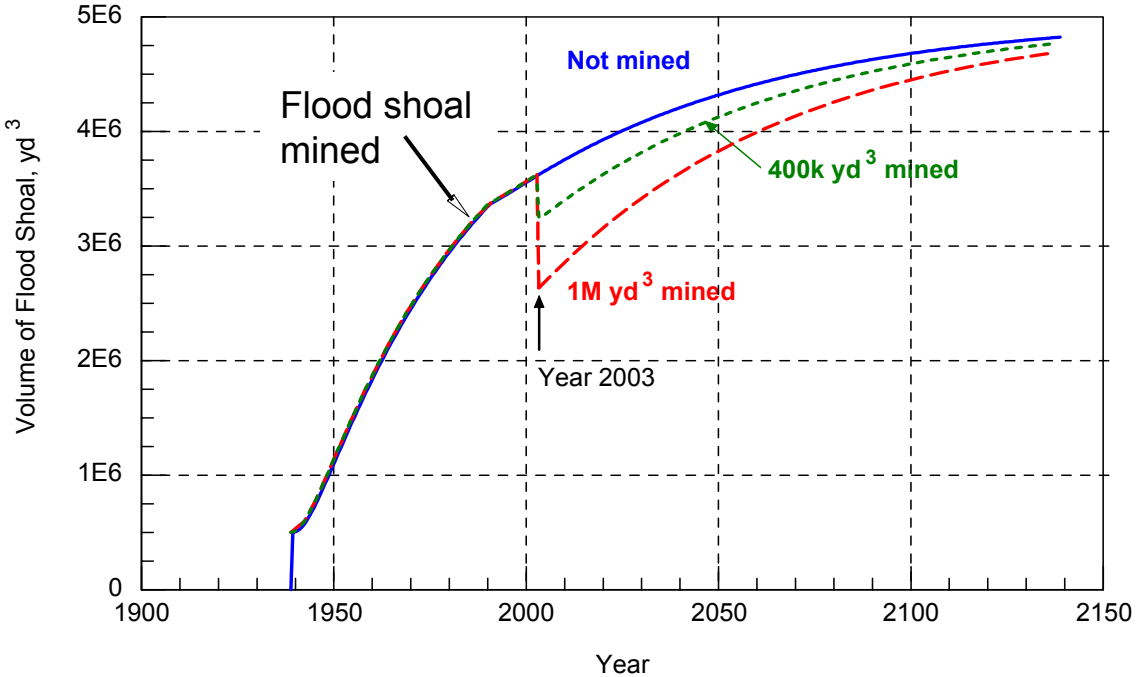
Model Results



Answering the engineering questions --



Consequences of mining a geomorphic feature



Reservoir Model of Volume Change, Sediment Exchange, and Natural Bypassing at Inlets

1. Reservoir model -- potential engineering use (passed blind tests)

2. Time scale of morphological evolution $\alpha = Q_{in}/V_{Ee} \sim Q/P$

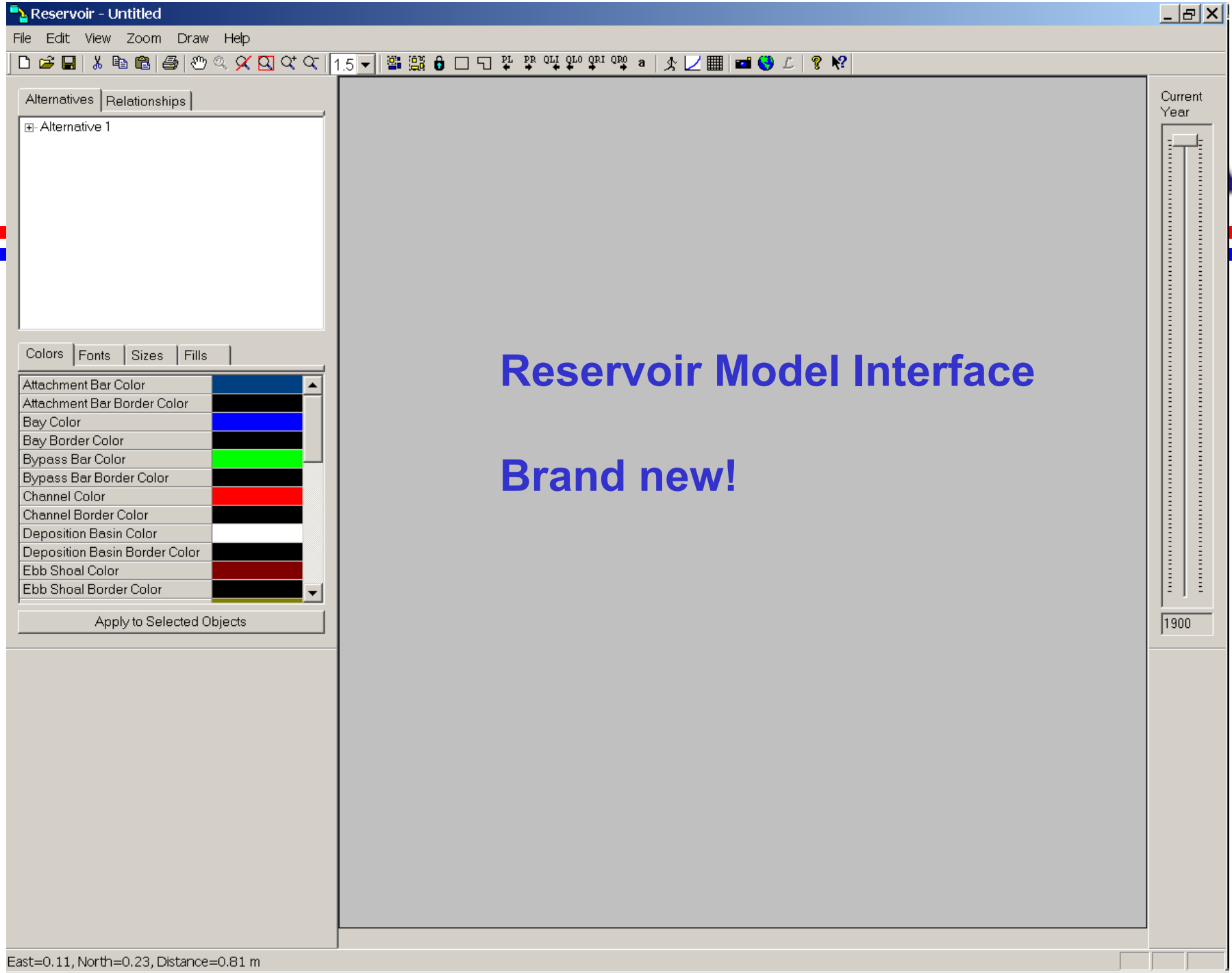
3. Time delay in morphology and evolution and bypassing predicted

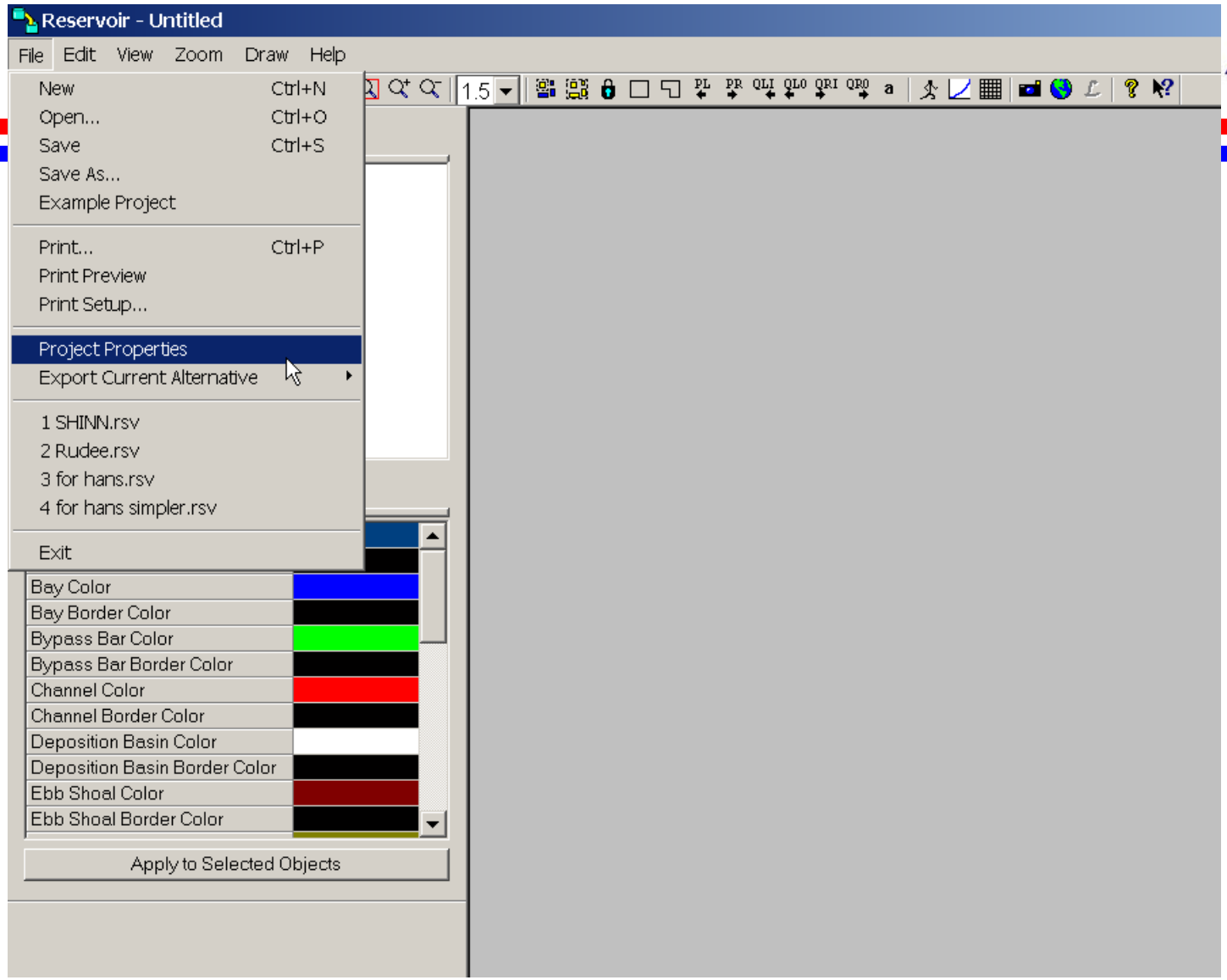
4. Predicted trends at Ocean City, Maryland agree for ebb-shoal volume, rate of growth, and time delay

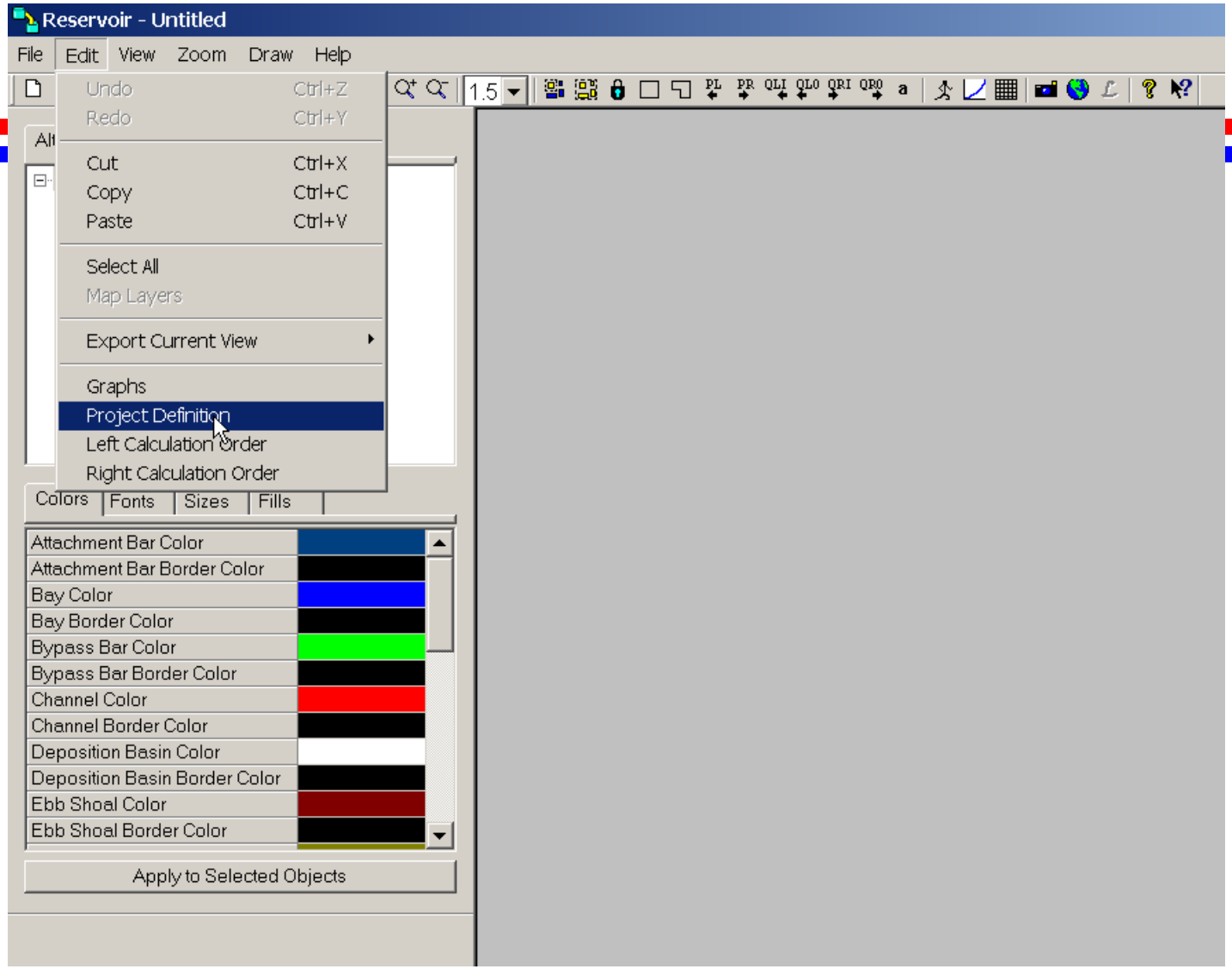
5. Model appears to generalize for all major inlet morphological features; reasonable results at Shinnecock Inlet, NY

6. Can estimate consequences for bypassing after ebb shoal mining (best times and stage of shoal evolution to remove sand; recovery rates; mine shoal, bar, attachment bar?)

7. Coupling coefficients can incorporate micro- and meso-physics, and reservoir model will still provide bounded answers


Reservoir - Untitled
File Edit View Zoom Draw Help
1.5
Alternatives
Relationships
Alternative 1
Colors
Fonts
Sizes
Fills
Attachment Bar Color
Attachment Bar Border Color
Bay Color
Bay Border Color
Bypass Bar Color
Bypass Bar Border Color
Channel Color
Channel Border Color
Deposition Basin Color
Deposition Basin Border Color
Ebb Shoal Color
Ebb Shoal Border Color
Apply to Selected Objects
Reservoir Model Interface
Brand new!
Current Year
1900
East=0.11, North=0.23, Distance=0.81 m


Reservoir - Untitled
File
Edit
View
Zoom
Draw
Help
New Ctrl+N
Open... Ctrl+O
Save Ctrl+S
Save As...
Example Project
Print... Ctrl+P
Print Preview
Print Setup...
Project Properties
Export Current Alternative
1 SHINN.rsv
2 Rudee.rsv
3 for hans.rsv
4 for hans simpler.rsv
Exit
Bay Color
Bay Border Color
Bypass Bar Color
Bypass Bar Border Color
Channel Color
Channel Border Color
Deposition Basin Color
Deposition Basin Border Color
Ebb Shoal Color
Ebb Shoal Border Color
Apply to Selected Objects


Reservoir - Untitled
File
Edit
View
Zoom
Draw
Help
Undo Ctrl+Z
Redo Ctrl+Y
Cut Ctrl+X
Copy Ctrl+C
Paste Ctrl+V
Select All
Map Layers
Export Current View
Graphs
Project Definition
Left Calculation Order
Right Calculation Order
1.5
Colors
Fonts
Sizes
Fills
Attachment Bar Color
Attachment Bar Border Color
Bay Color
Bay Border Color
Bypass Bar Color
Bypass Bar Border Color
Channel Color
Channel Border Color
Deposition Basin Color
Deposition Basin Border Color
Ebb Shoal Color
Ebb Shoal Border Color
Apply to Selected Objects

Reservoir - Untitled

File Edit View Zoom Draw Help

1.5

Alternatives | Relationships

- Alternative 1
  - Features
  - Pathways

Colors | Fonts | Sizes | Fills

Attachment Bar Color	
Attachment Bar Border Color	
Bay Color	
Bay Border Color	
Bypass Bar Color	
Bypass Bar Border Color	
Channel Color	
Channel Border Color	
Deposition Basin Color	
Deposition Basin Border Color	
Ebb Shoal Color	
Ebb Shoal Border Color	

Apply to Selected Objects

Project Properties

Author:

Keywords:

Comments:

Title:

Subject:

OK

Cancel

Units of measurement

- (•) cubic meters
- ( ) cubic yards

Current Year

1900

For Help, press F1

Reservoir - Untitled

File Edit View Zoom Draw Help

Alternatives | Relationships

- Alternative 1
  - Features
  - Pathways

Colors | Fonts | Sizes | Fill

- Attachment Bar Color
- Attachment Bar Border Color
- Bay Color
- Bay Border Color
- Bypass Bar Color
- Bypass Bar Border Color
- Channel Color
- Channel Border Color
- Deposition Basin Color
- Deposition Basin Border Color
- Ebb Shoal Color
- Ebb Shoal Border Color

Apply to Selected

Current Year

1900

Project Definition

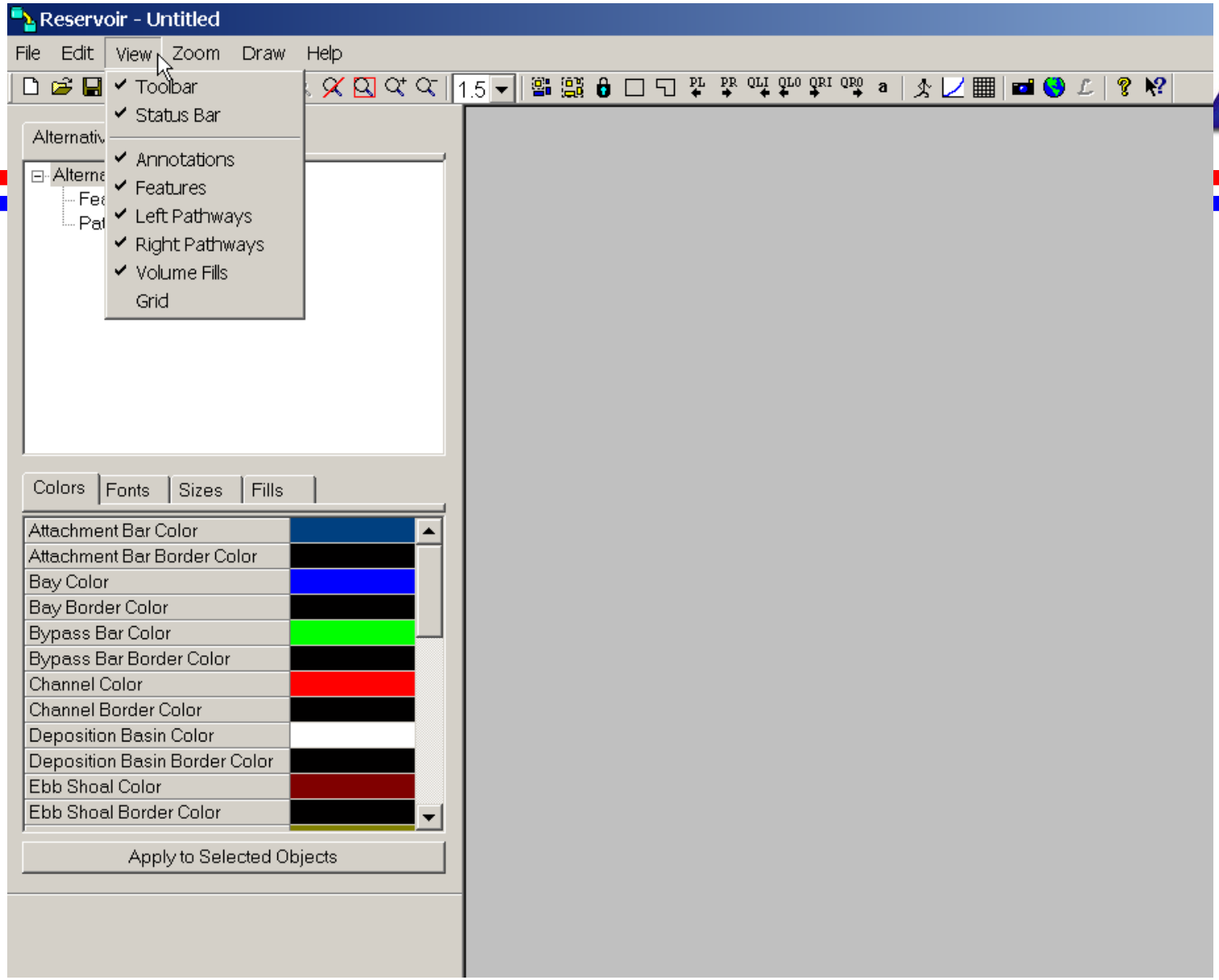
Coupling Coeff. | Coupling Coeff. Dependencies | Volumes | Measurements | Events | Dates

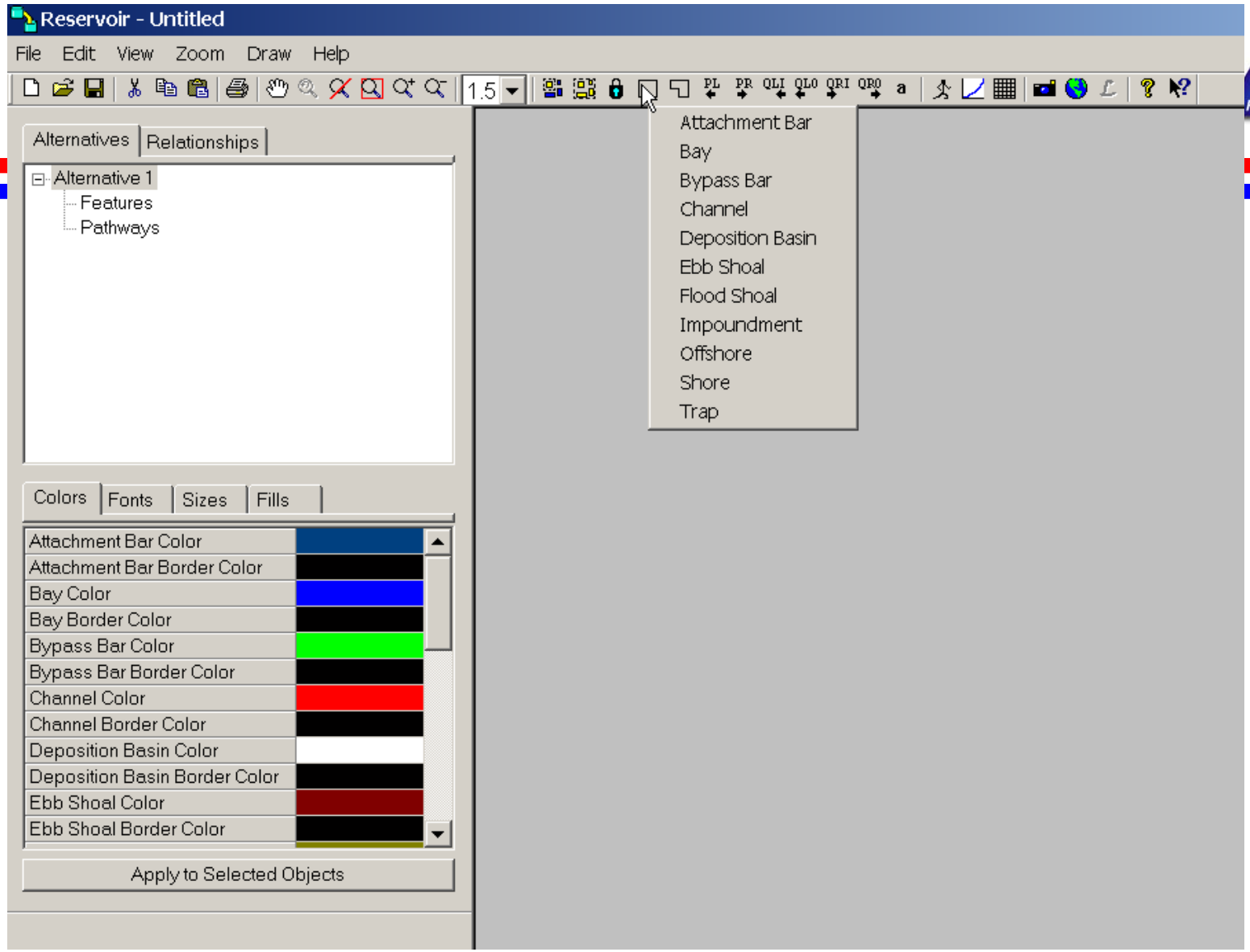
Coefficient	Date	Value	Comment

Double-click on a coefficient to deep edit its properties.

OK | Cancel | Apply | Help

For Help, press F1


Reservoir - Untitled
File
Edit
View
Zoom
Draw
Help
Toolbar
Status Bar
Annotations
Features
Left Pathways
Right Pathways
Volume Fills
Grid
1.5
PL
PR
QLI
QLO
QRI
QRO
a
Colors
Fonts
Sizes
Fills
Attachment Bar Color
Attachment Bar Border Color
Bay Color
Bay Border Color
Bypass Bar Color
Bypass Bar Border Color
Channel Color
Channel Border Color
Deposition Basin Color
Deposition Basin Border Color
Ebb Shoal Color
Ebb Shoal Border Color
Apply to Selected Objects


Reservoir - Untitled
File
Edit
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Help
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Alternatives
Relationships
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Attachment Bar Color
Attachment Bar Border Color
Bay Color
Bay Border Color
Bypass Bar Color
Bypass Bar Border Color
Channel Color
Channel Border Color
Deposition Basin Color
Deposition Basin Border Color
Ebb Shoal Color
Ebb Shoal Border Color
Apply to Selected Objects
Attachment Bar
Bay
Bypass Bar
Channel
Deposition Basin
Ebb Shoal
Flood Shoal
Impoundment
Offshore
Shore
Trap

Reservoir - Rudee.rsv

File Edit View Zoom Draw Help

Alternatives | Relationships

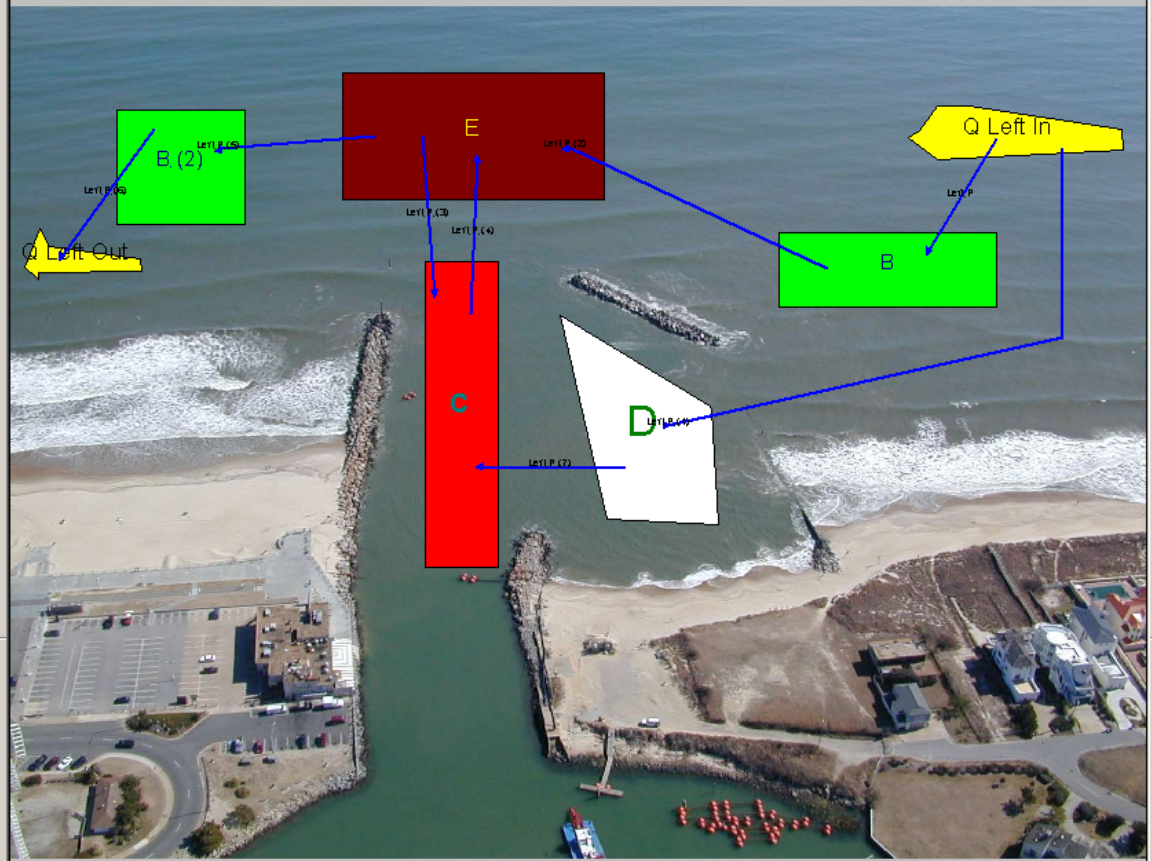
Alternative 1

Rudee Inlet, VA

Colors | Fonts | Sizes | Fills

Attachment Bar Color	
Attachment Bar Border Color	
Bay Color	
Bay Border Color	
Bypass Bar Color	
Bypass Bar Border Color	
Channel Color	
Channel Border Color	
Deposition Basin Color	
Deposition Basin Border Color	
Ebb Shoal Color	
Ebb Shoal Border Color	

Apply to Selected Objects



Current Year

1900

East=150.77, North=615.98, Distance=604.27 m

Reservoir - Rudee.rsv

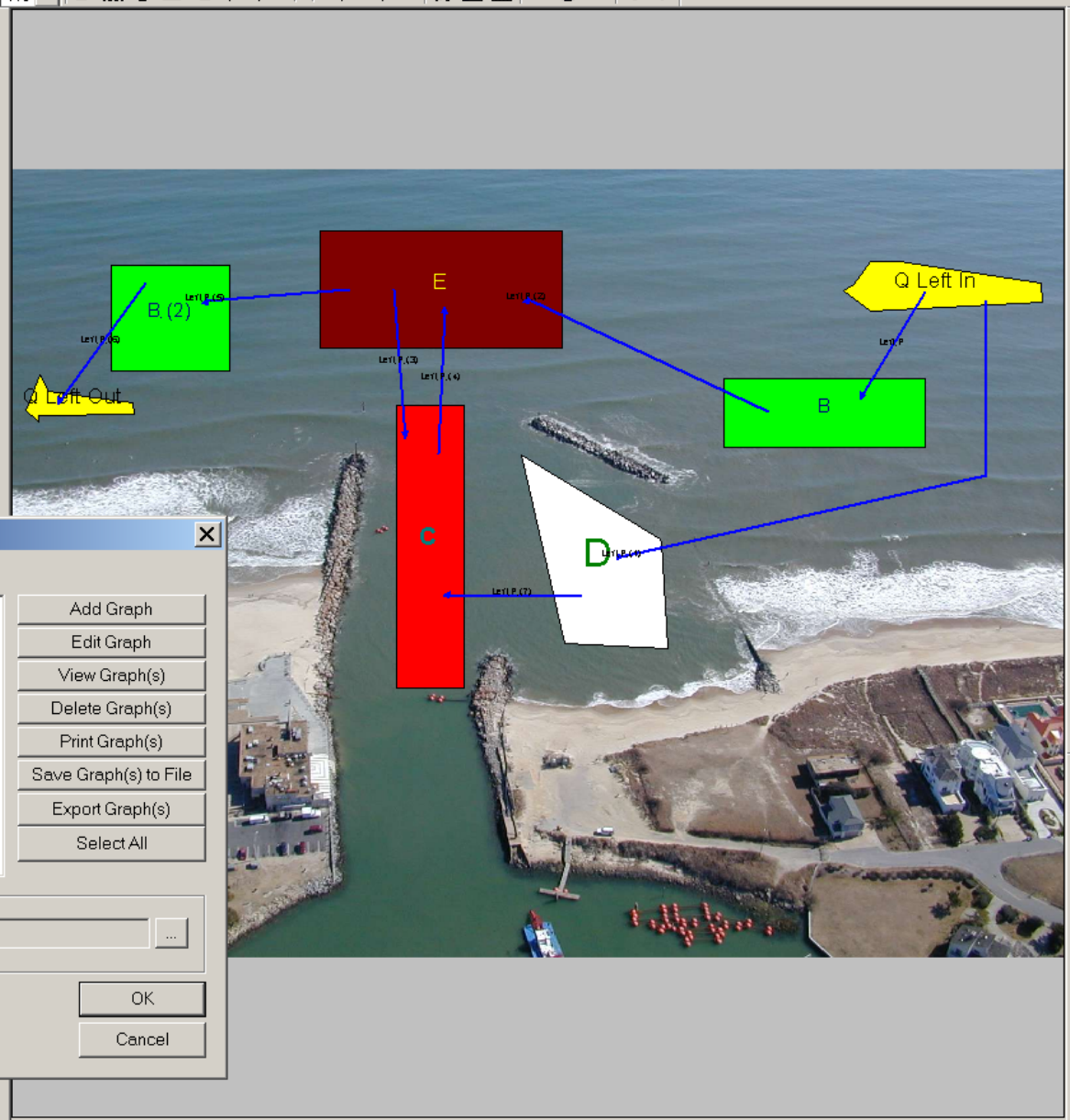
File Edit View Zoom Draw Help

Alternatives | Relationships

Alternative 1

Colors | Fonts | Sizes | Fills

Attachment Bar Color
Attachment Bar Border Color
Bay Color
Bay Border Color
Bypass Bar Color
Bypass Bar
Channel Col
Channel Bor
Deposition E
Deposition E
Ebb Shoal C
Ebb Shoal B



Current Year

1900

Graphs

Current Graphs

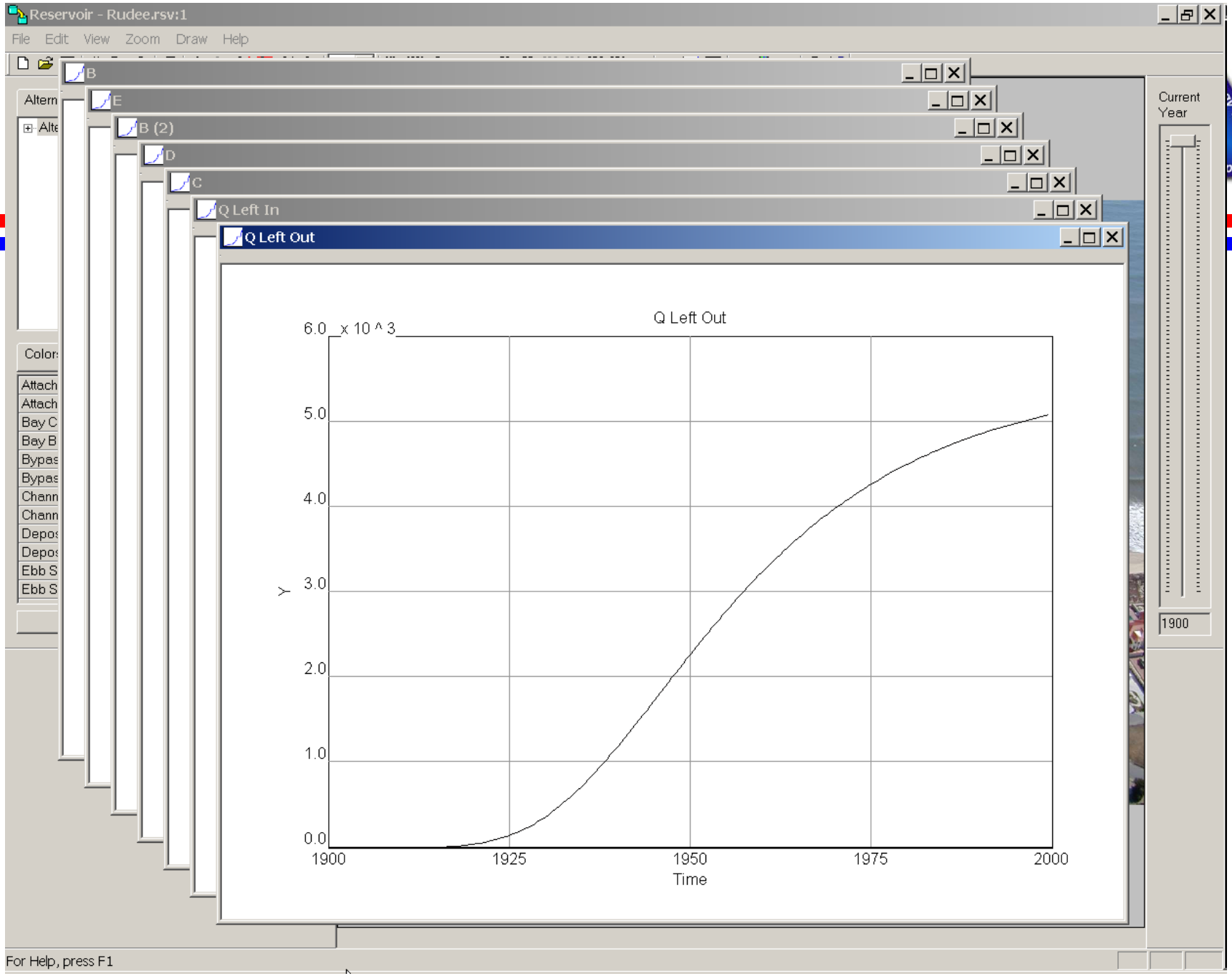
- B
- E
- B (2)
- D
- C
- Q Left In
- Q Left Out

Add Graph
Edit Graph
View Graph(s)
Delete Graph(s)
Print Graph(s)
Save Graph(s) to File
Export Graph(s)
Select All

Current File

OK
Cancel

For Help, press F1


Reservoir - Rudee.rsv:1
File Edit View Zoom Draw Help
B
E
B (2)
D
C
Q Left In
Q Left Out
Q Left Out
x 10 ^ 3
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Y
1900
1925
1950
1975
2000
Time
Current Year
1900
For Help, press F1

Reservoir - Rudee.rsv:1

File Edit View Zoom Draw Help

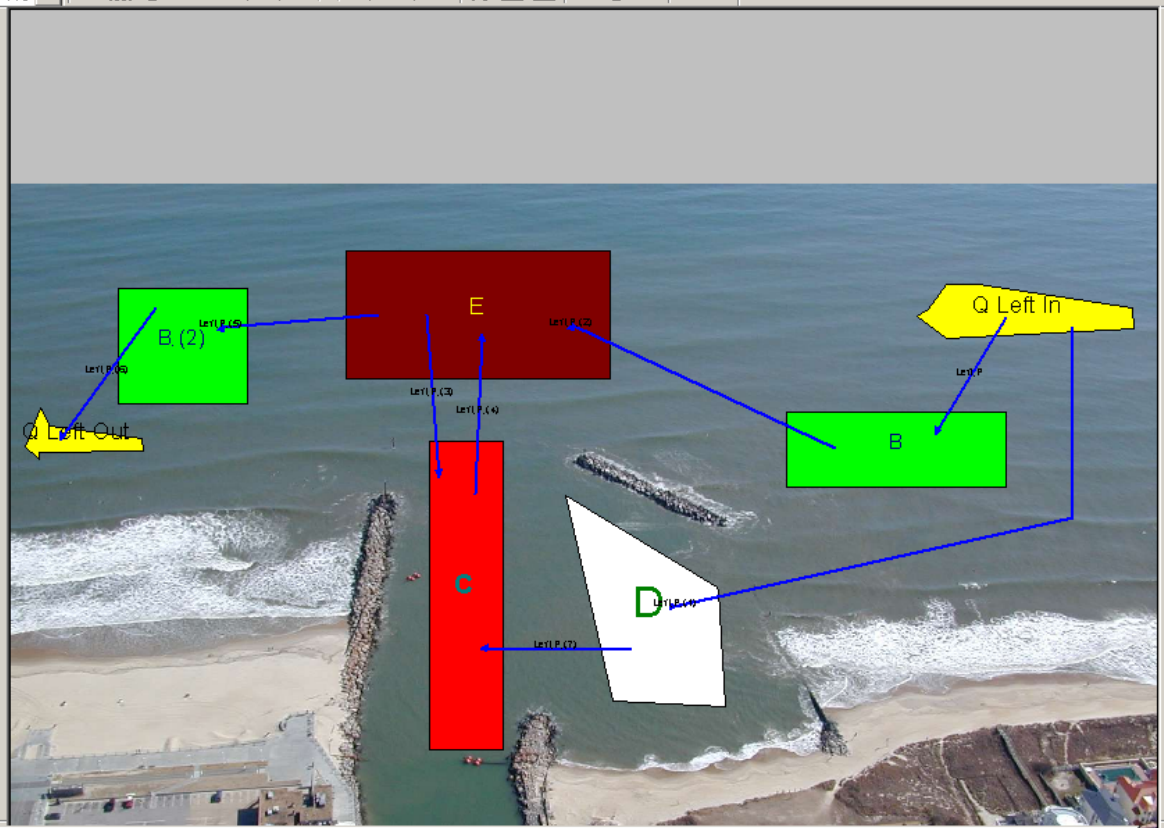
Alternatives | Relationships

- Alternative 1

Colors | Fonts | Sizes | Fills

Attachment Bar Color	
Attachment Bar Border Color	
Bay Color	
Bay Border Color	
Bypass Bar Color	
Bypass Bar Border Color	
Channel Color	
Channel Border Color	
Deposition Basin Color	
Deposition Basin Border Color	
Ebb Shoal Color	
Ebb Shoal Border Color	

Apply to Selected Objects



Current Year

1900

Project Definition

Coupling Coeff. | Coupling Coeff. Dependencies | Volumes | Measurements | Events | Dates

Coefficient	Date	Value	Comment
aBE (Left P (2))	1900.00	1.00	
aEC (Left P (3))	1900.00	0.30	
aEB (2) (Left P (5))	1900.00	0.70	
aB (2)Q Left Out (Left P (6))	1900.00	1.00	
aDC (Left P (7))	1900.00	1.00	
aCE (Left P (4))	1900.00	1.00	
aQ Left InB (Left P)	1900.00	0.50	
aQ Left InD (Left P (1))	1900.00	0.50	

For Help, press F1

Reservoir - seb.rsv:1

File Edit View Zoom Draw Help

Alternatives | Relationships

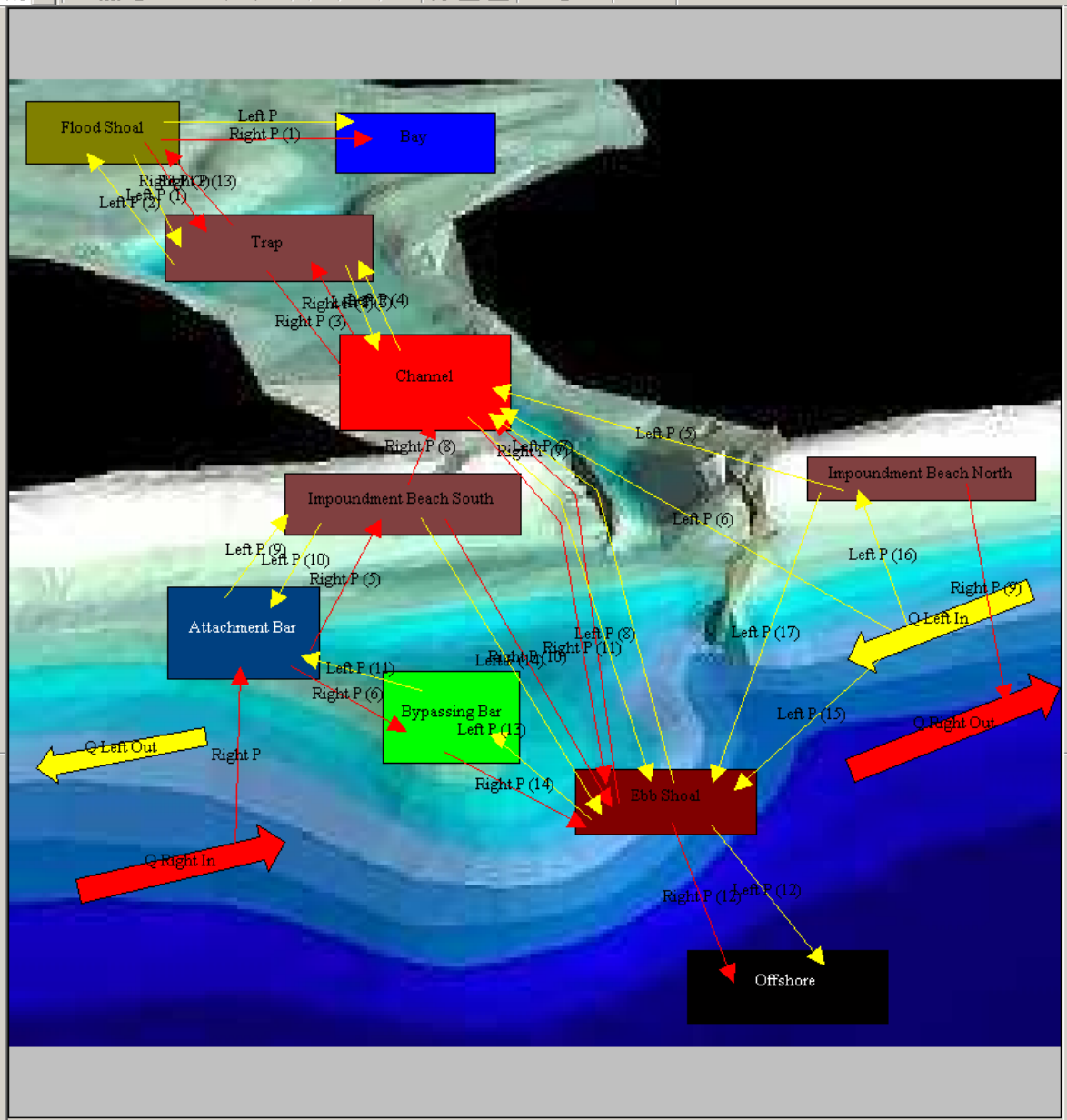
Alternative 1

Sebastian Inlet, FL

Colors | Fonts | Sizes | Fills

Attachment Bar Color	
Attachment Bar Border Color	
Bay Color	
Bay Border Color	
Bypass Bar Color	
Bypass Bar Border Color	
Channel Color	
Channel Border Color	
Deposition Basin Color	
Deposition Basin Border Color	
Ebb Shoal Color	
Ebb Shoal Border Color	

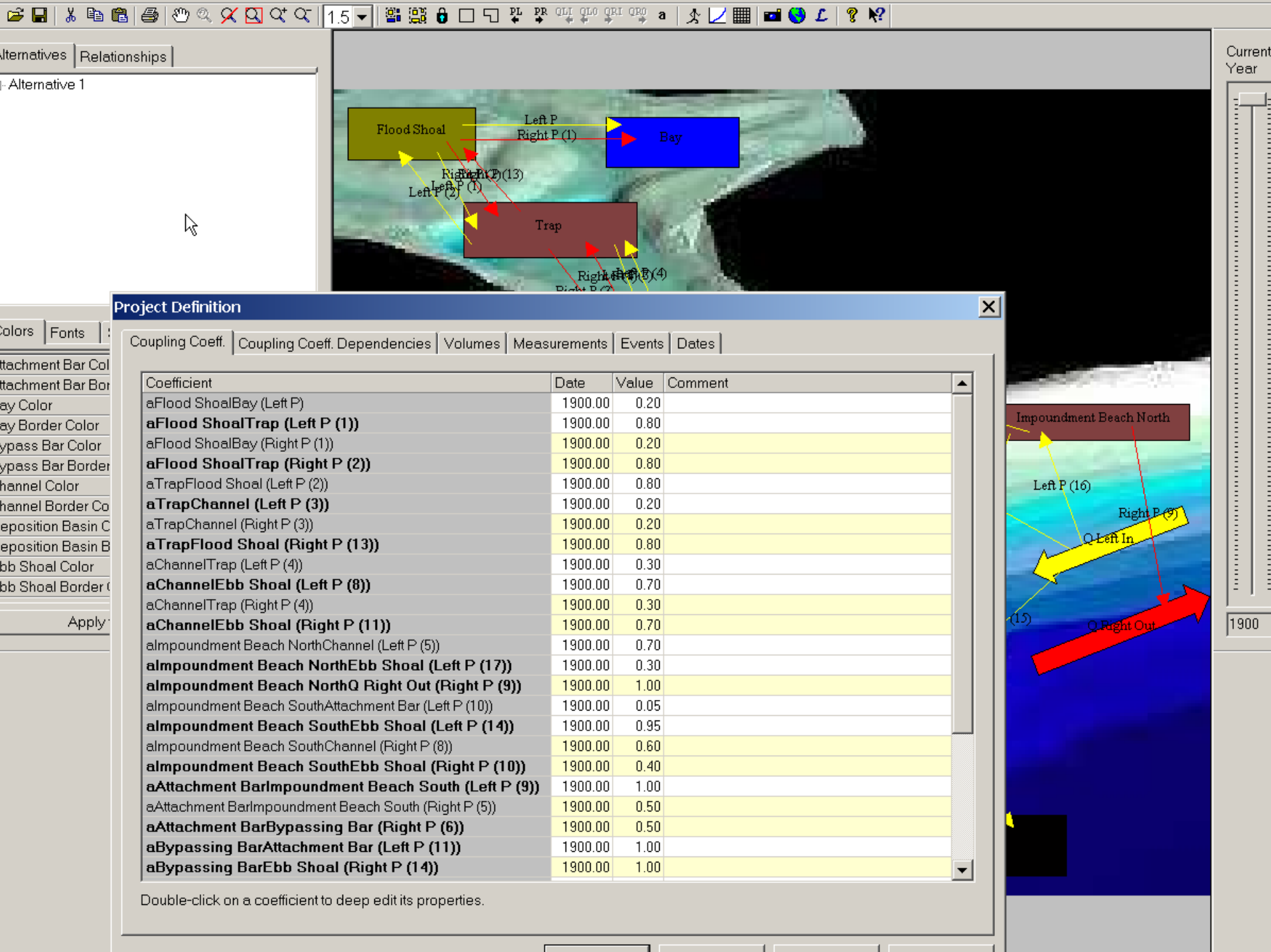
Apply to Selected Objects



Current Year

1900

East=0.13, North=48.33, Distance=170.22 m



Coefficient	Date	Value	Comment
aFlood ShoalBay (Left P)	1900.00	0.20	
aFlood ShoalTrap (Left P (1))	1900.00	0.80	
aFlood ShoalBay (Right P (1))	1900.00	0.20	
aFlood ShoalTrap (Right P (2))	1900.00	0.80	
aTrapFlood Shoal (Left P (2))	1900.00	0.80	
aTrapChannel (Left P (3))	1900.00	0.20	
aTrapChannel (Right P (3))	1900.00	0.20	
aTrapFlood Shoal (Right P (13))	1900.00	0.80	
aChannelTrap (Left P (4))	1900.00	0.30	
aChannelEbb Shoal (Left P (8))	1900.00	0.70	
aChannelTrap (Right P (4))	1900.00	0.30	
aChannelEbb Shoal (Right P (11))	1900.00	0.70	
aImpoundment Beach NorthChannel (Left P (5))	1900.00	0.70	
aImpoundment Beach NorthEbb Shoal (Left P (17))	1900.00	0.30	
aImpoundment Beach NorthQ Right Out (Right P (9))	1900.00	1.00	
aImpoundment Beach SouthAttachment Bar (Left P (10))	1900.00	0.05	
aImpoundment Beach SouthEbb Shoal (Left P (14))	1900.00	0.95	
aImpoundment Beach SouthChannel (Right P (8))	1900.00	0.60	
aImpoundment Beach SouthEbb Shoal (Right P (10))	1900.00	0.40	
aAttachment BarImpoundment Beach South (Left P (9))	1900.00	1.00	
aAttachment BarImpoundment Beach South (Right P (5))	1900.00	0.50	
aAttachment BarBypassing Bar (Right P (6))	1900.00	0.50	
aBypassing BarAttachment Bar (Left P (11))	1900.00	1.00	
aBypassing BarEbb Shoal (Right P (14))	1900.00	1.00	