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COMPUTATION OF SEDIMENT TRANSPORT IN RIVERS: ANALYSIS OF THE SEDIMENT RATING CURVES

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ABSTRACT

Some studies about analytical solutions of a 1-D morphodynamic model (*Fasolato et al., 2011*) have shown that any river reach maintains a stationary morphological situation (equilibrium condition) under the hypothesis that the boundaries of the river reach are in equilibrium as far as solid and liquid inputs are concerned. This hypothesis means that the bottom profile of the river reach and the grainsize composition of the bed should remain constant in time, provided that sediments and water entering the river reach are related by an equilibrium relation.

This condition is not always satisfied, especially in the mountain rivers, as the formation mechanisms of water and sediment inputs are quite different and seasonally delayed. These initial perturbations give place to important deviations from the "average" curve of sediment transport vs water flow curve (namely from the transport curve calculated in equilibrium conditions).

This work presents a general approach that can be used to explain and possibly predict these deviations. The approach is based on the deterministic analytical solution of the harmonic river (*Fasolato et al., 2011*), combined with a recursive model of ArMa type, which found the unknown parameters of the linear combination of the boundary conditions through minimizing a mean square error, in order to obtain the best ArMa model from two different points of view: its performances both in fitting the available data and providing a prediction algorithm for the future evolutions. The recursive model for a synthetic river reach will provide the instantaneous sediment discharge as a function of the instantaneous water flow (namely equilibrium conditions) and the water flow measured at one or more previous time (non-equilibrium conditions).

The model is applied to two Italian case studies: Adige River and Po River. In this poster we have reported only the application of the Po River.

1-D MORPHODYNAMIC MODEL

The 1-D model of the evolution of a river is formed by equations describing the water flow (De St. Venant eq.), the sediment exchange between stream and river bottom (Exner eq.) and the mass balance of sediment in the active layer (Hirano equation). To obtain an analytical solution, these equations are linearized around a reference stationary configuration (*Fasolato et al.*, 2009).

The harmonic solution is composed of an homogeneous part and a particular solution of the system. The solution of the homogeneous part can be expressed as the sum of three basic damped harmonic waves. These waves propagate in the downstream direction (waves n. 1 and 2) and in the upstream direction (wave n. 3) with a certain celerities. Wave celerities represent the response time of the reach to the perturbations created at the boundaries. All three morphological waves have celerities many orders of magnitude slower than water flow; this means that the three waves have a wave length much shorter than the length of the river reach. As a consequence, one may recognize along a river reach a sequel of sinusoidal waves, created by the combination of the perturbations. With numerical applications Fasolato demonstrates that the length of the second (i=2) and the third (i=3) wave are much less that the length of the first (i=1) wave. For this reason, at a short distance from the upper end and from the lower end of the reach, we may respectively neglect the second and third wave with respect to the first one. In other words, no matter the celerity of propagation of the three waves, only the first wave is not destined to disappear very soon, but to maintain a good part of its amplitude for the entire length of the reach.

Simplification of quasi-uniform model can be generally considered when, in a river, the energy variations from the bottom are considerably lower that the bottom slope (rivers with high Froude number).

COMPLETE MODEL

In the model 1-D the total sediment transport was counted as:

$$Q_{s_{mis}}(t) = M(t)\cdot Q_w^m(t) + Q_s^{'}(t)$$

where *M(t)* is the proportionality coefficient between solid and liquid flow in non-equilibrium conditions, which can be separated into a constant component M_0, corresponding to the equilibrium condition, and a time-variable component *M'(t)*, while *Q's(t)* indicates the divergence of the flow from the equilibrium conditions.

$$M(t) = M_0 + M^{'}(t) \longrightarrow \begin{cases} M_0 = \dfrac{\overline{Q_{s_{mis}}(t)}}{\overline{Q_w^m(t)}} \\ M^{'}(t) = M_0 \cdot m_{c_1}(t) \end{cases} \qquad Q_s^{'}(t) = \left\{M_0 \cdot Q_w^m(t)\right\}\cdot p_{c_1}(t)$$

With the above hypothesis, the equation of the total sediment transport becomes:

$$Q_s(t) = M_0 \cdot Q_w^m(t)\cdot\left\{1 + p_{c_1}(t) + m_{c_1}(t)\right\}$$

where $p_{c1}(t)$ and $m_{c1}(t)$ represent the deviations from the equilibrium values of the solid transport and of the coefficient of proportionality *M(t)*. These deviations depend on the boundary conditions of the catchment area.

PHYSICAL MEANING OF THE DEVIATIONS

The deviations can be calculated taking into account their different physical meaning. It is assumed that they are due to specific boundary conditions occurring in the catchment area at the time *(t-k)*; this perturbations are linearly combinated and create two waves of perturbations which propagate to the gauge station, located downstream from the centre of the basin.

Downstream, the disturbances will then be subject to attenuation and they result:

$$p_{c_1}(t) = \left\{E_1 \cdot p_c(t-k) + A_1 \cdot m_c(t-k)\right\}\alpha_A \qquad m_{c_1}(t) = \left\{B_1 \cdot p_c(t-k) + D_1 \cdot m_c(t-k)\right\}\cdot\alpha_A$$

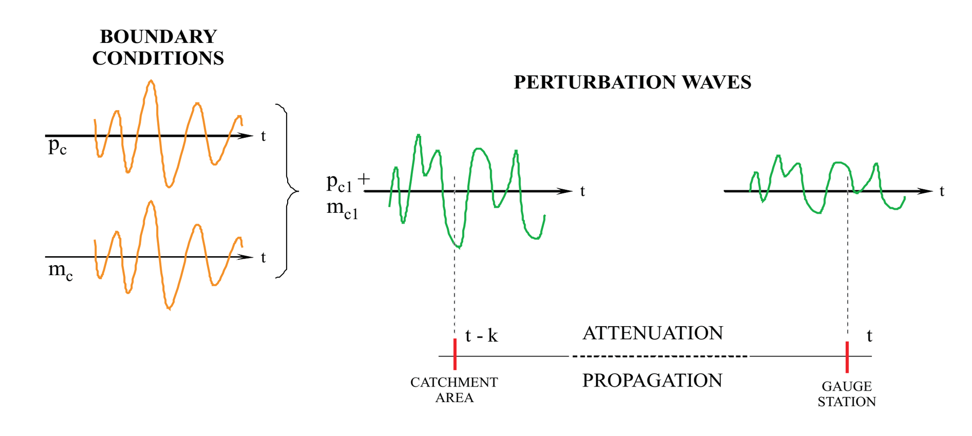
where $p_c(t-k)$ and $m_c(t-k)$ are the boundary conditions, A_1, B_1, D_1, E_1 are constant values valuated by an another study (*Fasolato et al., 2009*) and is the attenuation coefficient.

The boundary conditions $p_c(t-k)$ and $m_c(t-k)$, that given the relative deviations $p_{c1}(t-k)$ and $m_{c1}(t-k)$, are assumed, by Fasolato, to be determined on the alteration of solid transport and on the disturbances of the composition of the river bed.

The disturbance of the solid transport $p_c(t-k)$ is determined by a corresponding perturbation of the liquid phase $Q_w^m(t-k)$:

$$p_c(t) = b_1^* \cdot M_0 \cdot \left[\frac{Q_w^m(t-k) - \overline{Q_w^m}}{M_0 \cdot \overline{Q_w^m}}\right] \qquad m_c(t) = b_2^* \cdot M_0 \cdot \left[\frac{\sum_{i=t-p}^{t-k}\left(Q_w^m(i) - \overline{Q_w^m}\right)}{M_0 \cdot \overline{Q_w^m}}\right]$$

The disturbance of the river bed $m_c(t-k)$ is determined by mass movements triggered by instability of the slopes. This trigger is controlled by the imbibition of the mountain slopes caused by excessive rainfall preceding the event.

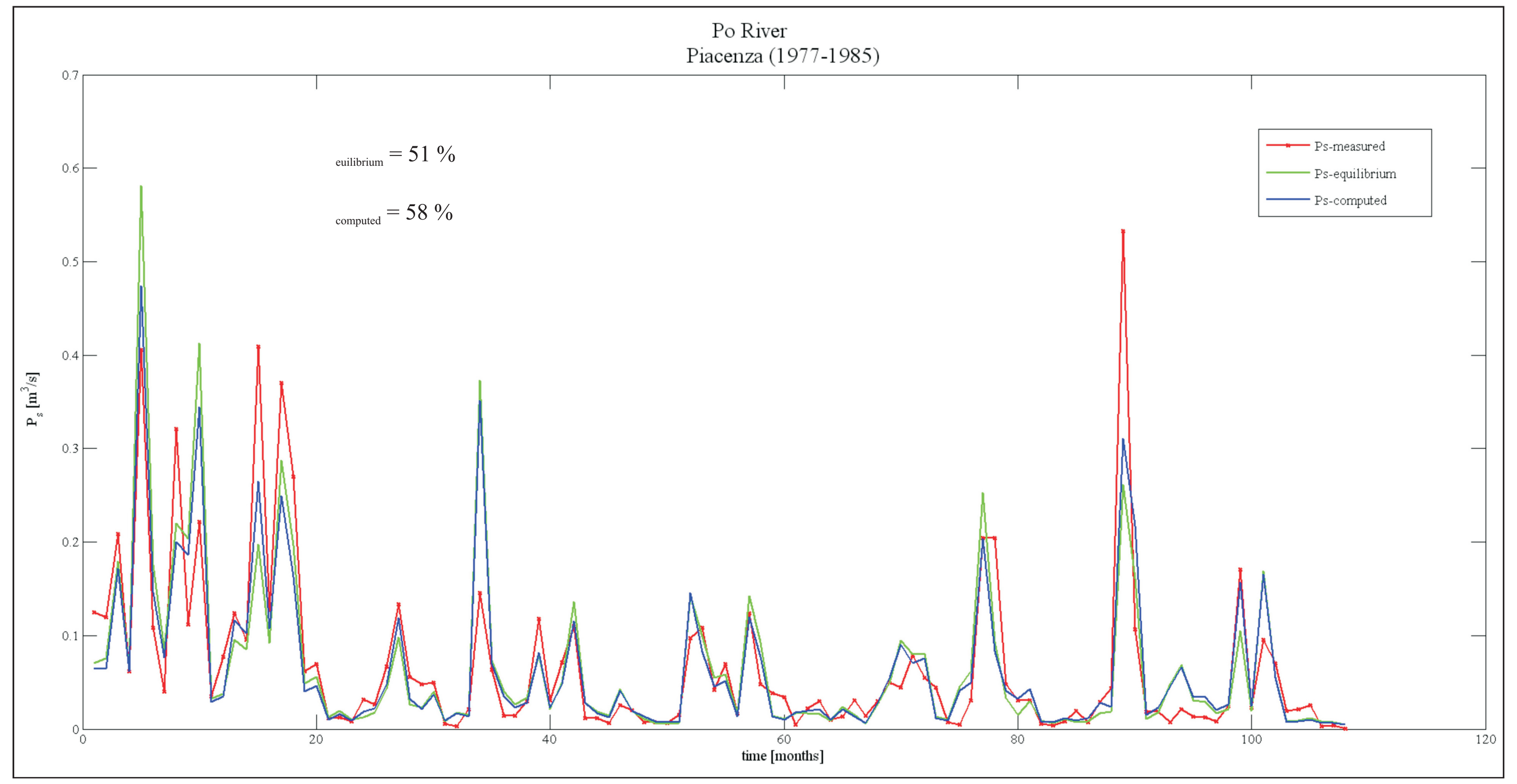


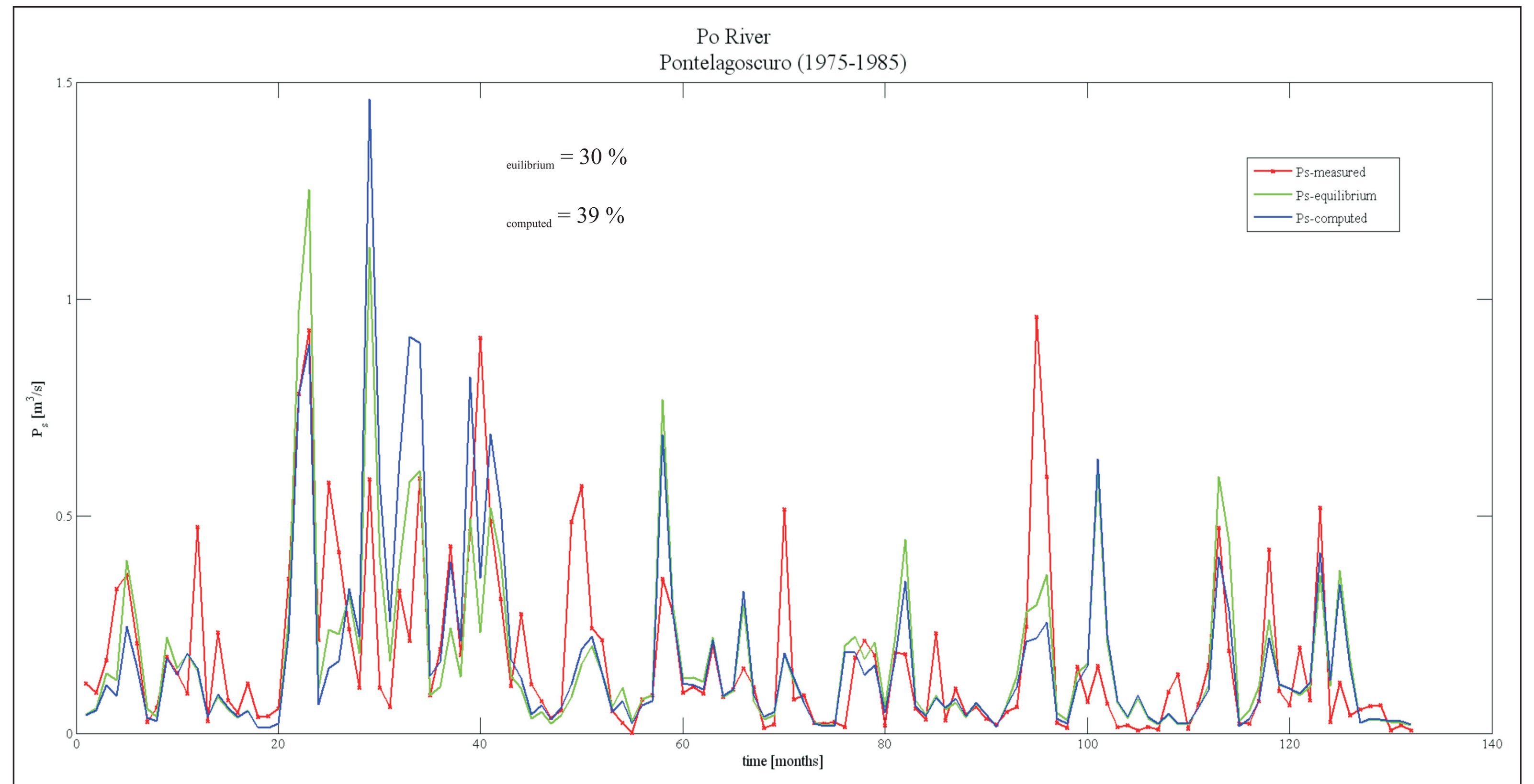
APPLICATION OF THE MODEL

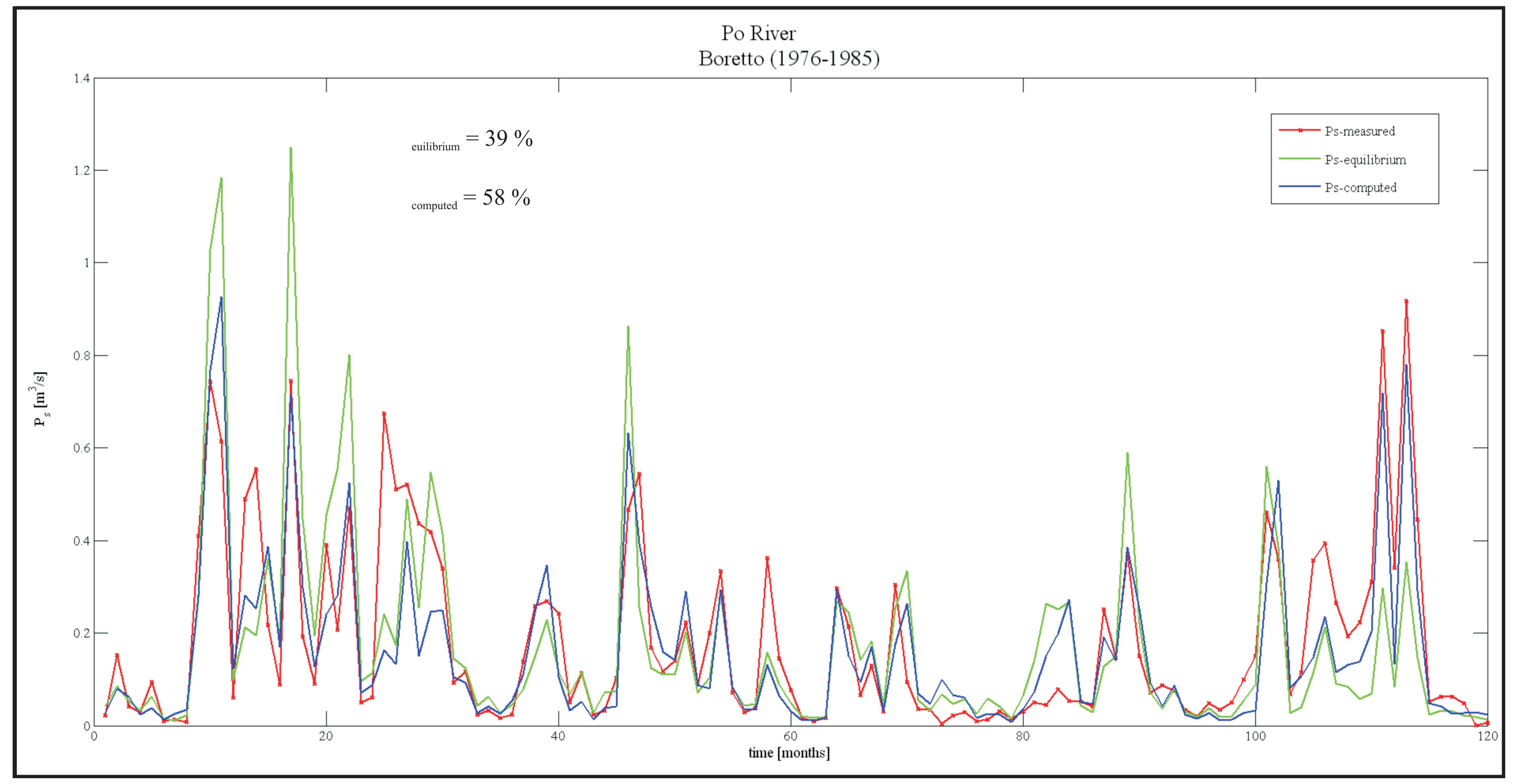
PO RIVER

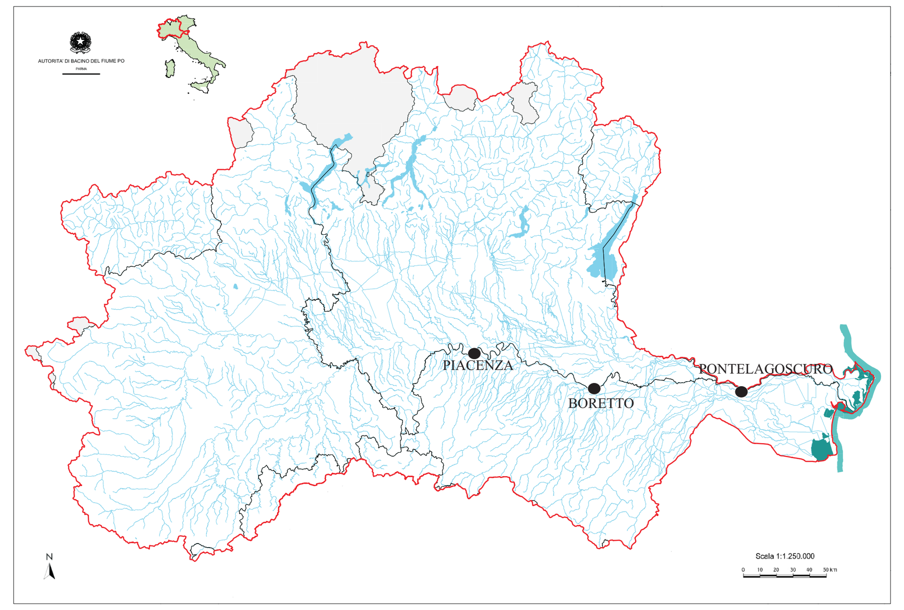
The Po River (652 km) flows across northern Italy, from a spring seeping from a stony hillside at Pian del Re, a flat place at the head of the Val Po under the northwest face of Monviso (in the Cottian Alps) through a delta projecting into the Adriatic Sea southern Venice. It has a drainage area of 74000 km² and is the longest river in Italy. The river flows through many important Italian cities, including Turin, Piacenza and Ferrara. Near the end of its course, it creates a wide delta (with hundreds of small channels). The river is subject to heavy flooding. Consequently over half its length is controlled with levees.

The analysis is performed at the gauge stations of Piacenza, Boretto (Re) and Pontelagoscuro (Fe) during the period 1970-1990.









GAUGE STATION	NUMBER OF DATA (MONTHS)	EFFICIENCY EQUILIBRIUM [%]	EFFICIENCY CALCULATED [%]
Piacenza	108	51	58
Boretto	120	39	58
Pontelagoscuro	132	30	39

CONCLUSIONS

From this implementation of the model it is possible to observe that the model is able to reconstruct the time history of sediment transport from the past records of water, with a better accuracy than the equilibrium analysis.

The model can include the daily precipitation as forcing term of the system (imbibition of the mountain slopes) or introducing the snow melt effect, in order to optimize the analysis, currently based only on the liquid flow.

In the future will be analysed the physical mechanisms that determine the boundary disturbances $p_c(t-k)$ and $m_c(t-k)$, to improve their empirical formulations, with the aim of improving the current model.

With this model is possible to study the data at daily scale, and so make a more accurate analysis of the sediment transport rating curve.

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