US Army Corps
of Engineers

Sediment Budget Analysis System (SBAS)

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PURPOSE: The Coastal Engineering Technical Note (CETN) herein presents the Sediment Budget Analysis System (SBAS), a PC-based method for calculating sediment budgets at single or multiple inlets and at the adjacent beaches. The SBAS runs on the Windows 95, 98, and NT platforms. This CETN is a companion to CETN-IV-15 (Revised September 1999) (Rosati and Kraus 1999), which presents sediment budget theory and methodology, and CETN-IV-16 (Kraus and Rosati 1998), which discusses uncertainty in sediment budgets.

BACKGROUND: Sediment budgets provide a conceptual and quantitative model of the magnitudes and pathways of sediment transport at inlets and adjacent beaches for a given time period. Sediment budgets give a framework for understanding complex inlet and coastal systems and their responses to coastal engineering projects. Any convenient method, such as a spreadsheet application, can be used to formulate and calculate a sediment budget. The SBAS is a convenient method for formulating regional sediment budgets for coastal regions, including inlets, because it is visually based, provides an integrated picture of the processes while archiving detailed calculations within the system, and allows variations in the sediment budget to be rapidly examined.

Capabilities of SBAS include the following:

- Automatically generates and updates sediment budget equations as the user defines computational cells and transport pathways with the SBAS toolbar menu.
- Is visually based by color coding computational cells according to their individual budgets (loss, gain, balance) and by showing transport paths with arrows.
- Allows different sediment budgets for the same coastal reach to be copied and modified to bracket seasonal, yearly, project-specific, and historical changes and to reflect uncertainty and sensitivity testing.
- Can accommodate different conceptual approaches in implementing a sediment budget.
- Facilitates a regional approach and joining of independently prepared budgets on contiguous sections of the coast by allowing an unlimited number of cells and transport pathways and page scrolling left and right or up and down.
- Allows user to track uncertainty and the sediment budget imbalance within each cell and within the budget of all combined cells (the macrobudget).
- Provides capability to define dependencies of one value upon another within the sediment budget.

- Produces report-quality graphics and has all typical Windows operating system features related to graphics, cut-and-paste operations, and similar actions between software applications.
- Allows images (e.g., aerial photographs of the coast) to be loaded as background wallpaper with the sediment budget, upon which computational elements are drawn.
- Contains a tutorial, example project, and help files with on-line guidance.

The following section reviews sediment budget theory (see CETN-IV-15 (Revised September 1999) for more detail). A sediment budget is a tallying of sediment **gains** and **losses**, or **sources** and **sinks**, within a specified control volume (or cell), or series of connecting cells, over a given time. A sediment budget can be developed in several ways (e.g., *Shore Protection Manual* 1984; Jarrett 1991; Bodge 1999). By conservation of mass (volume) of sediment, the difference between the sediment sources and the sinks in each cell, hence for the entire budget, must equal the rate of change in sediment volume occurring within that region, accounting for pertinent engineering activities such as sand placement and dredging. In SBAS, the sediment budget equation is

$$\sum Q_{source} - \sum Q_{sink} - \Delta V + P - R = Residual \qquad (1)$$

in which all terms are expressed consistently as a volume or as a volumetric change rate; Q_{source} and Q_{sink} are the sources and sinks to the control volume, respectively; ΔV is the net change in volume within the cell; and P and R are the amounts (volume or volume rate) of material placed in and removed from the cell, respectively. The *Residual* represents the degree to which the cell is balanced. If the budget of an individual cell is balanced, its residual is zero. For a reach of coast consisting of many contiguous cells, the budget for each cell must balance in achieving a balanced budget for the entire reach.

SBAS also presents the *Residual* for a macrobudget, which is the solution of Equation 1 for all cells. One of the steps in the recommended procedure (see CETN-IV-15 (Revised) for more detail) is to balance the macrobudget before detailed cell-by-cell calculations commence. If the macrobudget is not balanced, at least one of the individual cells will be out of balance.

The purpose of this CETN is to highlight the features of SBAS and demonstrate its application through an example problem. Companion CETNs (CETN-IV-15 (Revised) and CETN-IV-16) contain background information.

OVERVIEW: SBAS organizes the user's workspace for maximum convenience in all aspects of sediment budget formulation, visualization, and reporting. Within the right-hand side of the screen, called the topology window, SBAS formulates a sediment budget by allowing the user to create a series of cells and arrows representing sources, sinks, and sediment-transport pathways that characterize the sediment budget. The left-hand side of the screen organizes alternatives within a particular project (Figure 1). Alternatives may represent various time periods, different boundary conditions for the same time period, or modifications to assumptions within the budget reflecting a sensitivity analysis. Once a sediment budget alternative has been defined, and the user has created sediment budget cells with sources and sinks, values can then be assigned to the various components of the sediment budget topology. The SBAS indicates by color coding

whether a cell is balanced or not. Systematic balancing of individual cells within the macrobudget is a central property of the SBAS methodology.

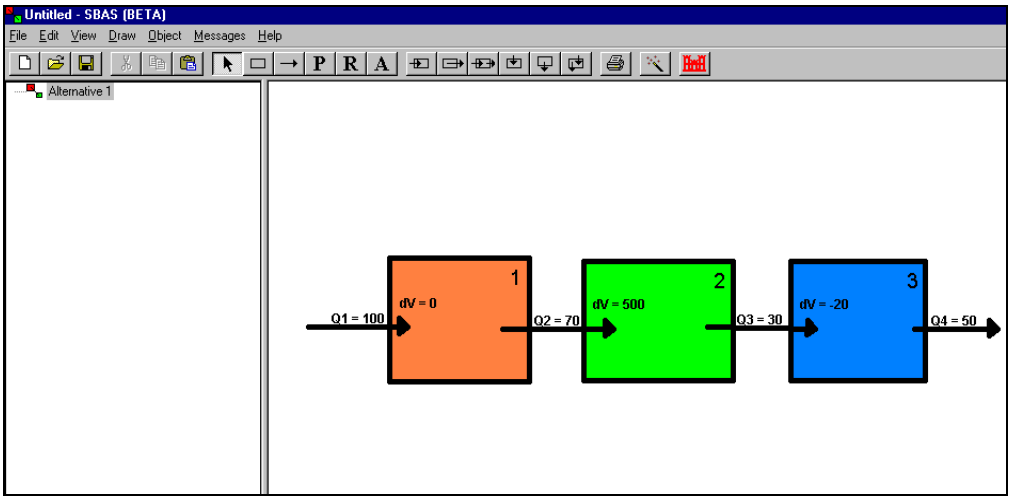

Figure 1. SBAS alternative window (left); topology window (right)

Sediment budget cells, arrows expressing directions of net, left-, and right-directed transport rates, and notation of *P*- and *R*-values comprise the sediment budget topology. The topology window can be expanded to scroll to the right and left (for an east-west sediment budget) or up and down (for a north-south sediment budget). The SBAS automatically formulates and substitutes the quantities from the topology window into the sediment budget equation (Equation 1) based on the origin, terminus, and direction of arrows representing rates. This visual procedure allows an integrated quantitative budget to be formed based on the conceptual budget. At any time, the user can conveniently check the macrobudget to ensure it is balanced before proceeding with detailed calculations.

The basic SBAS procedure is discussed in an on-line format within the Tutorial file (provided with the installation package) and is performed as follows:

- Draw arrows through and between cell boundaries, defining the sources and sinks for each cell (establish the sediment budget topology).
- Define engineering activities *P* and *R* for each cell.
- Assign best-estimate and uncertainty values to volumes, transport rates, and engineering activities within each cell.
- Balance the budget of each cell and the total system (macrobudget) by reducing the residual to zero.

The residual term in Equation 1 allows the user to explore the consequences of adding, removing, changing the magnitude of, or changing the pathways of sources, sinks, and engineering activities within SBAS.

A sediment budget with an effectively limitless number of cells, sources, sinks, and engineering activities can be copied to a new alternative. The new alternative may be modified to reflect different assumptions about sediment-transport magnitudes and pathways, and engineering activities within the budget, or a different time period as compared with the original formulation. SBAS has an option to append and pre-pend alternatives from another project file to the alternative within the topology window.

Uncertainty provides a powerful means of comparing cells within the budget and quantifying the reliability of the budget as a whole (see CETN-IV-16 for discussion of uncertainty). The uncertainty of sediment budgets for different reaches can also be compared. Within SBAS, a total cell uncertainty is calculated by adding all uncertainty values, u, within that cell. This value is normalized by the absolute-value magnitude of sources, sinks, and engineering activities within that cell and expressed as a percentage U (percent) as follows:

$$U(\%) = \frac{\sum u}{\sum Qsource + \sum Qsink + |\Delta V| + P + R} \quad (100),$$

$$for \left[\sum Qsource + \sum Qsink + |\Delta V| + P + R\right] > 0; \qquad (2)$$

$$U(\%) = 0 \quad for \left[\sum Qsource + \sum Qsink + |\Delta V| + P + R\right] = 0$$

Similarly, a percent uncertainty is calculated for the entire alternative using Equation 2. The percent uncertainty for various alternatives can then be compared, revealing the degree to which various assumptions are known and thereby giving a means to quantify the reliability of the budget as a whole.

SBAS has several features designed to streamline the process of formulating a sediment budget. Transport rate quantities may be calculated as associated with relative sea-level change and onshore or offshore transport or based on values of other transport rate values. Scanned photographs or bathymetric maps may be included as wallpaper within the topology window, allowing calculation cells to be drawn on top of the regions of interest in the proper location. Sediment budget cells may be rotated to more closely approximate the shoreline and bathymetric orientation. An extensive help file provides on-line guidance for formulating a sediment budget and estimating various quantities.

With the SBAS installation package, Tutorial and Example files are provided. The Tutorial simply provides an on-line presentation of the basic methodology within SBAS and is self-explanatory. The Example file pertains to the following discussion below, and the user is encouraged to read through the example while performing calculations in the on-line Example.

EXAMPLE: Although SBAS is a convenient tool for formulating a sediment budget, any systematic solution approach, such as a spreadsheet, could be taken. Within this example, uncertainty in length and time values are assumed to be negligible, although this is not necessary.

GIVEN: A 1,000-m-wide inlet will be cut through the center of a barrier island that has length Δx = 10 km. From analysis of shoreline-position data, the barrier island erosion rate has been estimated as $\Delta y/\Delta t = 0.3 \pm 0.1$ m/year/m for the past Δt = 10 years (see Figure 2). The active depth of transport for the barrier (the range over which the shoreline is assumed to translate parallel to itself, defined as the absolute elevation from the berm crest to depth of closure) is estimated as $D_A = 10 \pm 1$ m. In the absence of other information, assume that uncertainty in transport rates is 40 percent of the given value. Net longshore sediment transport is to the north and is estimated as $Q_{net\text{-}N} = 150{,}000 \pm 60{,}000$ m^3/year at the northern boundary of the barrier. Based on deposition rates at a weir jetty south of the project area, the right-directed component of the net transport (for a land-based observer) is estimated as $Q_{R\text{-}S} = 200{,}000 \pm 80{,}000$ m^3/year at the southern boundary. Because of the similarity in wave fetch and bathymetry, the right-directed component of the net transport is assumed to be the same for the northern portion of the barrier, $Q_{R\text{-}N} = 200{,}000 \pm 80{,}000$ m^3/year. Beach fill $F = 200{,}000 \pm 10{,}000$ m^3 was placed along the entire barrier at the start of the 10-year period. Assume that the north and south boundaries are sufficiently removed from the inlet's influence, and transport rates at these boundaries of the barrier do not change after the inlet is cut.

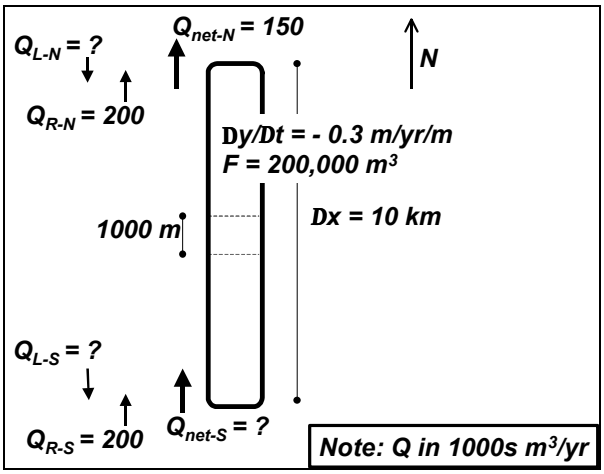

Figure 2. Example: pre-inlet data

FIND: **(a)** Formulate a pre-inlet sediment budget. **(b)** Calculate the adjacent beach shoreline change immediately after sandtight jetties are constructed (initial impoundment). **(c)** Once impoundment is complete, assume the inlet is a gross sink. Assume that 50 percent of the material transported to the ebb shoal accretes on the shoal, and the remainder is passed to the channel. Assume that 50 percent of this material shoals in the channel, and the remainder is accreted within the flood shoal and bay. Calculate the volume change and net transport rates for the adjacent barriers, ebb shoal, channel, and flood shoal/bay. **(d)** Determine the sediment budget representative of a partial bypassing to the downdrift beach. Assume that 25 percent of the material entering the ebb-tidal shoal is bypassed to the downdrift beach, 25 percent is transported to the channel, and the remaining 50 percent deposits on the ebb-tidal shoal.

SOLUTION: The solution follows the recommended procedure for developing a sediment budget. Refer to CETN-IV-15 (Revised) for additional discussion of the procedure. Also,

several equations are taken directly from CETN-IV-15 (Revised September 1999) and CETN-IV-16.

Step 1: Develop a Conceptual Sediment Budget. Determine the conceptual sediment budget by delineating sediment budget cells, indicating sediment-transport pathways, and entering place holders for volume and placement rate data. Within SBAS, the conceptual sediment budget (Figure 3) is designed to encompass all the cases discussed above. The lengths of the southern or updrift cell and the northern or downdrift cell are equal: 4,500 m. The length of the inlet cell is 1,000 m.

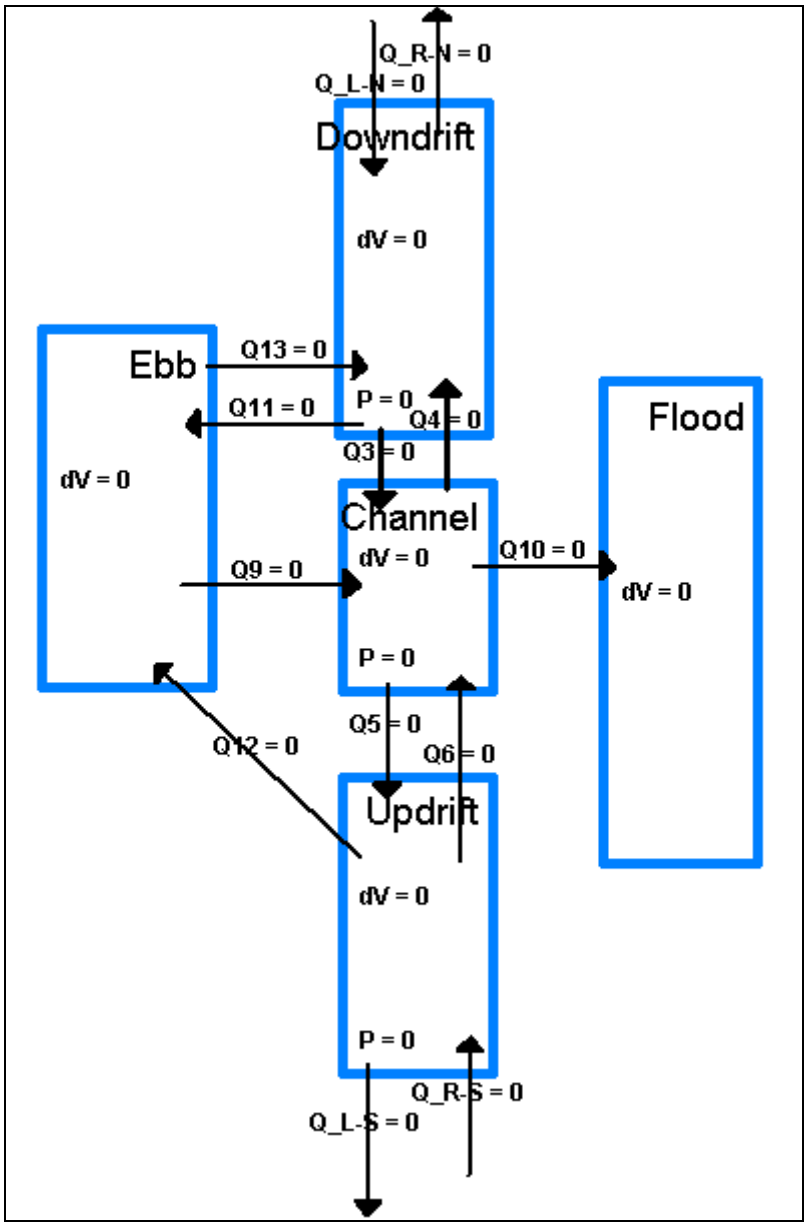

Figure 3. Conceptual sediment budget

Step 2: Pre-Inlet. Within SBAS, the conceptual sediment budget was copied to another alternative and titled "Pre-Inlet: Apply macrobudget." Values within the budget were estimated from the given values as in the following.

At the north boundary, Equation 2 of CETN-IV-15 (Revised) gives $Q_{L\text{-}N} = Q_{R\text{-}N} - Q_{net\text{-}N}$. Thus, $Q_{L\text{-}N}$ = 50,000 m^3/year. Applying Equation 5b of CETN-IV-16 gives

$$\delta Q_{L\text{-}N\,best} = \sqrt{\delta Q_{R-N}^2 + \delta Q_{net-N}^2} = \sqrt{80,000^2 + 60,000^2} = 100,000 \text{ m}^3\text{/year}$$

For all transport rate uncertainties, we have assumed that they were approximately 40 percent of the given value (implying $\delta Q_{L\text{-}N}$ = 0.4(50,000) = 20,000 m^3/year), which differs from the uncertainty calculated above. For consistency within this example problem, we will adopt the 40-percent value; thus $Q_{L\text{-}N}$ = 50,000 ± 20,000 m^3/year. However, for a site-specific project, other information might indicate the higher value was more appropriate, or perhaps the engineer would create another alternative with the higher value to determine its impact on the uncertainty of the macrobudget.

For the entire pre-inlet barrier, Equation 5 of CETN-IV-15 (Revised) gives $\Delta V = (\Delta y/Dt)(D_A)(Dx)$ = (-0.3 m/year/m)(10 m)(10,000 m) = -30,000 m^3/year. According to Equation 9b of CETN-IV-16, the associated uncertainty is

$$d\Delta V_{best} = \Delta V \sqrt{\left(\frac{d\Delta y}{\Delta y}\right)^2 + \left(\frac{dD_A}{D_A}\right)^2 + \left(\frac{dL}{L}\right)^2} = -30,000 \sqrt{\left(\frac{0.1}{0.3}\right)^2 + \left(\frac{1}{10}\right)^2 + \left(\frac{0}{10,000}\right)^2} = \pm 10,400 \text{ m}^3\text{/year}$$

This volume change and associated uncertainty were portioned for each segment of the barrier according to its length, $\Delta V_{updrift} = \Delta V_{downdrift}$ = -13,500 ± 4,700 m^3/year and ΔV_{inlet} = -3,000 ±1,000 m^3/year. The pre-inlet ebb and flood shoals do not exist; thus $\Delta V_{ebb} = \Delta V_{flood}$ = 0.

The beach fill was converted to a placement rate, $P = F/Dt$ = 200,000 m^3/10 years = 20,000 m^3/year. Applying Equation 6b of CETN-IV-16,

$$dP_{best} = P \sqrt{\left(\frac{dF}{F}\right)^2 + \left(\frac{d\Delta t}{\Delta t}\right)^2} = 20,000 \sqrt{\left(\frac{10,000}{200,000}\right)^2 + \left(\frac{0}{10}\right)^2} = \pm 1,000 \text{ m}^3\text{/year}$$

This placement rate was portioned to the pre-inlet barrier according to each cell length, $P_{updrift} = P_{downdrift}$ = 9,000 ± 450 m^3/year and P_{inlet} = 2,000 ± 100 m^3/year. No beach fill was placed within the ebb- and flood-shoal regions.

All known data were entered into SBAS in units of 1,000's of m^3/year, done for convenience but not being necessary. Within SBAS, the macrobudget Option combines all cells. The residual for the macrobudget indicates that the only unknown for the macrobudget $Q_{L\text{-}S}$ = 100,000 m^3/year

(Figure 4). We will assume a 40-percent uncertainty; thus $Q_{L\text{-}S}$ = 100,000 ± 40,000 m^3/year. These values are then entered into the sediment budget.

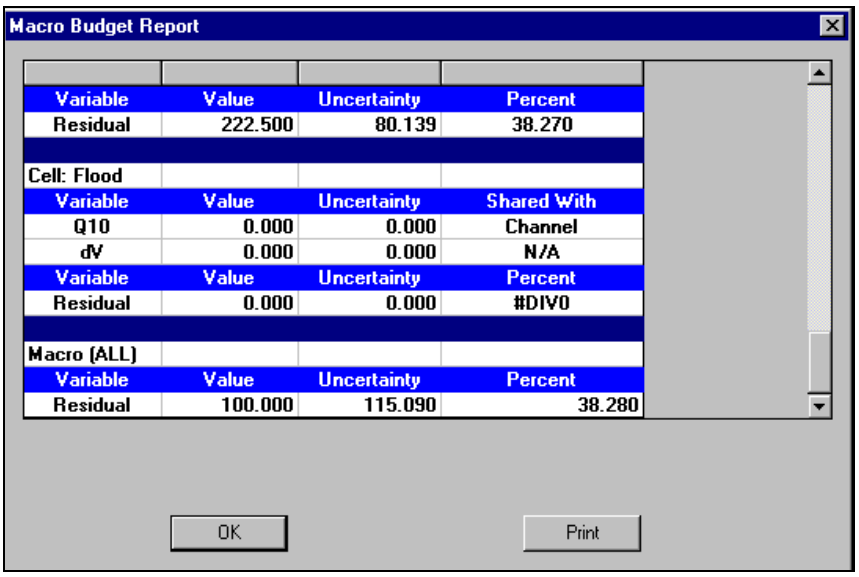

Figure 4. Macrobudget option within SBAS

Because right-directed transport has been assumed to be constant for the entire barrier, set values of right-directed transport at the pre-inlet boundaries, *Q4* and *Q6* = 200,000 m^3/year. Assume for the pre-inlet condition that *Q9=Q10=Q11=Q12=0*. Use the residual values or the "force balance cell" option for each cell to determine the unknowns. The final pre-inlet sediment budget is shown in Figure 5.

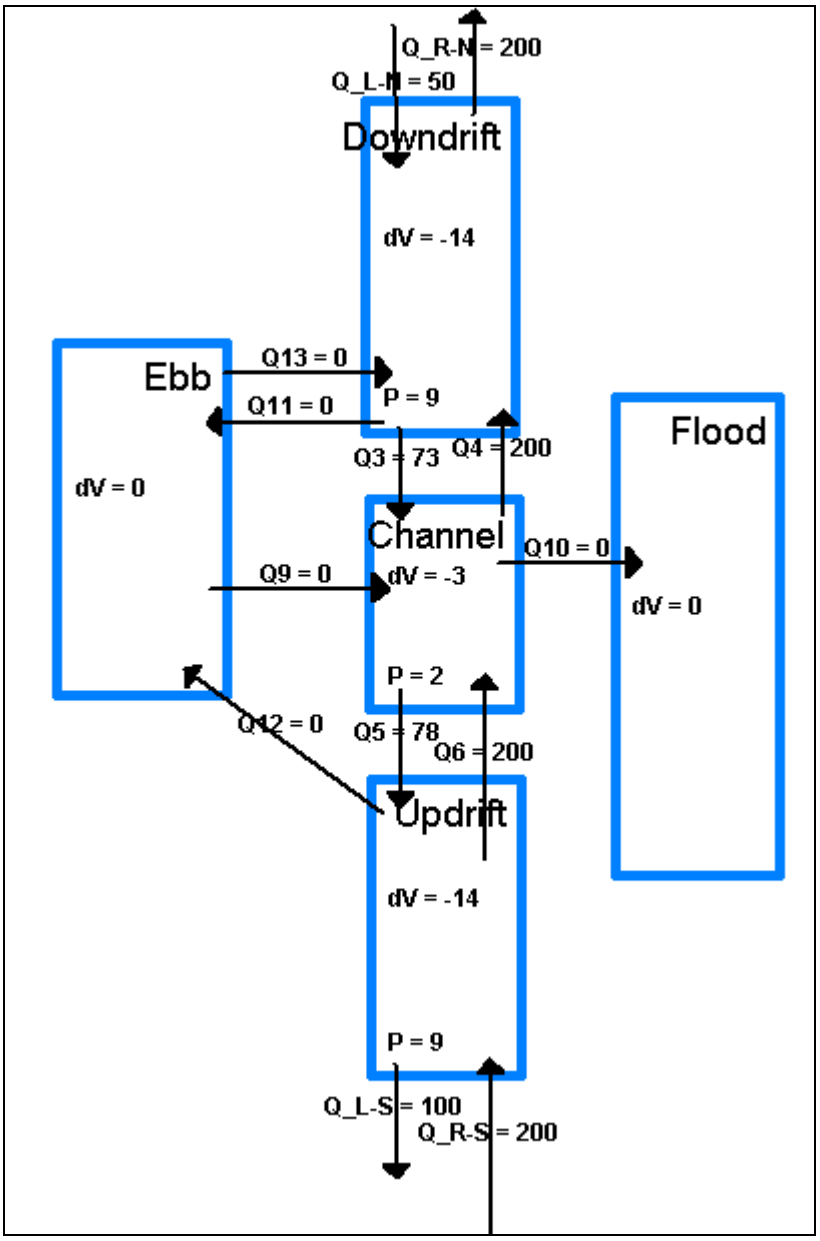

Figure 5. Sediment budget for "Pre-Inlet: Final"

Step 3: Post-Inlet: Initial Impoundment. Within SBAS, the "Pre-Inlet: Final" sediment budget was copied to another alternative and titled "Post-Inlet: Initial Impoundment." Values were set so that *Q3=Q4=Q5=Q6=0*, indicating that no sediment was transported over or through the jetties. Values of adjacent beach erosion or accretion were calculated using the "force balance cell" option for calculating ΔV. Associated uncertainties $\delta(\Delta V)$ were set at approximately 35 percent of the value, as occurred for the pre-inlet case. Figure 6 shows the sediment budget representing initial impoundment.

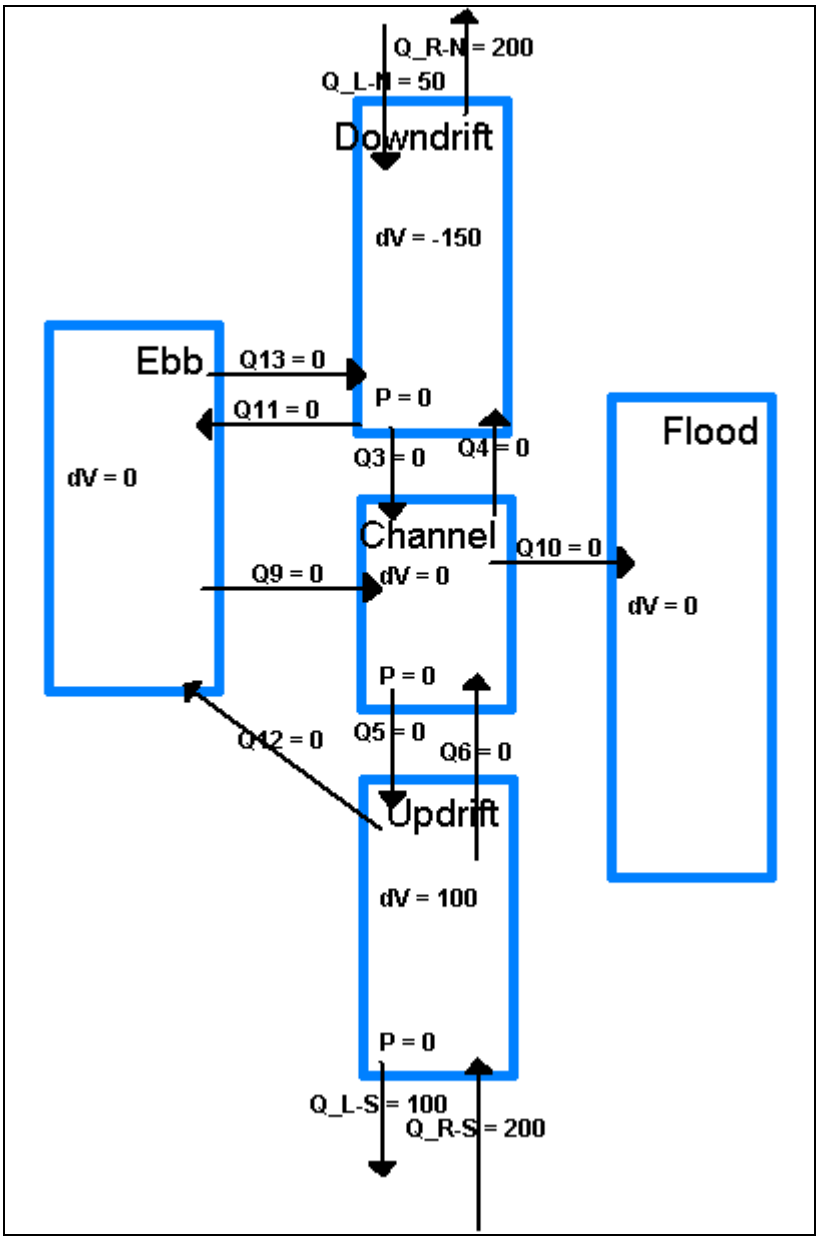

Figure 6. Sediment budget for "Post-Inlet: Initial Impoundment"

Step 4: Post-Inlet: Gross Sink. The gross sink sediment budget was similarly developed by copying and renaming the previous alternative. The left-directed transport rate at the north jetty, *Q11*, and the right-directed transport rate at the south jetty, *Q12*, were set equal to the pre-inlet rates. That is, *Q11=Q3* (*Q3* taken from "Pre-Inlet: Final" alternative) and *Q12=Q6* (*Q6* taken from "Pre-Inlet: Final" alternative) and directed towards the ebb-tidal shoal. The right-directed transport at the north jetty, *Q4*, and the left-directed transport at the south jetty, *Q5*, were set to zero, indicating no transport over or through the jetties to the adjacent beaches. Within SBAS, an option exists for setting a dependency for a *Q* value based on other *Q* values. Entering the Cell Properties Menu for the ebb-tidal shoal and double-clicking on *Q9* allows us to define the relationship $Q9 = 0.5 \times (Q11+Q12)$ (Figure 7). The out-of-balance residual or solving using the

"force balanced cell" option indicates the magnitude of ΔV = 136,250 ± 47,700 m^3/year (assuming 35 percent uncertainty in ΔV) for the ebb-tidal shoal. Similarly, a dependency can be defined for $Q10 = 0.5 \times Q9$ within the Cell Properties Menu for the inlet channel, and the residual (or applying "force balanced cell" option) indicates that ΔV = 68,125 ± 23,800 m^3/year (assuming 35 percent uncertainty in ΔV) for the inlet channel. Finally, accretion on the flood-tidal shoal is calculated using the residual or the "force balanced cell" option for the flood shoal, ΔV = 68,125 ± 23,800 m^3/year (assuming 35 percent uncertainty in ΔV) (Figure 8).

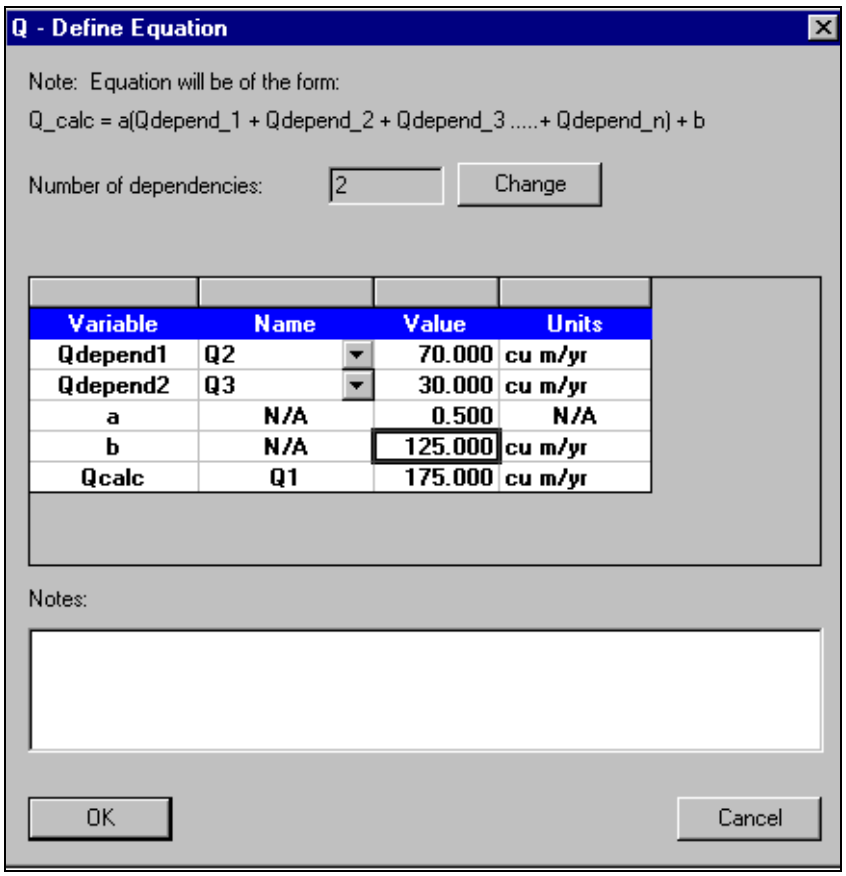

Figure 7. Defining a dependency for a transport rate within SBAS

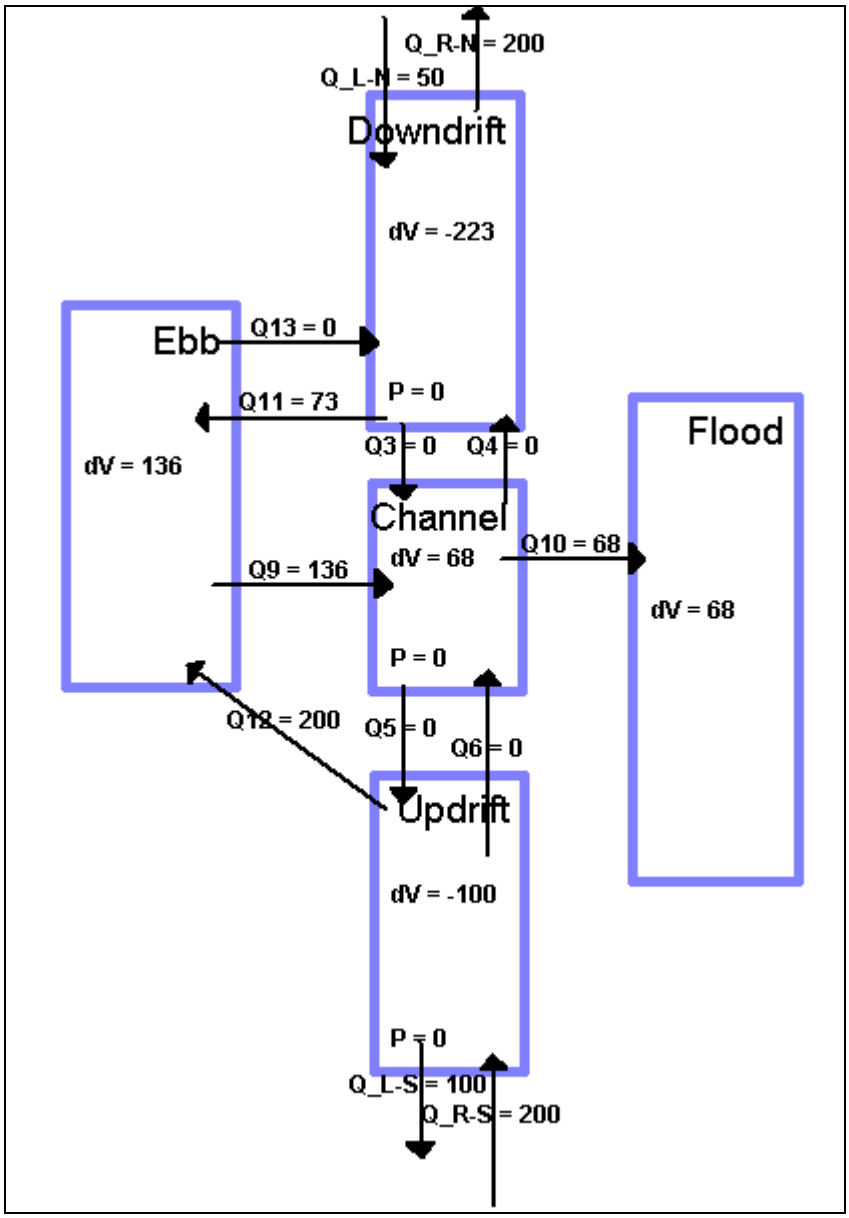

Figure 8. Sediment budget for "Post-Inlet: Gross Sink"

Step 5: Post-Inlet: Bypassing Begins. This sediment budget is a slight modification of the previous alternative. Within the Cell Properties Menu for the ebb-tidal shoal, a dependency for inlet bypassing is established, $Q13 = 0.25 \times (Q11 + Q12)$. The dependency for $Q9$ is modified from the previously set value such that $Q9 = 0.25 \times (Q12+Q11)$. The budget is balanced for each of the remaining cells by using the residual as an indicator of the required volume change rate. Figure 9 shows the balanced budget.

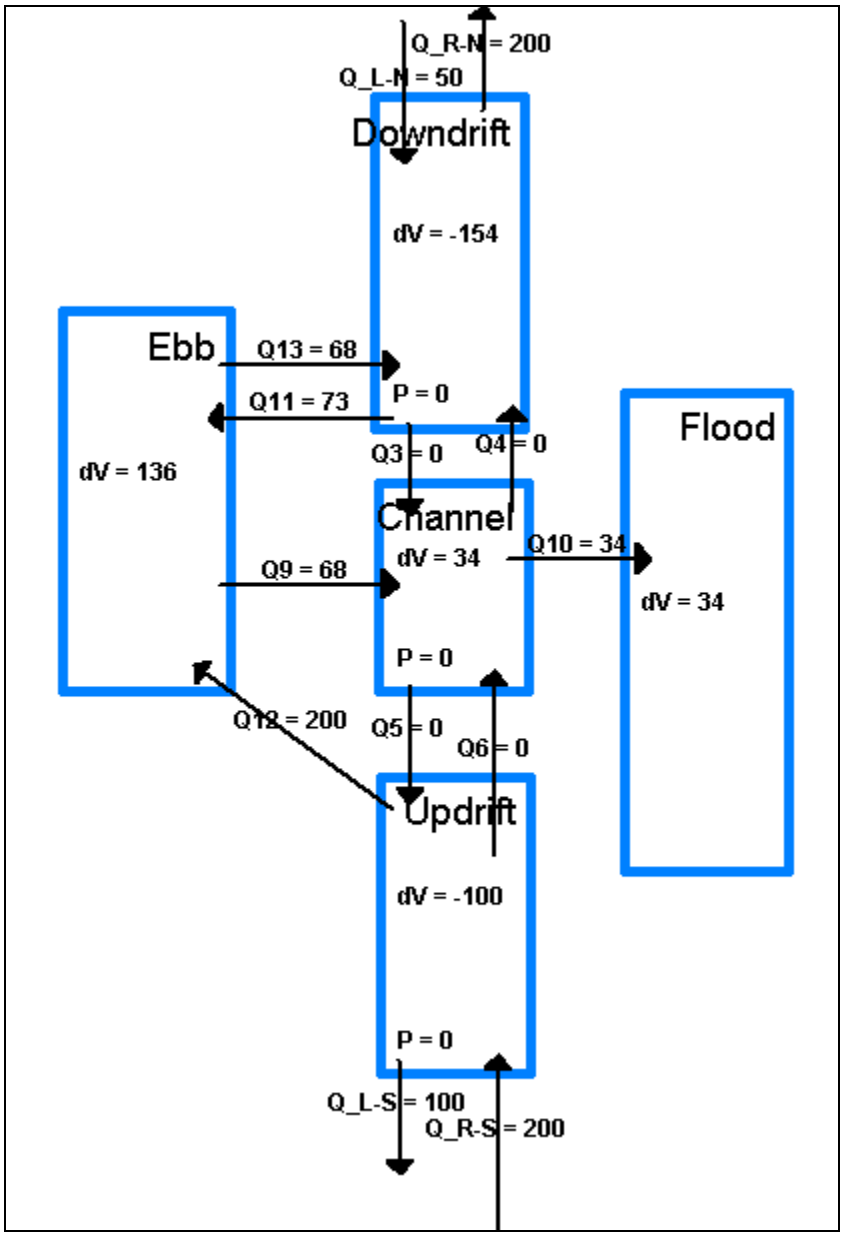

Figure 9. Sediment budget for "Post-Inlet: Bypassing Begins"

HOW TO OBTAIN SBAS: SBAS is available free of charge to U.S. Army Corps of Engineer District, Division, and Laboratory users. These users may obtain SBAS by contacting Ms. Ann R. Sherlock (601-634-2074, FAX 601-634-4314, *sherloa@wes.army.mil*). Questions on this CETN may be directed to Ms. Julie D. Rosati (601-634-3005, FAX 601-634-4314, *rosatij1@wes.army.mil*) and to Dr. Nicholas C. Kraus (601-634-2016, FAX 601-634-3080, *krausn@wes.army.mil)*.

The software is being distributed to others through a contract established under the Cooperative Research and Development Act (CRDA) with an independent consultant. A reduced cost has

been established for academic institutions and students. For these users, SBAS may be obtained from the CRDA partner:

Veri-Tech, Incorporated
P.O. Box 820109
Vicksburg, MS 39182-0109
USA
Voice (601) 636-1454
FAX (601) 638-5641
http://www.veritechinc.com

ADDITIONAL INFORMATION: Questions about this CETN can be addressed to Ms. Julie Dean Rosati (601-634-3005, Fax 601-634-4314, e-mail: *rosatij1@wes.army.mil*) or Dr. Nicholas C. Kraus (601-634-2016, Fax 601-634-3080, e-mail: *krausn@wes.army.mil*). For information about the Coastal Inlets Research Program, please contact the Program Manager, Mr. E. Clark McNair (601-634-2070, e-mail: *mcnairc@wes.army.mil*). The authors appreciate review of this CETN by Mr. Mark B. Gravens and Ms. Joan Pope, Coastal and Hydraulics Laboratory.

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http://bigfoot.wes.army.mil/cetn.index.html

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