EVOLUTION OF THE SEDIMENT DISCHARGE IN THE SONTECOMAPAN LAGOON IN VERACRUZ MEXICO.

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ABSTRACT

We present the example of a costal lagoon in the Tuxtlas region in Veracruz Mexico that is a natural laboratory of erosion sedimentation process.

The deforestation of the region with high slopes makes an acelerated process of erosion sedimentation that changes continuously the shape of the lagoon.

Our model, basically simulating the sedimentation process with the data given by a very simple erosion model, predicts the changes in the shape of the lagoon and has been accurately calibrated with the historical data.

1. INTRODUCTION

Approaches used to estimate erosion and sedimentation consist generally of three types, empirical modeling, physically based modeling, and methods in between the two. Empirical methods such as the rating curve method have been widely used in erosion estimation, however, is open to large errors due to the highly variable relationship between flow and sediment transport.

Physically based models have been developed to simulate sediment processes on a storm basis. Most of these and other erosion and sedimentation models can be incorporated within or linked to GIS models for watershed erosion and deposition estimation.

A major problem with some of the traditional GIS models lies in that they make steady state estimates of erosion and sedimentation which do not account for dynamic, time-variant processes such as storm rainfall and runoff processes.

Models interrill and rill processes require details of rills for the plot or hillslope. The model simulates the erosion sedimentation process in each net element. Finally a family of curves are obtained with minimal requirements.

The Sontecomapan lagoon is located inside the volcanic mountain mass of the Tuxtlas region in the state of Veracruz, between the river basins of the Coatzacoalcos and the Papaloapan Rivers. Its only and permanent connection with the ocean takes place in a channel named the Sontecomapan Barrier, where the greatest depth of the lagoon is registered at 5.5 meters, leaving the rest with a shallow average of 2 meters. A warm and humid climate characterizes the lagoon, and low salinity levels are typically due to the large fresh water influx. The system is divided into several zones. A barrier expands from the beach to Roca Morro and El Real channel, which includes the area around La Palma River and ends in a channel that opens up and forms, to a great extent, the lagoon. Sontecomapan is further divided into three partial zones, thanks to two deltas formed by the Coxcoapan River. The lagoon’s littoral is bordered by mangrove forests. The area is free of oil exploitation complexes, chemical plants or industrial operations. In the seventies, the Sontecomapan was considered one of the richest mangrove vegetation zones in the country and a highly productive lagoon.

2. THEORY

Wherever natural systems and human activities co-exist in the coastal environment, conflicts of interest are inevitable. There are innumerable examples in the world where competition between human goals and natural processes assume sometimes dramatic proportions. The process soil detachment - sediment transport capacity - sediment transportation and deposition takes time and human activities such as deforestation breaks the equilibrium in nature.

The coastal lagoon is fraction in equal elements and the process is estimated en each one of them. The erosion and sedimentation model developed in this study includes the mathematical representation of the sediment continuity equation.

2.1 Sediment Equations

The sediment continuity equation is described as

$$\frac{\partial(Ch)}{\partial t}+\frac{\partial(Cq)}{\partial x}=D_i+D_r \qquad (1)$$

where C is sediment concentration (kg/m^3), q is discharge per unit width (m^2/s), h is local depth of flow or hydraulic radius (m), t and x are time and distance along the flow line respectively. D_i and D_r are interrill and rill erosion rates, respectively (kg/m^2/s). When (1) is used to calculate channel sediment transport, the rill erosion rate is replaced by channel erosion rate, and the interrill erosion rate is replaced by lateral sediment inflow rate per unit length of the channel. (1) can be delineated into a finite difference form as (Sun, 1999)

$$\begin{aligned}\frac{2\Delta t}{\Delta x}qC_4q_4+C_4h_4=C_1h_1+C_3h_3-C_2h_2\\ +\frac{2\Delta t}{\Delta x}(1-q)\left(C_1q_1-C_3q_3\right)\\ +\frac{2\Delta t}{\Delta x}qC_2q_2+2\Delta t\left(D_i-D_r\right) \quad (2)\end{aligned}$$

where subscripts 1, 2, 3, 4 represent the time and distance grid, representing the four corners of an element at (t, x), (t + Δt, x), (t, x + Δx) and (t+ Δt, x+ Δx) respectively. Δt and Δx are time and distance increments, respectively. Using Newton Raphson the mass conservation equation was solved numerically and the flow variable is in the basedata. Once the flow variables are obtained, (2) can be explicitly solved for C_4. Deposition is calculated as a constant process of erosion and deposition in an element during a runoff event, depending upon whether the sediment concentration exceeds the local sediment transport capacity calculated by the unit stream power method described in section 2.3.

2.2 Rill erosion

Rill erosion can be described by the hydraulic processes in rills. The shear stress on the rill surface by the flow in a rill, is the primary force for rill detachment. When this incisive force exceeds the critical shear stress of the soil, which is the force required to detach soil particles in a rill, soil particles are released and rill erosion occurs. Rill detachment is usually represented by

$$D_r = a(\tau - \tau_{cr})^b \quad (3)$$

with

$$\tau = \gamma RS \quad (4)$$

where D_r is the rill erosion detachment capacity rate (kg/m^2/s); τ is the flow shear stress (N/m^2); τ_{cr} is critical shear stress (N/m^2); *a* and *b* are fitted parameters. γ is density of water (N/m^3) multiplied by the acceleration of gravity *g* (m/s^2); *R* is hydraulic radius (m) and *S* is slope gradient of rill bottom.

But (4) requiere the defining of rill shape and density in a watershed, which is not very practical under field conditions. On the other hand, runoff or flow information can usually be obtained with greater accuracy. Consequently, rill erosion can be simplified as

$$D_r = \alpha QSKC_{s/r} \quad (5)$$

where α is a calibrated parameter and *Q* is discharge (m^3/s); other variables are described earlier. The flow rate and the slope are calculated by the model on an element basis, which enables (5) to be used for erosion and deposition estimation on an element basis in a watershed.

2.3 Sediment Transport Capacity Estimation

Yang (1972) used unit stream power, defined as the time rate of potential energy expenditure per unit weight of water in an alluvial channel, to derive a relationship between unit stream power and total sediment concentration as

$$\log C_t = I + J \log((VS - V_{CR}S)/\omega) \quad (6)$$

In which

$$I = 5.435 - 0.386\log(\omega d/\upsilon) - 0.457\log(U^*/\omega) \quad (7)$$

$$J = 1.799 - 0.409\log(\omega d/\upsilon) - 0.314(U^*/\omega) \quad (8)$$

where C_t is total sediment concentration, parts per million (ppm); *VS* is unit stream power, m/s (*V* is flow velocity in m/s and *S* is slope gradient m/m); $V_{cr}S$ is critical unit stream power (V_{cr} is critical flow velocity) required at the incipient motion (m/s); ($VS - V_{cr}S$) is effective unit stream power; ω is the sediment terminal fall velocity in water (m/s); d is the median particle size of the bed material (mm); υ is the kinematic viscosity of the water (m^2/s). U^* is the average shear velocity (m/s), and $U^* = (gDS)^{0.5}$; D is water depth (m); and g is acceleration of gravity (m/s^2).

For most cases, the term $V_{cr}S$ can be assumed zero when C_t is equal to or greater than 100 ppm (Yang, 1973), Moore and Burch (1986) found that Yang's equation, which was originally applicable to natural channels, could also be extended to overland sediment flow prediction.

2.4 Erosion and Depositation on an Element

The model calculates the flow rate and velocity at a fixed time interval in each element of the watershed. These flow variables were then used for estimating the sediment concentration at the inlet and outlet of the element during the time interval. The erosion/deposition rate was then estimated by calculating the sediment fluxes entering and exiting the element. For an element, assuming the upslope inlet flow rate and sediment concentration are Q_u and C_u respectively, and the downslope outlet flow rate and sediment concentration are Q_d and C_d respectively, the net sediment flux Y_d (mL/s/m^2) at time t within an element area of A_e, is

$$Y_d = \left(Q_u C_u - Q_d C_d\right)/A_e \qquad (9)$$

Assuming the specific gravity of the soil is 2.65, the erosion/deposition per unit area (g/m^2) during the time interval Δt is

$$Y_r = 2.65 Y_d \Delta t \qquad (10)$$

And the erosion/deposition per unit area (g/m^2) during an event time T is

$$Y_e = \sum_{t=0}^{T} Y_r \qquad (11)$$

(11) was used for sediment erosion and deposition calculation for each element during a storm runoff event. Annual erosion or deposition on an element scale can be estimated based on all the storm events of the year

$$T_{as} = \sum_{e=1}^{L} Y_e \qquad (12)$$

where T_{as} is the total annual sediment (erosion/deposition) per unit area (g/m^2) for the element, Y_e is the event erosion/deposition per unit area (g/m^2) for the element, and L is the number of storm events during the year.

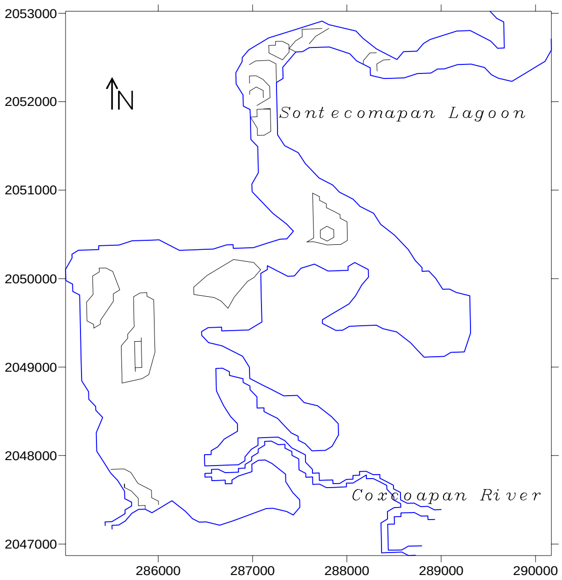

FIGURE 1. Lagoon Bathymetric

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