**River sediment fluxes to the ocean**

**(Instructor Version)**

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1. **Introduction**

Rivers are the most important source for water and sediment from land to the ocean, and they form the broad plain at the coastal zone, comprising deltas and estuaries. The amount of sediment flux from river to the ocean is a critical factor that determines the evolution of these coastal morphological units.

For instance, the increase of sediment flux may speed up the progradation rate of coast line to the ocean; on the other hand, the decrease the sediment flux to the ocean, may cause the coastline to be eroded and retreat.

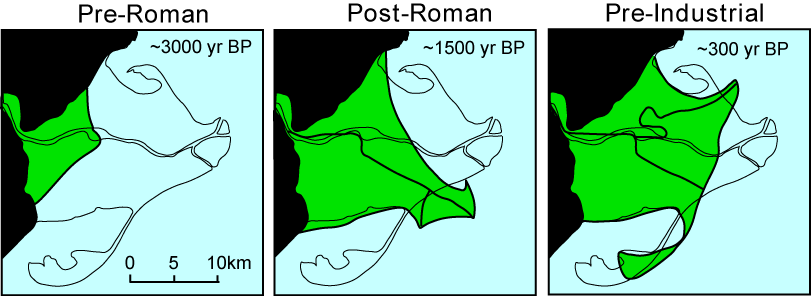


Figure 1. The evolution of Ebro Delta over the last 3000 years.

Figure 1 shows the evolution of Ebro Delta in Spain, which forms at the mouth of the Ebro River. The delta sediment is redistributed by wave action of the Mediterranean Sea. The Ebro Delta built out significantly, over more than 10 km, in the last 3000 years. Rapid progradation followed prehistoric and Roman deforestation, continuing into the Middle Ages. However, presently it is estimated that more than half of the Ebro delta will be lost within the next 50 years. Approximately 47% of its delta lowlands lie only 50 cm above sea level, and several cultivated areas in Ebro delta lie below sea level. Damming of the upper reaches of the Ebro River has caused sediment loss, and erosion of the delta front (of upto 15 meters a year) is now a serious problem. Global sea level is estimated to be rising at approximately 1.5 mm per year and the delta is currently sinking due to the weight of sediment by between 1 - 8 mm a year. (<http://geographyfieldwork.com/Ebro%20Delta%20Natural%20Park.htm>)

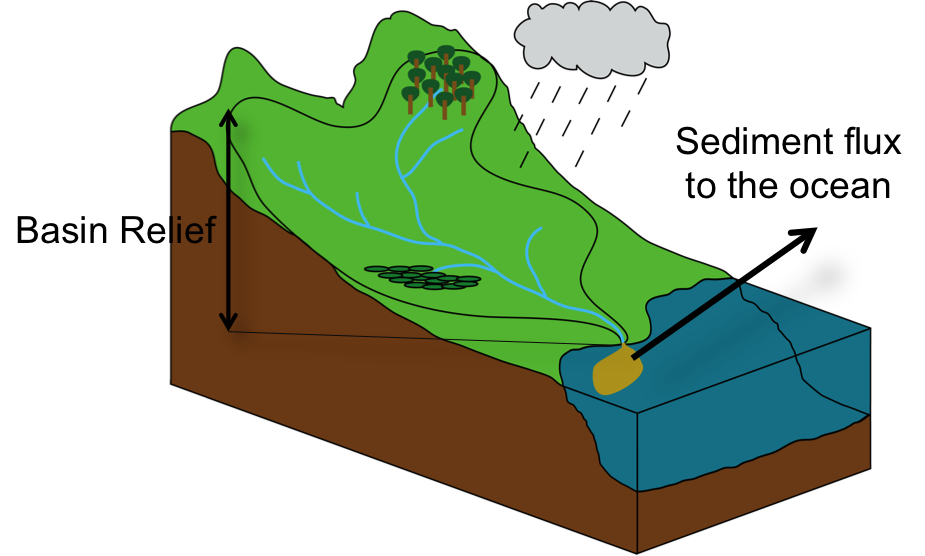
**2 Model Approach**

One model that can model sediment fluxes to the global ocean is HydroTrend. HydroTrend is a numerical model that creates synthetic river discharge and sediment load time series as a function of climate trends and basin morphology and has been used to study the sediment flux to marine basins. As a drainage basin simulator, the model provides time series of daily discharge hydraulics at a river mouth, including the sediment load properties. HydroTrend was designed to provide input to lake or shelf circulation and sedimentation, and study the impact of land-sea fluxes given climatic change scenarios.

HydroTrend simulates the major processes that occur in a river basin, including:

* Glacial processes with advances and retreats depending on the climate scenario,
* Snow accumulation in the winter and melt in the subsequent spring/summer,
* Rainfall with canopy or vegetation evaporation,
* Groundwater recharging and discharging,
* The impact of lakes and reservoirs.

The following cartoon shows the hydrologic process that Hydrotrend simulates, it uses climate changes (precipitation and temperature) as input parameters to calculate the river discharge and sediment flux to the ocean at the river mouth, other factors, like the lithology, anthropogenic factors, glacier area, basin area and relief are all considered in the model equations. It is important to realize that HydroTrend is a 1D, point source model, which uses the averaged value for the whole basin, and that it is a generic model, which is not specific to a certain river basin.



More detailed information on HydroTrend can be found on this website: <http://csdms.colorado.edu/wiki/Model:HydroTrend>

Related literature:

*Kettner, A.J., and Syvitski, J.P.M., 2008. HydroTrend version 3.0: a Climate-Driven Hydrological Transport Model that Simulates Discharge and Sediment Load leaving a River System. Computers & Geosciences, Vol. 34, 1170-1183.*

*Syvitski, J.P.M. and Milliman, J.D., 2007, Geology, geography and humans battle for dominance over the delivery of sediment to the coastal ocean. J. Geology 115: 1-19.*

*Vorosmarty CJ, Meybeck M, Fekete B, Sharma K (1997) The po- tential impact of neo-Castorization on sediment transport by the global network of rivers. In: Human impact on erosion and sedimentation. Proceedings of the Rabat Symposium, IAHS Pub. No. 245:261–273*

**Practice:**

*Question for Students 1*

*The most important output parameters calculated with the Hydrotrend model are the water discharge, Q, and sediment flux at the river mouth, Qs. What do you think are the factors that will influence water and sediment output at a river mouth? How do you think these factors will influence the resulting sediment flux? (Hint: describe effects of two aspects: human activities and natural factors).*

Answer for Instructors 1

The main factors that influence sediment flux at the river mouth are classified into two groups: human activities (mainly consider deforestation and dam construction); and natural factors (climate changes, river basin topography (basin relief), geology (lithology factors), and river basin area).

|  |  |  |
| --- | --- | --- |
| **Control** | **Discharge** | **Sediment flux** |
| Deforestation |  | Proportional with deforestation rate |
| Dam construction |  | Decrease with dam construction |
| Precipitation | Proportional | Proportional (more water can carry more sediment) |
| Temperature |  | Proportional with temperature rise (increase erosion rate) |
| Basin area | Proportional | Proportional (more area to provide water and sediment) |
| Basin topography | Proportional | Proportional (steeper slope raises the power of river to erode and carry sediment) |
| Geology |  | Increase if the bedrock is weak |

*Question for Students 2*

*2A In the Excel file named RiverFluxtoOcean.xlsx, there are three separate worksheets. The worksheet called ‘Suspended load’ shows the equation used in Hydrotrend for the calculation of suspended sediment load. First read the equation and the example for Ebro delta, and then calculate the value of sediment flux for the given groups, while thinking about the following question: What happens to Qs if the mean annual temperature increases? And why?*

Answer for Instructors 2

Empirical data shows that Qs is positively correlated with temperature. The possible mechanism is that a temperature increase would increase the soil weathering rate in the basin and thus potentially the erosion rate.

2B *What happens to Qs if the mean annual discharge increases? And why? What could cause this?*

Answer: Qs increases with water discharge; simply because more water can carry more sediment. As discharge is mainly controlled by precipitation, this is mainly caused by change in precipitation, but it could potentially also be affected by groundwater regime change. The calculations do not show these more complicated hydrological balance effects.

*2C What happened to Qs if B increases? And what could lead to this?*

Answer: Qs will greatly increase with B.

As B is determined by factors such as L=lithology, Eh=human impact, and I=glacial processes. B could dramatically increase if Eh increase (for example if the deforestation rate in a basin increases); or when the glacial area in a basin headwater increases. Lithology changes in the basin are unlikely on short time-scales unless there is considerable seismic activity.

2D *What factor could cause B to decrease for the present-day Ebro River?*

The decrease of B is mainly caused by extensive dam construction. There are now 187 large dams in the river basin, that are used for irrigation systems in the Ebro plains. Whereas the Ebro Basin was naturally semi-arid, now farmers grow fruit and even have rice paddies.

2E *Plot a graph of Qs as a function of step-wise temperature change. How much range would the temperature axis have? How much change in mean annual temperature occurred approximately between the last glacial maximum (21,000 yrs ago) and the present? (Weaver A.J., et al., 1998)*

Answer: See Spreadsheet *RiverFluxtoOcean.xlsx*, the worksheet ‘Suspended load’ shows the calculation result for the groups and an example plot. The relationship indicates that Qs is proportional to T changes, but that small increase of T could bring about much larger raise of Qs. The mean annual temperature occurred approximately between the last glacial maximum and present is about 5.9 K according to the study given as a literature reference. Of course, temperature ranges from the last ice age to the present varied for different regions, the temperature axis should be in a range of 2~8 degrees.

*Question for Students 3*

*3A In the Spreadsheet RiverSedimentFluxtoOcean.xlsx, on the worksheet called ‘Bedload , we show the equation used in Hydrotrend for the calculation of river bedload. How does bedload change with channel slope or water discharge?*

*Think about the following: the construction of a dam close to the river mouth would potentially trap all the bedload from the basin, however, the equation does not reflect this trapped bedload, could you give the reason? (Hint: discharge is not zero after dam construction).*

Answer: The calculated result is in the worksheet called ‘Bedload’, bedload will increase when the channel slope becomes steeper, or when the river discharge increases. The reason why the bedload prediction is not consistent with the real case is that in the equation, bedload is solely determined by slope and discharge. As the dam in the model only dampens the water discharge, but ultimately releases it again, this equation does not reflect the bedload trapping process in a reservoir.

The HydroTrend model traps suspended load with dams, using the equations in the next spreadsheet, but is insensitive for bedload trapping in the upstream basin.

3B *Plot a graph of Qb versus river channel slope, S; what is the range of slopes in natural deltas (gradient of the delta plain) approximately? (Hint: you can look in Syvitski and Saito, 2007. Global and Planetary Change)*

Answer: The plot is shown in *RiverSedimentFluxtoOcean\_forInstructors.xls* on the worksheet called ‘Bedload’. The reference shows that the slope of the delta can vary from 0.00001 to 0.001 m/m for different delta systems. The plot shows that Qs is proportional to S, and Qs increases greatly with small changes of delta slope.

*Question for Students 4*

*The HydroTrend model uses Brune and Brown equations to estimate the reduction of sediment load from damming, the equations are shown in sheet 2. Calculate the reduction of sediment load caused by different values of dam mean volume, and river discharge. What could you get from the Qs changes? (Reference: Brown, 1943; Brune, 1953)*

Answer for Instructors 4

The calculation results are posted in worksheet 3, it is very obvious that the dam could dramatically reduce the suspended sediment flux.

*Related Reference:*

*Brown, C.B., 1943. Discussion of sedimentation in reservoirs, by J. Witzig. Proceedings of the American Society of Civil Engineers 69, 1493–1500.*

*Brune, G.M., 1953. Trap efficiency of reservoirs. Transactions American Geophysical Union 34, 407–418.*

*Syvitski, J.P.M., Saito, Y., 2007. Morphodynamics of deltas under the influence of humans. Global and Planetary Change 57, 261–282.*

*Weaver AJ, Fanning AF, Eby M, Wiebe EC (1998) The climate of the last glacial maximum in a coupled ocean GCM/ Energy-moisture balance atmosphere model, Nature 394 : 847~853.*