

Third Report of the Technical Review Group for the Bollinas Lagoon Ecosystem Restoration Feasibility Study

First Review of Sediment Budget and Modeling Details
27 August 2004

This report is based on the modeling sub-team meeting of the TRG held on 29 July 2004
at Audubon Canyon Ranch.

Attendees

TRG

Josh Collins
Bill Carmen
Ted Foin
John Largier

Researchers

Phil Williams
Michael Josselyn
Don Danmeier

Meeting Objectives

1. Encourage communication between researchers and TRG members concerned with conceptual, statistical, or numerical modeling of Bollinas Lagoon.
2. Share updates on progress of the project so SFEI can brief the entire TRG.
3. Ascertain what technical materials are forthcoming from the researchers for review by the TRG.
4. Identify interim action items to help the studies.

Highlights of TRG Discussion

1. The conclusions and recommendations of the studies should not go beyond what the improved scientific understanding of the Lagoon ecosystem will support. The studies are likely to greatly improve the general understanding of how the relative roles of littoral and terrestrial sediment sources are influenced by land use, seismic events, and sea level rise. But it is not clear how to deal with the variances and uncertainties of the data and the models. Because the variances of the processes being measured are so great, and because there are so many uncertainties for which there are no data, one may not be able to state with known degrees of certainty whether or not the inlet will close. It is also unlikely that the data and models will reveal clear thresholds of tidal prism change that should trigger management actions. A more likely outcome of this research is a much-improved understanding of habitat evolution along two trajectories, each starting from a relatively deep Lagoon, but one leading through closure of the inlet and the other not, plus a general assessment of the relative likelihood of either trajectory, based on informed professional judgment. The studies are likely to provide strong recommendations about what to measure or monitor to reduce the uncertainty of the forecasts.

2. The proposed work to explore the possible effects of shoreline engineering along the marine side of the spit on littoral drift seems unlikely to significantly influence the ability to forecast changes in the Lagoon, and therefore, from the perspective of the Lagoon Project, is probably not a major priority. A summary of the existing understanding about the relative roles of the Bolinas bluffs, Duxbury Reef, the spit, and the larger Gulf of the Farallones as sediment sources may be more useful.
3. The larger concern should not be about the system response to onetime catastrophic events, such as a great quake, but what mostly influences the current scenario. While it is interesting to model how the flood shoal (Kent Island) may evolve after quake-induced subsidence, and thus derive rates of initial rapid sedimentation, what matters most for forecasting the future of the system is an understanding of the current and recent rates of sedimentation.
4. The ecological services of the Lagoon should not be conceptualized as only a passive result of the physical processes. The ongoing influence of vegetation on sedimentation, and how this influence varies with plant species composition and elevation, should be more formally evaluated. The ecologists should consider the role of dominant plant species as sediment producers (i.e., coarse organic matter production and accumulation), and filters of inorganic sediments that significantly contribute to sedimentation rates. This will cause more effective interactions between the physical and ecological modeling efforts, and will reduce the risk of decoupled models at the end of the project.
5. The description of probable shifts in the energy base of the ecosystem (i.e., from detritus or benthic filter-feeders to plankton) as endpoints in succession should be augmented with descriptions of likely changes in ecological linkages between the Lagoon, the ocean, and the local watersheds. For example, a tidal system is linked to the ocean via fish as well as birds, whereas the role of fish as a direct linkage is eliminated if the system becomes non-tidal. In a tidal system, there tends to be three fairly discrete food webs: one for the marsh plain, with links to the uplands and intertidal flats and channels, one for the intertidal flats and channels with links to the subtidal; and one for the subtidal with links to the ocean. It might be helpful to describe how these links change as the habitat mosaic and water regime change.
6. It is essential that the physical and ecological modelers develop a concordance table or “crosswalk” between the lists of “geomorphic units” of the physical model and the “habitats” of the ecological model. There should be a one-to-one correspondence between the geomorphic units and the habitat types, if, as intended, the ecologists are to translate the physical model output into ecological consequence.
7. Another complementary approach to the ecological model might be to identify the key species, or indicator species, most sensitive to changes in the overall habitat mosaic, and suggest the thresholds of mosaic change at which significant responses by the key species might be expected. For example, would the loss of

harbor seal haul-outs correspond to the advent of a certain composition of open water, intertidal flat, and vegetated marshland?

8. The TRG looks forward to delving into more detail of the source data and internal workings of the models.

Updates

1. Geodetic Benchmark Network

Bill is managing the collaboration between the TRG member Marti Ikehara of NGS and the County to establish a network of geodetic benchmarks around the Lagoon as necessary to achieve comparability and adequate vertical and horizontal control of elevation surveys and maps of all kinds, as recommended earlier by the TRG. The network will consist of at least two new benchmarks on each side of the Lagoon, plus the existing mark on the sea wall at the inlet in Bolinas. Network should be established within a few weeks. County is conducting the surveys and will produce a report for the NGS.

Consultant Action Items

- Don will make sure that all PWA and WRA temporary benchmarks are tied to the new network with a survey report of closure.

TRG Action Items

- Josh will convey to Roger Byrne the need to tie his cores to the geodetic benchmark network. This might be done by taking readings from shore on rods held at the substrate surface to be cored. Closure may not be possible on sub-aqueous cores.
- Bill will make sure that all benchmark coordinates are provided to PWA, WRA, and Roger Byrne, such that project maps can indicate benchmark locations.
- Bill and Josh will explore locations for a project archive into which all reports should be submitted, including the geodetic survey reports. Audubon Canyon Ranch (ACR), the PRBO, and the Marin County Community College were mentioned as possible archive locations. Of these, ACR seems most readily available.
- Josh will contact Marti to make sure the TRG gets a copy of the geodetic survey report.

2. Sedimentary Coring

At the suggestion of the TRG, Roger Byrne has resigned from the TRG and assumed the responsibility of designing and supervising a project to core the Lagoon to develop estimates of sedimentary rates, as previously recommended by the TRG. Estella Leopold of the University of Washington and Doris Sloan UC Berkeley have agreed help replace Roger on the TRG for paleo-ecological and Holocene estuarine transgression expertise.

The plan for cores at this time consists of 54 cores on a 200-m grid from Kent Island north to the full extent of the Lagoon. The chronologies for at least four cores will be based on isotopic dating and palynology, and the resulting chronologies will be transferred to other cores based on stratigraphy. The extent of the core grid is limited by sandy substrates.

Bill is helping Roger get the permits needed to conduct the coring. The fieldwork is expected to be completed this year.

Consultant Action Items

None

TRG Action Items

Josh will convey to Roger the following.

- 54 cores on a grid as proposed may be too many. Consider adjusting work plan to include some cores in the far Southeast end of the Lagoon (toward the hamlet of Stinson Beach), to understand the chronology of marsh development there.
- In every core, note the depth of any sandy horizons; this is especially important in the most seaward cores and across Kent Island to assess historical extent of marine sand incursion. For this purpose, consider adjusting work plan to include a few cores further south into sandy substrate. A fence diagram of the basal sand horizon and mudflat will be helpful
- With regard to modeling marine sediment input, it will be helpful to know how grain size varies with distance from inlet. Consider measuring grain size of sandy horizons in cores.

3. Tide Gauge

Jim Hubbard of the TRG is working with NOS and the Marine Sanctuary people of NOAA, and the USACE to revise and finalize the estimated cost of establishing a permanent gauge in Bolinas near the inlet. Cost estimates for first year, which include installation, vary from about \$25k to \$75k based on the expected role of the data within the NOAA gauge network, who assumes maintenance costs, etc. Bill is the TRG liaison to Jim. It is expected that NOAA will establish the gauge and then transfer its maintenance to the County.

Consultant Action Items

None

TRG Action Item

- Josh will write a memo from the TRG to Jim in support of his efforts. The tide gauge and the geodetic benchmark network are the cornerstones of the proposed foundation of empirical observation that is absolutely essential to the future management of the Lagoon.

4. Other Updates

Marin County may have purchased new geo-rectified aerial imaging that may cover the Lagoon and therefore be helpful to WRA and PWA, especially with regard to mapping vegetation and geomorphic units (i.e., habitat types).

Don needs access to historical (first survey) CGS T-sheets for the Lagoon.

PWA would like an update regarding the status of USNPS Lidar imaging including the Lagoon.

Consultant Action Items

None

TRG Action Items

- Josh will look into the availability of digital versions of the T-sheets from the Coastal Zone management community.
- Josh will look into the availability of new Marin County imaging and the status of USNPS Lidar.

Discussion of Physical Modeling

1. Basic Approach

The basic approach is to model sedimentation and its effects on tidal prism, hence its effect on inlet behavior (closure patterns over time) and thus changes in the distribution and abundance of major geomorphic units as habitat types (deep and shallow water, intertidal flat, tidal marsh, fluvial deltas, etc), and thus forecast effects of sedimentation on ecological services. The basic approach was already affirmed by the TRG with some reservations about the details of the physical modeling, ecological modeling, and their linkages. This discussion was informed by a handout from Don and Phil illustrating a basic conceptual model of sediment budget terms (attached).

2. Sediment Budget Framework

PWA proposes to develop a sediment budget for the Lagoon with five rate terms: watershed delivery, organic accumulation, direct anthropogenic fill or removal, net littoral transport, and the resulting net change in lagoon sediment storage (i.e., a proxy for tidal prism). The proposed accounting within these terms is shown on the handout. Except for littoral drift, rates will be based on Roger's cores. This puts a premium on the core data, including the distribution of sand horizons at depth, and highlights a dependence on additional sources of information from other places not cored by Roger for input to the littoral drift model.

3. Littoral Drift

The discussion was focused on the littoral drift and aeolian terms of the sediment budget. Previous studies of the sedimentation in Lagoon have not adequately addressed the role

of littoral drift. The watershed and anthropogenic fill/removal terms will be discussed more fully by the TRG at a later date.

Historical evolution of Kent Island as the flood shoal, as indicated on historical maps and photos, has been suggested as evidence of littoral drift rates from early to late stages of sedimentation (Island seems to be at a maximum extent). Reputable maps show the Island size and shape before 1906 seismic event, during which the Island disappeared from the intertidal zone, and subsequent maps and aerial photos show the re-emergence of the Island over time. Cores will probably indicate that the Island is sandy and owes itself to littoral drift. Historical changes in size and shape may therefore indicate approximate drift rates. Model can then be used to “remove” the Island to simulate the effect of a great quake as a reset mechanism (deepening the basin and setting the stage for renewed sedimentation and shoal building eventually leading again to an island).

Extrapolation of historical net littoral drift rates into the future may be complicated by the introduction or colonization of new plant species at both the lower intertidal zone (*Spartina foliosa* and perhaps now also *S. alterniflora*) and in the upper zone (non-native beachgrass, *Ammophila arenaria*) that can increase sedimentation by trapping sediment.

The lack of aeolian transport of sand over the dune strand and spit into the Lagoon due to residential development and the artificial lagoon should also be reflected in future net aeolian drift rates.

PWA is requesting separate funding from the USACE to explore possible influence of shoreline change, especially hardening of the spit and possible resulting loss of sand storage capability, on littoral drift into the Lagoon. The TRG questions the importance of this particular aspect of drift, given the large sand supply available, the possible role of the Bolinas bluffs as a direct source that may or not be affected by the hardening of the beach, and the difficulty in quantifying these effects.

4. Seismic/Tectonic Influences

Sedimentation rates may vary across the fault trace, due to differential subsidence or uplift. The cores should indicate this as discontinuities in sedimentation rate or stratigraphy across the fault trace. Right-lateral movement is affecting basin shape and may be affecting sedimentation rates by altering the location of channels relative to the inlet (the inlet and major sub-aqueous channel are on different sides of the fault trace). The influence of creep, upwarping or downwarping, and differential vertical movement across the trace during a quake should be considered.

Consultant Action Items

- Consider that the studies of beach hardening may have low priority relative to the central topic of net sedimentation and tidal prism within the Lagoon.
- Add an aeolian drift term to the sediment budget framework, and note that this term may be historically important but less important now due to development of the spit and its adjoining artificial lagoon.

TRG Action Items

On behalf of the TRG, Josh will:

- ask Roger to provide some guidance on the ability of his cores to determine the date of native *spartina* colonization in the Lagoon.
- recruit one or more watershed processes experts to the TRG to review the watershed aspects of the sediment budget.
- recruit one or more experts to the TRG to help guide a review of possible tectonic/seismic influences on sedimentation in the Lagoon.
- look into the availability of digital versions of the T-sheets from the Coastal Zone management community.

Discussion of Ecological Modeling

The model essentially depends on inference from natural history studies of dominant plant and animal species associated with the various geomorphic units to forecast shifts in overall community composition and trophic structure based on geomorphic change.

Interactions between ecological processes and hydro-geomorphic processes are not emphasized at this time. The TRG recommends more emphasis on these kinds of interactions, especially how vegetation may affect sedimentation rates. The role of shellfish in processing sediment, contributing to the sediment pile, and reducing sediment density might also be considered.

1. Vegetation

Two data products seem to be required: a statistical model of the relationship between tidal elevation and plant species composition, and a planimetric map of the aerial extent of the species indicative of elevation. Transect data are being used to develop the statistical model. Aerial imaging is being used to map the extent of the indicative plant species.

Edaphic factors add variability to the relationship between vegetation and elevation. The edaphic factors do not co-vary with elevation. Removing the influence of soils from the elevation model will not be possible, because the controlling edaphic factors are not known, and the general soil conditions, such as bulk density and salinity, that might reflect the controlling factors will not be mapped. To the extent possible, outlying plant patches that may correspond to local edaphic conditions can be excluded from the dataset used to generate the elevation model.

Influence of vegetation on sedimentation, both in terms of contributing organic sedimentary materials and trapping sediment, should be further considered.

Consultant Action Items

- Consider testing the statistical model by running additional transects (not used to develop the model) chosen at random from the plant map. This will provide some measure of the error of the model.
- Members of the TRG have previously observed an unusual reversal in the vertical range of two common plant species, *Spartina foliosa* and *Salicornia virginica* (i.e., *Spartina* occurring at higher elevations than *Salicornia*). If this condition still exists, then an explanation should be posited. For example, since these perennial plants tend to persist wherever they colonize, and can grow at elevations above and below where they tend to naturally colonize, their reversed elevation zonation might indicate either local subsidence or uplift.

TRG Action Item

- Josh will provide information on the status of new aerial imaging and possible Lidar imaging for the Lagoon.
- Josh will convey to Roger the need to know from the cores how the relative amount of organic sedimentary material changes as the Lagoon marsh builds upward over time.

2. Food Chain

The modelers intend to forecast or describe changes in trophic structure of the community as a whole based on hydro-geomorphic changes. For example, inlet closure and Lagoon impoundment may lead to a great role of phytoplankton in providing energy to the Lagoon ecosystem, whereas a tidal system may be more dependent on detritus and benthic shellfish as filter-feeders.

Descriptions of likely changes in ecological linkages between the watershed, Lagoon, and Ocean, and between the major habitat types within the Lagoon, might be helpful. For example, a tidal system is linked to the ocean via fish as well as birds, whereas the role of fish is eliminated if the system becomes non-tidal. In a tidal system, there tends to be three fairly discrete food webs: one for the marsh plain, with links to the uplands and intertidal flats and channels, one for the intertidal flats and channels with links to the subtidal; and one for the subtidal with links to the ocean. It might be helpful to describing how these links change as the habitat mosaic and water regime change.

Another complementary approach might be to identify the key species, or indicator species, most sensitive to changes in the overall habitat mosaic, and suggest the thresholds of mosaic change at which significant responses by the key species might be expected. For example, would the loss of harbor seals haul outs correspond to the advent of a certain composition of open water, intertidal flat, and vegetated marshland?

End.

PWA/WRA Handout:
TRG Meeting 29 July 2004

A sediment budget will be the primary tool used to assess long-term morphologic change within Bolinas Lagoon. As shown in Figure 1, the sediment budget is simply an accounting of sediment input and outputs within a fixed boundary or time period. The sediment budget will be used to assess the change in storage (tidal prism), by accounting for sediment input and outputs, sea level rise, subsidence, tectonic activity, and volumetric changes in the morphologic units within the lagoon (ΔM).

After a conceptual sediment budget has been finalized, appropriate estimates for each term in the budget will be developed from existing data. These order-of-magnitude estimates will assist in identifying major components that drive the sediment budget. Analyzes will then be focused to refine estimates of these major components.

We will develop different sediment budgets for different time periods in the past in order to establish ranges of values for particular terms. For example, watershed delivery probably was probably at a minimum prior to Euroamerican colonization and at a maximum after logging, grazing and farming altered the landscape in the mid 19th century. We intend to examine changes documented in historic T-sheets and core chronologies developed by Roger Byrne of UC Berkeley to 'calibrate' the volumetric change in storage terms of the sediment budget. Applying the sediment budget to the past will improve our confidence in projecting the existing sediment budget into the future. Based on the history of Bolinas Lagoon, we will develop sediment budgets for the following conditions that characterize different physical processes and conditions:

- Sediment Budget under Natural Conditions (T-200). This sediment budget will represent the natural rates of sediment delivery that occurred prior to Euroamerican colonization.
- Sediment Budget following Watershed Modifications (T-150). This sediment budget will represent changes in the natural system due to 19th century land uses in the watershed. The initiation of the logging, grazing, farming and other activities from the mid to late 19th century may have increased the amount of watershed delivery to the lagoon.
- Sediment Budget following the 1906 Earthquake (T-100). This sediment budget will reflect early 20th century sediment delivery rates. The 1906 quake significantly altered lagoon morphology, and probably changed the geomorphic processes and rates of sediment delivery (e.g., re-shaping of the flood tide shoal).
- Sediment Budget under Existing Conditions (T0). This sediment budget will represent active processes and sediment delivery of the watershed-lagoon-coastal system. The late 20th century sediment budget will also include reflect the continuing recovery of the watershed, diminishing effects of the 1906 earthquake and recent human alterations (e.g., construction of Seadrift Lagoon).

- Sediment Budget under Future Conditions (T+50). This sediment budget will represent the changes in sediment delivery expected to occur over the next 50 years. These changes will be based upon geomorphic processes and our understanding of how these processes are likely to respond to modifications in lagoon morphology, future sea level rise, and subsidence. This will be the sediment budget used to develop projections of future lagoon morphology ($\Delta M+50$).

The paragraphs below describe the specific source for each term in the sediment budget.

- Watershed yield (S_Y). This is the amount of alluvium produced by erosion in the hillslopes, and its rate is influenced by climate, vegetation cover, geology and soils. Tetra Tech (2001) has estimated the 20th century annual sediment yield, and Heimsath *et al.* (1997, 1999) has estimated a Holocene average basin erosion rate for Tennessee Valley from cosmogenic analysis which can be used to estimate pre-Euroamerican rates.
- Floodplain storage and channel erosion (S_{CS}). Sediment produced in the watershed will either be stored in the stream channels and floodplains or transported downstream and delivered to the lagoon. The relative balance between transport capacity of the streams and the sediment yield will determine the amount of floodplain/channel storage. We will use numerical modeling (HEC-RAS) of lower PGC to generate hydraulic parameters for input into empirical sediment transport equations and establish sediment-rating curves. The numerical model will be modified to account of historical changes stream-floodplain connectivity, and then applied to various scenarios to estimate transport capacity under historic and future conditions.
- Bedload delivery (S_B). Stream hydrology controls the availability of bedload, and channel morphology sets transport capacity. Over-sized channels will aggrade, and under-sized channels will incise. Bedload either deposits on floodplains or forms alluvial fans and deltas at mouths of creeks. Results from the hydraulic modeling will be applied to empirical equations to assess the amount of bedload delivery. Computed delivery will be compared to MCOSD records of gravel removal from lower PGC and PWA field observations.
- Washload delivery (S_W). Watershed yield sets the availability of washload. A portion of the washload delivered to the lagoon will form mudflats and salt marsh, if wind-wave action is below a critical value and settling velocity exceeds residence time. Results from the hydraulic modeling will be applied to empirical equations to assess the amount of washload (suspended-sediment) delivery. Computed delivery will be compared to USGS measurement collected in 1968-69 along PGC and Morses Creek (Ritter 1973).
- Organic accumulation (S_O). Roger Byrne will use 'loss on ignition' analysis to determine the organic content of the four cores chosen for dating. We will use

results from the dates cores extracted from the salt marshes between PGC delta and Kent Island to assess the rate(s) of organic accumulation.

- Fill placement / removal (S_F). Records of fill placement and removal will be used to determine the amount of sediment mechanically excavated from the lagoon. This will include removal of coarse gravel at the downstream reach of PGC. Impoundment of tidal waters that resulted from construction of Seadrift Lagoon will be represented in this term.
- Flood tide sand transport (S_{FS}). Flood tide currents sweep a portion of the beach sands that are transported along Stinson and Bolinas Beaches through the tidal inlet and into the lagoon. The amount of sand transport into the lagoon varies with tide stage and the wave climate in Bolinas Bay. Beach sands swept into the lagoon are deposited on flood-tide shoals where tidal current slacken. Over the long-term, flood tide sand transport offsets the effects of sea level rise and maintains the flood tide shoals. Ritter (1973) has measured suspended and bedload transport through the inlet during five series of measurements (on 06/22/1967, 10/24-25/1967, 05/16-17/1968, 11/14/1968, and 05/20/1969) and derived a sediment-rating curve for suspended load versus tide stage. However, the limited duration of his field measurements make long-term predictions difficult. PWA has proposed to apply a computer-based DELFT3D model to simulate a sediment transport and morphologic change through the inlet. We intend to apply a multi-year simulation based on percent occurrence of various wave climates.
- Ebb tide sand transport (S_{ES}). A portion of the beach sand swept into the lagoon during flood tides are re-mobilized during ebb tides and transported out through the inlet. These sands deposit on the submerged ebb-tide shoal or into deeper waters. Although the Ritter (1973) has analyzed ebb tide sand transport through the inlet, extrapolations to long-term rates is difficult due to the limited duration of data collection. PWA proposes to apply numerical modeling to assess the annual rate of sand transport from the lagoon during ebb tides. The net sand transport through the inlet is probably a small fraction of the gross transport and difficult to assess accurately. The high gross-to-net ratio also represents the potential for rapid changes to sedimentation if an equilibrium state is disturbed. Estimates of net transport are likely to be best accomplished by examining the amount of sand deposited within the lagoon to re-form the flood tide shoal after the 1906 quake.
- Discharge of alluvium from the lagoon during river floods (S_{FA}). Higher river flows that contribute a significant portion of freshwater to the lagoon may change circulation patterns and produce unusually large pulses of washload during ebb tides. These high river flows may deliver a substantial portion of the annual delivery of alluvium. We will examine the flow duration curve during high river flow events to obtain an approximate estimate of the volume of alluvium discharged through the inlet over a tidal cycle.

- Discharge of re-suspended washload from the lagoon during ebb tide (S_{EA}). Ebb tidal currents will export a portion of the washload delivered through the tidal inlet and to the ocean. In areas exposed to energetic wind waves, previously deposited washload may be resuspended from mudflats and exported from the lagoon. Export of washload may also occur if the settling velocity of fine grain material is less than residence time set by tidal hydrodynamics and circulation patterns within the lagoon. We will examine the flow duration curve during low river flow events to obtain an approximate estimate of the volume of alluvium discharged through the inlet over a tidal cycle.

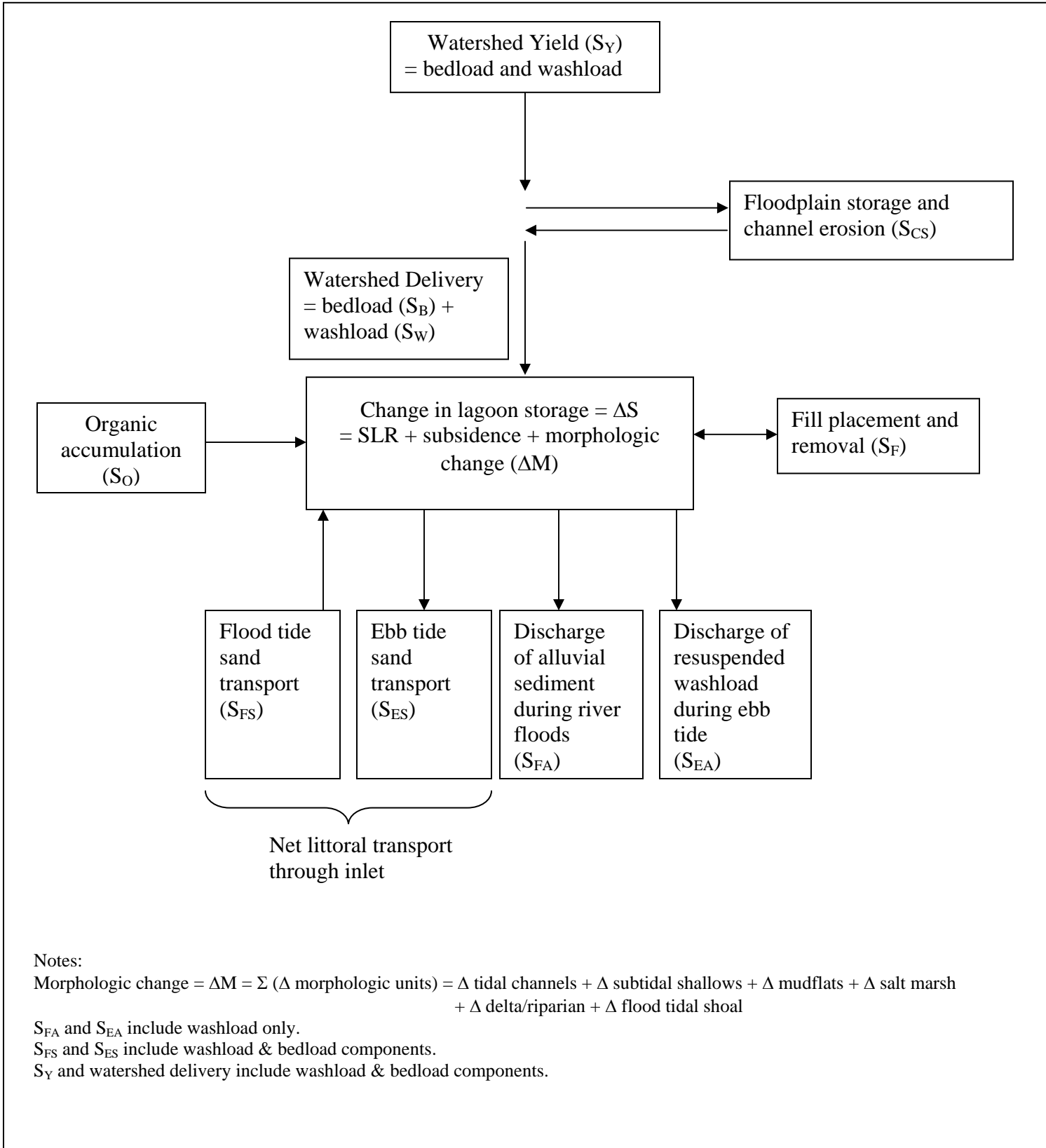


Figure 1. Sediment Budget Terms