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Modeling the morphodynamic equilibrium of an intermediate reach of the Po River (Italy)

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ABSTRACT

The Po River, in the last century, has undergone significant altimetrical and planimetrical changes, mostly induced by a progressively increasing human pressure. The extensive protection and regulations works carried out to reduce the risk of flooding, the narrowing of the river for improving the navigation, the local interruption of sediment transport caused by a large mobile barrage built for hydropower purposes and the intense sand mining caused huge alterations of the river morphology. These changes were initially very fast and determined a significant and generalized deepening of the middle water course. In the last few decades, however, the pressure induced by human activities on the river decreased significantly and, consequently, a dynamic equilibrium condition tended to be re-established along most of the reaches, as suggested by topographic surveys spanning a period of about twenty years. The present contribution investigates this equilibrium condition by means of a one-dimensional movable bed model, with reference to a 98 km long reach located between the confluence with the Oglio stream and the gauging section of Pontelagoscuro, for which an up to date stage-discharge relationship is available. Considering steady forcing conditions, we estimate the formative discharge producing the observed river topography and the corresponding sediment transport capacity. The field surveys of cross section geometry used to investigate the possible existence of an equilibrium morphology span a period (1982–2005) of about twenty years. In the presence of fixed banks, the rived bed morphology appears to be controlled by relatively moderate discharges, quite close to the mean yearly discharge and significantly smaller than both the ordinary flood discharge and the maximum annual discharge. Even though significant deviations from equilibrium are produced by the sediment waves triggered by larger floods, deposition occurring during lower stages and the continuous reworking of the bed due to less intense but more frequent discharges implies a tendency of the river to recover its equilibrium profile.

1. Introduction

The Po River, with a length of about 652 km, is the longest river of Italy. It originates in the Cottian Alps (north west of Italy), crosses an extensive alluvial, low-gradient floodplain (the Pianura Padana) and finally flows into the Adriatic sea through a five branched delta (Po di Maistra, Po della Pila, Po delle Tolle, Po di Gnocca and Po di Goro). It drains a basin of 74,000 km^2, corresponding to about one fourth of the total extension of Italy, with a population of 16 million people (Fig. 1).

In the highlands the Po River alternates between bedrock and gravel-bed morphologies. This latter configuration dominates as the river flows onto the lower slopes of the Pianura Padana. The transition from gravel-bed to sand-bed morphology occurs further downstream, between the confluences with the Ticino and Trebbia Rivers, and is characterized by the presence of a natural weir in the correspondence of a stony pre-Quaternary substrate [3].

Depending on floodplain slope, sediment bed composition, water discharge, solid inputs ensured by the tributaries, protection and regulation works, the Po River exhibits multi-channel braided reaches and single thread meandering/sinuous reaches [11]. These planform configurations, in turn, affect the topography of the river [26,28], controlling the formation and dynamics of large scale morphological features (e.g., multiple, alternate, and point bars), as well as the processes leading to bank erosion and, hence, to the planform migration of the river [14,18].

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The annual hydrologic regime is characterized by two low-water periods (in winter and in summer) and two flood periods (in late autumn and in spring) associated with intense fall precipitations and snow melting, respectively. The mean yearly minimum, mean and maximum discharges measured at the gauging section of Pontelagoscuro (about 90 km far from the Adriatic sea) are 600, 1500 and 5000 m^3/s, respectively, with flood peaks around 10000 m^3/s and drought discharge up to 250 m^3/s [32]. The solid discharge delivered yearly to the sea, estimated on the basis of the sediment load observations reported by Visentini [30], Canali [7,8] and Nelson [23], is about 11.5 Mt/yr with a range of 2.9 Mt/yr (in 1983) to 22.4 Mt/yr (in 1937) [27]. On the other hand, estimates made by Cati [10], based on the past rate of delta extension and land subsidence data, suggest that the transport of bed sediment have decreased in the last century from about 16 to 8 Mt/year.

The protection and regulation works carried out on the tributaries and the main river in the past century determined a substantial reduction of flood expansion areas and, consequently, an overall increase of the storage capacity of the active channel in the upper and middle Po (i.e., up to the junction with the Mincio stream). In turn, flood peak discharges underwent a progressive growth in the lower Po and in the delta, increasing their vulnerability to hydrological hazards [22].

The river morphology has undergone significant altimetrical and planimetrical changes as well. The levee system, initiated in the late '800 and completed in the 1960s, has freezed the planform configuration of the river. The extensive longitudinal bank protection works, carried out after the 1951 catastrophic flood that caused the inundation of the Polesine upstream of Pontelagoscuro, have altered the lateral exchange of sediment, with the consequent reduction and closure of many secondary flow branches [1]. The mobile barrage of Isola Serafini (about 300 km far from the Adriatic sea), built in the period 1960–1964 for hydropower purposes, caused a discontinuity in the sediment transport with consequent upstream aggradation, due to backwater effects, and erosion downstream. The incision of the active bed has been further enhanced by the closure of secondary branches and the construction of groynes, carried out in the second half of 1900 for navigational purposes. A large sediment excavation activity also took place in the decade 1960–1970. The morphological consequences of all these human interventions were initially quite fast and led to a significant and generalized deepening (of the order of 2–4 m) of the middle river in the period 1954–1980 [9,15,21].

Nowadays, the Po River reach comprised between Isola Serafini and the confluence with the Mincio stream (about 160 km far from the Adriatic sea) can transport flood discharges of about 4000–6000 m^3/s flowing through a section having an average width of 250–300 m, almost half of the original one. The groynes, designed for being submerged by low water conditions (1000–1500 m^3/s), are now over flooded only by discharges of 3000–4000 m^3/s. In the last three decades, however, the pressure exerted on the river by human activities has significantly decreased. As a consequence, a dynamic equilibrium condition tends to be attained along most of the reaches. The volumetric balance between erosion and deposition carried out by comparing the river bed topography surveyed in the period 1979–2005 suggests a relatively small morphological response to ordinary floods [11]. In the following we then concentrate our attention on the post '80 period, characterized by a tendency towards a dynamic equilibrium of most of the river reaches.

The goal of the present contribution is to investigate this quasi-equilibrium condition with reference to an intermediate reach, located between the junction with the Oglio stream (about 190 km far from the Adriatic sea) and the gauging section of Pontelagoscuro. In particular, we address the problem of estimating the discharge that determines the observed longitudinal river

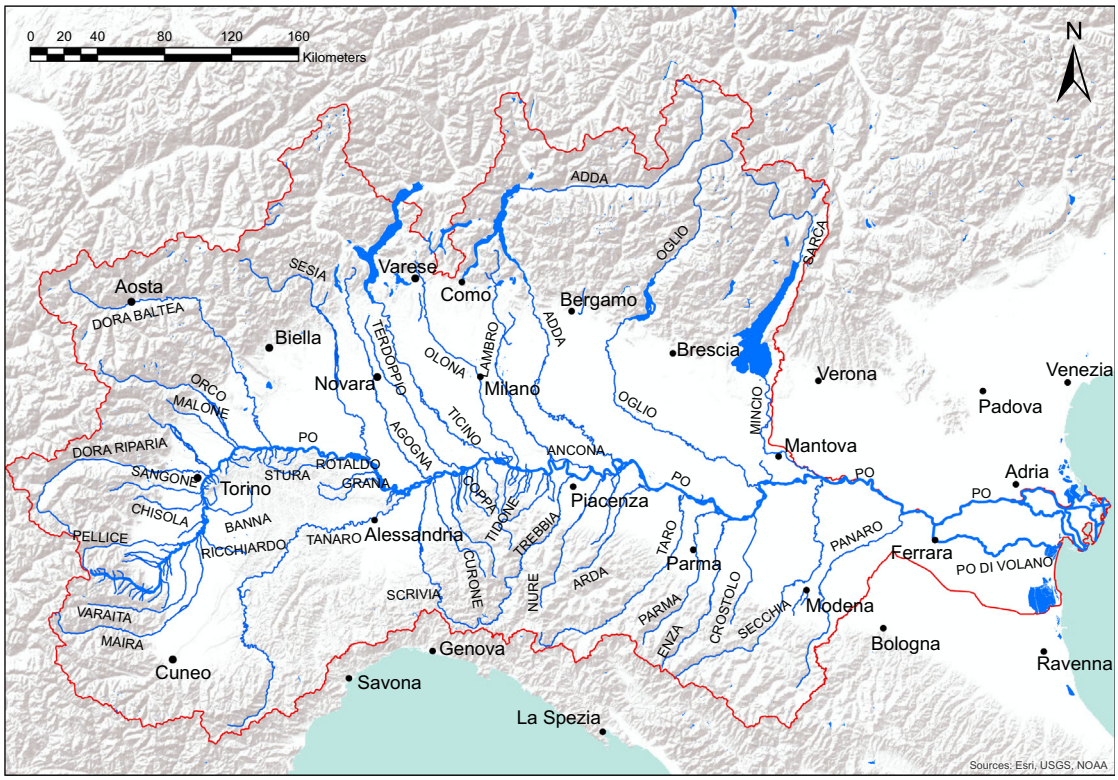

Fig. 1. The drainage basin of the Po River. The 98 km long reach investigated in the present study is located between the confluence with the Oglio tributary and the gauging station of Pontelagoscuro (located north of the city of Ferrara).