The 'Cavo Napoleonico' Channel: from the past to the present, hydraulic risk reduction programmes

ENRICO MAZZINI[1], PAOLO LUCIANI[2] & GIUSEPPE SIMONI[3]

[1] *Regione Emilia-Romagna - STBR. (e-mail: emazzini@regione.emilia-romagna.it)*
[2] *Regione Emilia-Romagna - Servizio Geologico. (e-mail: pluciani@regione.emilia-romagna.it)*
[3] *Regione Emilia-Romagna - STBR. (e-mail: gsimoni@regione.emilia-romagna.it)*

Abstract: Since the Middle Ages, the area located in the alluvial plain between the provinces of Ferrara and Bologna (north-eastern Italy) and its hydraulic network, has long been the subject of strong social and political contrasts for local governments. Such contrasts were mainly related to the control of inland commercial navigation and the land use of those fertile territories. As a result, many engineering solutions have been set up to defend the human settlements from hydraulic risk and to drain ponds and lagoons, and one of the most important of these was the creation of an artificial channel to connect the Po and Reno rivers. This channel, the "Cavo Napoleonico", was first proposed by the technical commission set up by Napoleon Bonaparte (Cavo stands for excavation or excavated channel). Nowadays those socio-political problems no longer exist, however, due to its heavy seepage problems, the hydraulic function of the Napoleonic Channel is still far from that first envisaged by Napoleon and subsequently by the Italian Public Administration. The same geotechnical limitations afflict the water supply functions that the channel assumed after the construction of the "Emiliano-Romagnolo" Channel, which brings fresh water from the River Po, via the Cavo Napoleonico, to the Adriatic coastal area. This is especially evident during the summer season when the water requirements are greater because of agricultural and tourist activities. The geological and geotechnical models are illustrated and supported by a series of monitoring programmes and model flow simulations in order to support the engineering solutions proposed to limit water infiltrations and reduce the flood risk to the surrounding towns. These possible solutions are shown in comparison to the costs of different technological strategies and the environmental impact on the local water circulation.

Résumé: Depuis le Moyen Age, le territoire localisé dans la plaine alluviale parmi les provinces de Ferrara et de Bologne (nord-est Italie), et son réseau hydraulique, ont étés le sujet de forts contrastes sociaux et politiques entre les gouvernements locaux. Les contrastes ont été principalement dû au contrôle de la navigation commerciale intérieure et l'usage agricole de ces territoires fertiles. Par conséquent, de nombreux ouvrages d'ingénierie ont étés construits pour défendre les habitats urbains du risque hydraulique et pour drainer les marais et les lagunes. Un des plus importants de ceux-ci était la création d'un canal artificiel pour connecter le Po et le Reno. Ce canal, le "Cavo Napoleonico", était proposé pour la première fois par la commission technique nominée par Napoléon Bonaparte (Cavo signifie excavation ou canal excavé). De nos jours ces problèmes sociaux et politiques n'existent plus .Toutefois il y a encore d'importants problèmes d'infiltration et donc la fonction hydraulique du "Cavo Napoleonico" est encore loin de celle envisagée premièrement par Napoléon, puis par l'Administration Publique italienne. De plus, les limitations géotechniques affligent les fonctions d'approvisionnement hydrique que le canal doit garantir après la construction du Canal "Emiliano-Romagnolo", qui porte l'eau du Po, à travers le Cavo Napoleonico, jusqu'à la côte Adriatique. Ceci est évident surtout pendant la saison estivale quand les exigences d'eau sont plus grandes à cause des activités agricoles et touristiques. Les modèles géologique et géotechnique sont illustrés et renforcés par les résultats de plusieurs programmes de monitorage et par les simulations avec modèles de flux afin de soutenir les solutions d'ingénierie proposées pour limiter les infiltrations d'eau au-dessous du canal. Ces solutions, qui réduisent ainsi les risques d'inondation des villes limitrophes, sont illustrées en comparaison des coûts des différentes stratégies techniques et de l'impact environnemental sur la circulation des eaux souterraines.

Keywords: waterways, embankments, floods, seepage, monitoring, models.

INTRODUCTION

The STBR (Regional Technical Service of the Reno River Basin) of the Regione Emilia-Romagna has recently begun a survey programme, financed by the Authority of the Reno River Basin (Autorità di Bacino del Reno 2002), focused on the study of the hydraulic and geotechnical conditions of the river dikes inside the territory under its jurisdictional authority (Mazzini & Simoni 2004). Within this programme, the study of the "Cavo Napoleonico" Channel takes a primary part due to its strategic role in the lower hydraulic network of the Reno River. In addition, the year 2005 marks the 40th anniversary of the completion of the Channel, and the study of this important waterway has, therefore, grown in importance. Furthermore, the Napoleonic Canal is still the most important artificial structure built, at least in the last 300 years, for the hydraulic government of the territory included in the provinces of Bologna and Ferrara (North-Eastern Italy). This paper describes the reasons why it was built, the technical problems which have arisen since construction, and the future hydraulic integrity of the structure. The double function of the channel is highlighted, both as a flood control reservoir and an irrigation canal, focussing on the economic opportunity to increase its hydraulic efficiency for future use.

A Brief history of the "Cavo Napoleonico" Channel

The morphological evolution of the study area has been created by past lateral migrations of the main rivers on the Po Plain, including the Po, Reno and Panaro (Castiglioni, Biancotti, Bondesan *et al.* 1999; Regione Emilia-Romagna 1999). The River Po has always been the main waterway on the plain and, with its general east-west flow direction, has changed position over the last 3 000 years, migrating progressively northward (Bondesan 2001). The Reno River, a major tributary, has kept a transverse direction to the Po (south-north or south west-north east) and for a long time it had over flooded the area to the south, nourishing marshes and ponds (Leoni 1990). From the Middle Ages to the present, land reclamation works have completely changed the natural attitude of the territory by stabilizing the hydraulic network of the alluvial plain (Marchetti 2002) and enlarging the urban settlements in hazardous areas (Brath 2003). In response, the adaptation to the new environmental equilibrium has created a high hydraulic risk, as demonstrated by the numerous floods that have hit lands and towns in this district. Drainage works on the wetlands have favoured the development of agricultural activities and land management became the subject of controversy among the resident populations.

The unification of the territories in the Middle Ages under one government allowed many of the ancient conflicts to be resolved with the construction of important hydraulic structures. Among them was the "Cavo Napoleonico" Channel. This represented the technical solution to hydraulic problems manifest between the districts of Ferrara and Bologna, constituting a diverting channel suitable for diverting and storing part of the flood waters of the Reno River (Supino 1965). The project proposed by the technical commission set up by Napoleon Bonaparte (in that time this part of Italy was under French rule), was commenced in 1808. However, after just three years, and before completion, work was stopped, as both Napoleon and the political order established by the Emperor fell in disgrace. (Leoni 1990).

After the unification of Italy (1861), the opportunity to continue the works and complete the channel was re-examined and because of two catastrophic floods by the Reno River in 1949 and 1951 a new project was proposed and financed by the Ministries of Public Work and Agriculture. This project was to connect the River Po to a new artificial channel (Emiliano-Romagnolo Channel) that was to bring fresh water from the Po to irrigate the upper plain between Bologna and Rimini. The works recommenced in 1951 and ended in 1965. In 1966 the first filling test began, but was interrupted due to seepage losses from the basis of levees (STBR Archive; Supino 1965; Leoni 1990). The new course of the channel has deteriorated, in comparison with the original one, for two main reasons. Firstly, the Napoleonic project was supposed to connect the Reno to the Po through the lower Panaro River, and not directly to the River Po, forcing the canal onto a highly permeable zone. Secondly, the need for greater hydraulic efficiency made it necessary to raise the levees in order to reach higher heads (Consorzio C.E.R. 1990), caused the stress increase on the land under the earth embankments. In Figure 1a the courses of the hydraulic network of the Napoleonic Channel are illustrated in relation to the two rivers and the Emiliano-Romagnolo Channel. In Figure 1b, on a larger scale, the present course of the canal is shown and compared to the one built in the first years of the nineteenth century (dashed lines); the two paths are coincident from the village of Sant Agostino to Bondeno. Even if the modification of the original Napoleonic project has brought a potential hydraulic improvement to the channel, it has created geotechnical problems such that the new artificial levees that cannot guarantee the flood safety of the adjacent areas, even after the partial impermeable coating works carried out on the channel bed during the 1960s and 1970s.

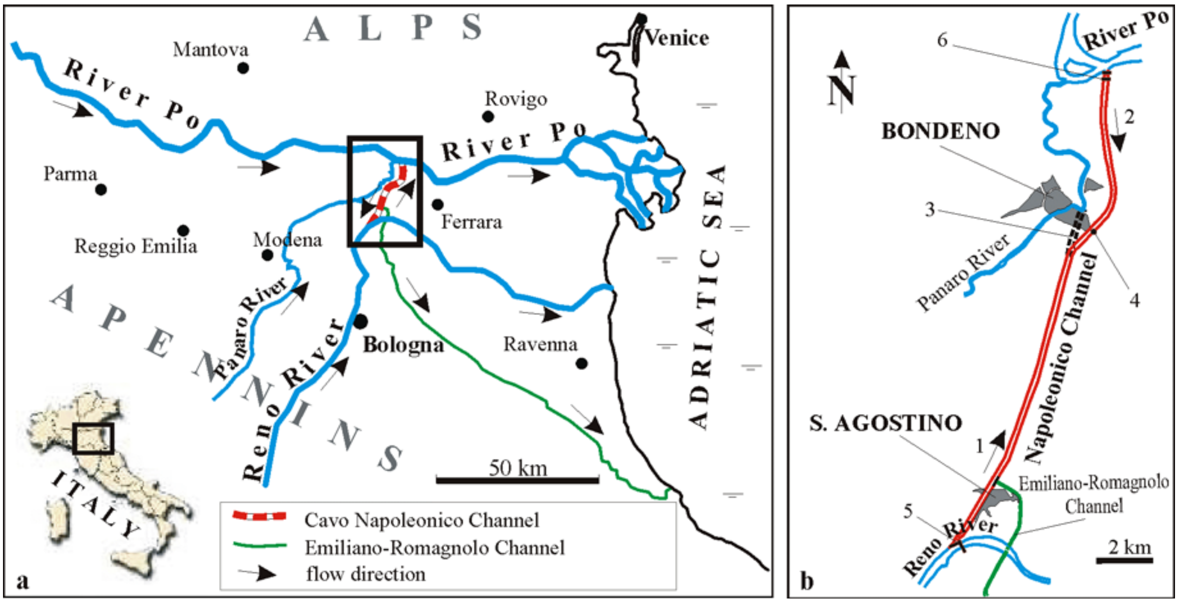

Figure 1. Location of the study area, on a small scale (a) and in detail (b). At the regional scale some important rivers of the Po Plain have been excluded in order to focus attention on the hydraulic system. Numbers indicate respectively: 1, flow direction of Reno floods; 2, flow direction of water drifted from River Po to Emiliano-Romagnolo Channel; 3, morphological trace of the old course of the Channel (Napoleonic project); 4, 5, 6, important concrete hydraulic structures.

Present hydraulic function of the channel and future prospects

The Napoleonic Channel, 18 km long and 180m wide, has two functions. Firstly, it diverts away Reno flood waters (shifting its discharges to the Po, or keeping them inside its own course, as an emergency reservoir, for a maximum capacity of 1.8 million m^3), with a southward flow direction, and secondly, it acts as an augmentation waterway for the CER, with the opposite flow direction. In the latter the two artificial channels generate an hydraulic system about 148 km long (Consorzio C.E.R. 1990). To succeed in this double function, the channel bed slope is zero. The connection to the other streams is regulated by two hydraulic concrete structures. These were designed in the 1950s, at the laboratory of hydraulic structures in the University of Bologna (Supino 1965). A third structure governs the water flow to the CER and, if needed, it could be used in the opposite direction for hydraulic safety. Because of the very high permeability of the channel bed, the "Cavo Napoleonico" cannot be used at its maximum capacity. The fill volume cannot exceed one third of the maximum design volume, and it can be utilized for the irrigation procedure only for a limited period of time during the year (from April to September). The present work is designed to provide the channel with improved hydraulic security.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The study area belongs to the structural domain of the Apennine belt and is covered by recent alluvial deposits, underlain by terrigenous layers of Plio-Pleistocene sediments. The convergence of the African and European plates which has been occurring since the Late Cretaceous and has generated the northern Apennines folds and thrusts (Neogene) including the ones constituting the Ferrara arc. According to seismological data from the earthquakes of Parma (1983) and Reggio Emilia (1996), the area shows the presence of a predominant compression stress directed approximately north-south (Montone & Mariucci 1999). The presence of this tectonic uplifted zone reflects the low subsidence rates (not more than 10 mm/year) of the area (Carminati & Martinelli 2002). Furthermore, the tectonic uplift of the Apennines front belt is considered the main reason for the northward migrations of the River Po in the last 3 000 years (Bondesan 2001). The area comprises alternate sequences of Pleistocene-Holocene sediments deposited by the main streams that have flowed on this area since the end of the Pliocene marine ingression (Bondesan, Dal Cin & Mantovani 1974).

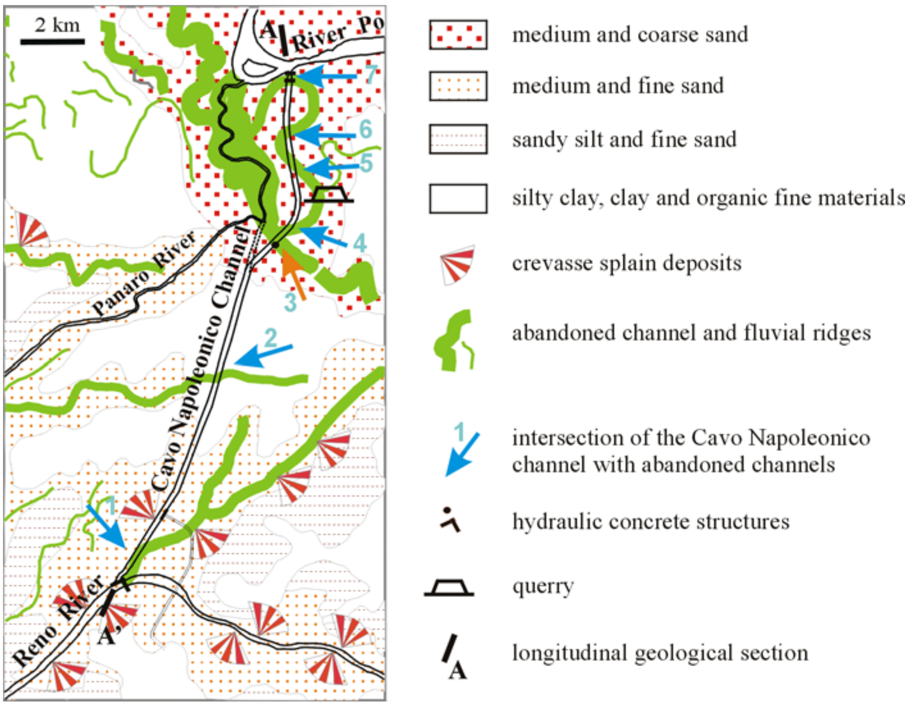

Figure 2. Geomorphologic and lithologic sketch of the study area (From Regione Emilia-Romagna 1990, redrawn and modified). Blue arrows point out the segments of the Napoleonic Canal where the channel bed is directly connected with abandoned channels or fluvial ridges.

A simplified geomorphologic and lithologic map of the study area is shown in Figure 2. It shows the fluvial ridges and abandoned channels as well as the abandoned course of the River Po in the northern margin of the Napoleonic Channel. The present pathway of the canal intersects the higher permeability zone while the old course drawn by the Napoleonic Commission does not. The presence of those sandy-gravely sediments is related to an ancient course of the Po, before it was naturally diverted by a violent burst of the left dike in the twelfth century. This flood permanently changed the morphological, social and economical history of these lands (Ferri & Giovannini 1997; Bondesan 2001).

Figure 3, illustrates a longitudinal geological section of the Napoleonic Channel. The section is based on the geological and geotechnical surveys that have been carried out on its course since 1949 (STBR Archive) and placed under the topographic profile developed before the channel was constructed. The sediment classification in the section is simplified to highlight the thick Pleistocene sandy layer which derives from a different fluvial morphological environment, typically a high energy environment, that related the River Po to a past fluvial-glacial climatic age. The bottom level of those Würmian sands can reach a depth of 40m and there are alternate sediments of fine and coarse Holocene materials for a thickness of between 7 to 12m near the top, deposited by a meandered fluvial system, similar to the present (Bondesan *et al.* 1974).

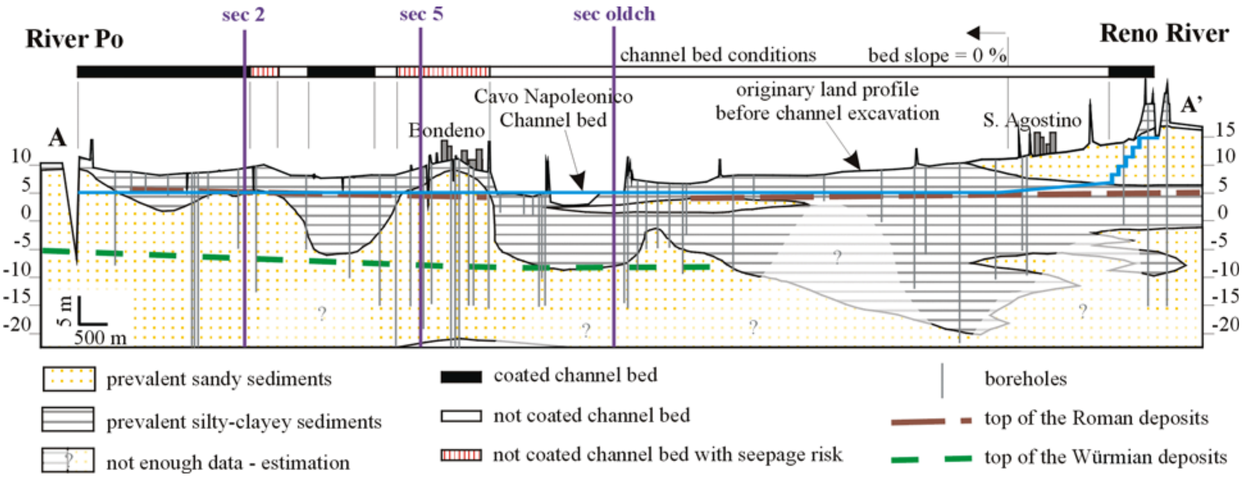

Figure 3. Longitudinal geological section along the axis of the "Cavo Napoleonico" Channel. Lithology has been simplified in order to show the limits between high and low permeability sediments. The traces of the three transversal sections drawn in Figure 5 are shown. Two temporal limits (Wurm, Roman time) have also been noticed and approximately positioned in the sketch.

HYDROGEOLOGY OF THE AREA

The conceptual hydrogeological model within the geological framework described above, features the superficial level (denominated A0 and A1) of the sandy-gravely Pleistocene-Holocene deposits of the regional multilevel aquifer (Regione Emilia-Romagna 2002; Severi, Guermandi, Larucca *et al.* 2002), in direct hydraulic contact with the main surface waters. The "Cavo Napoleonico" intersects a series of abandoned channels of the River Po that are still connected to the Po through a lateral (unconfined aquifer) and a deeper (confined aquifer). It is possible that the water supply in the Po has been incremented by the rapid incision of its bed (from 1 to 6 m) inside the Würmian deposits since the 1950s (Surian & Rinaldi 2003). The study of these interactions has been investigated by Gargini & Messina (2004), who considered potable exploitation of a quarryed area next to the Napoleonic Channel. They verified the connection between the Po and the quarry, using an hydrogeological profile (Woessner 2000) almost parallel to the geological section of Figure 3, longitudinal to the abandoned course of the River Po and perpendicular to the Würmian deposits. The average hydraulic conductivity of the aquifer varies from $4.1*10^{-4}$ to $8.2*10^{-4}$ m/sec, while the transmissivity fluctuates from $1.6*10^{-2}$ to $4.1*10^{-2}$ m^2/sec. Comparable values of hydraulic conductivity were obtained from permeability tests in boreholes in the same sediments adjacent to the "Cavo Napoleonico" levees (STBR Archive). The groundwater level near the channel and the head in the two main waterways (The Po and the Napoleonic Channel) has been monitored, albeit with different time steps, since 1965 (just before the first filling test of the channel) (STBR Archive).

Many piezometers have been installed during the last 40 years, but they are mainly distributed close to few transverse sections of the canal, considered as the most representative. In Figure 4, for instance, monitoring sections number 1 and 5 are illustrated. The first shows the effect of the impermeable coat construction on the filtration throughout the channel bed. Piezometer levels on both sides of the channel proved, in the interval October/December 1966 (first testing period), that groundwater levels were very close to ground surface, with a trend comparable to the Napoleonic Channel head variations. After the coating, using concrete sheets, groundwater levels dropped immediately and began to show (in the period May 1973/September 1974) a tendency similar to the Po level trend. The Po and the sediments are known to be in hydraulic contact. Section 5 (like number 3 and 6) also reflects the head in the channel, as proved by the simultaneous response of groundwater to Napoleonic Channel head variations. However, in the same recording period a combined effect of the heads of the Po and the Napoleonic canal is registered as a partial decrease of piezometer levels in the aquifer. This double effect prevents use for irrigation during flooding of the River Po, in order to avoid an excessive increase in pressures below the levees of the channel.

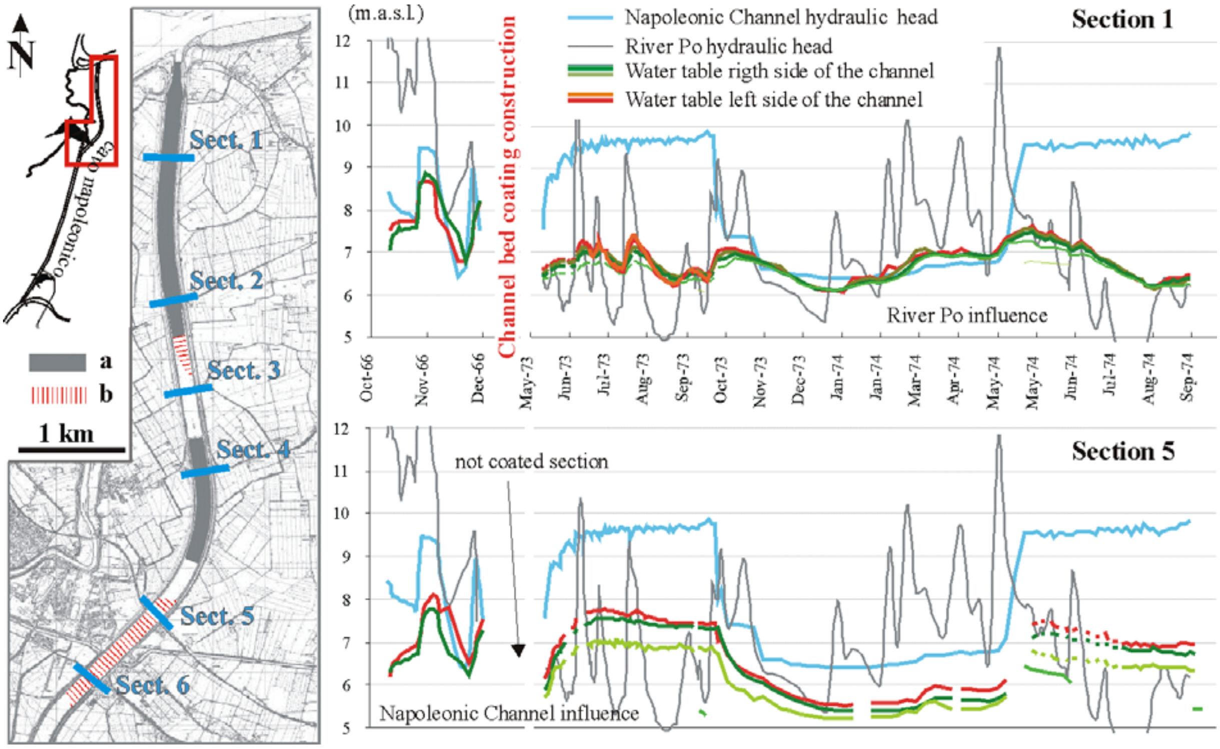

Figure 4. Monitoring activities along the northern part of the Napoleonic canal. Among the six main sections of hydrogeological groundwater registrations, two are shown before and after the construction of the lining (Dec 1966 – May 1973). Section 1 reveals a relevant decrease of groundwater level in comparison with channel water change, while Section 5, without lining, does not, even if the consolidation of the terrains under the embankments has induced a small reduction of groundwater levels. On the map, "a" and "b" are respectively coated and seeping segments of the channel.

The installation of modern groundwater level monitoring instruments has permitted more detailed observation of the correlation with the channel head fluctuations. These relationships are partially illustrated in Figure 5. In the same picture three sections, illustrated in Figure 3 and 4, are shown: section 2 symbolizes the coated segments; section 5 is indicative of the most problematic portion of the channel where the excessive rate of filtration under the embankments has been detected; finally, section oldch (old channel) illustrates the differences between the actual profile of the channel and the old section, as found and investigated in the 1950s. In this last case the new profile has provided a rise of 2m and an enlargement of 8m for each levee. The hydraulic reaction of the piezometers positioned in proximity of non-coated segments of the Napoleonic Channel (Piez2 sec5 and Piez3 Sec5) is almost immediate. There is a greater sensitivity on the left side, compared to the the right, probably due to grain size differences between the two flanks. Piezometers placed along the segment of the channel protected by filtration (Piez3 Sec2) show a trend which does not reflect channel head fluctuations.

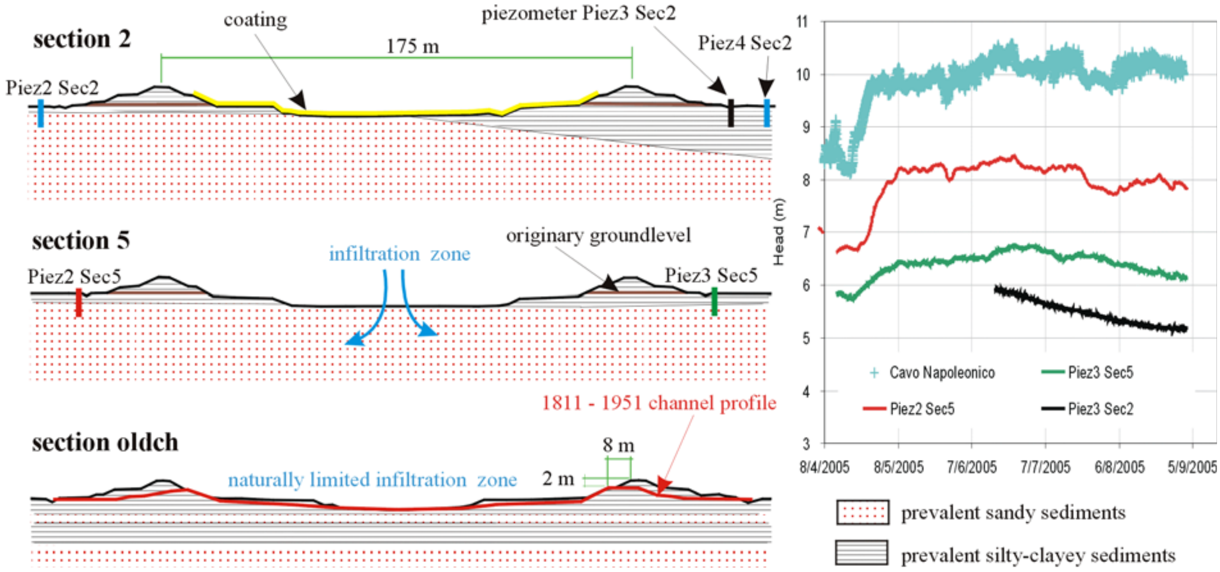

Figure 5. Three transverse sections are illustrated in relation to the underlying geology. Section 2 is located on a coated segment of the channel. Section 5 is constantly losing water from the bed, and the regime of piezometers n. 2 and 3 are shown beside it. Section oldch is located (Figure 3) where the channel overlaps the old extent as built in Napoleonic times.

GEOTECHNICAL PROBLEMS

Where the Napoleonic Channel bed is directly in contact with the sandy strata belonging to the abandoned channels, especially if the contact had not been lined, there is a state of flood risk for the near urban areas, induced by the under seepage phenomena which could be responsible for a potential deterioration of channel embankments. For this reason the hydraulic heads imposed by the manager of the channel, have not been allowed to exceed 10.70m (above sea level). The original maximum design head was 14.50 m. With the aim of verifying the real hazard for the geotechnical weakening of the earth embankments of the canal, a detailed analysis of the problem was conducted with the help of numerical modelling. The computer procedure was applied selected channel sections also taking into account the technical intervention proposed by the Administration of the Channel to limit the seepage problems. Technical parameters were adopted from the geotechnical surveys that have been carried out, and the assumed alarm threshold for the modelling was the start of impounding phenomena in the bordering areas of the channel.

Proposed solutions

Among the various projects proposed since the 1970s in order to limit the loss of water from the bed of the Napoleonic Channel, two main hypothesis located in the STBR Archive have been taken into consideration: to complete the concrete coating already placed in the critical segments, or to adopt a different technique by means of vertical bentonite diaphragms of variable depth. Other composite hypotheses were considered but are not discussed. In Figure 6 three typologies found in the Archive (STBR) are illustrated.

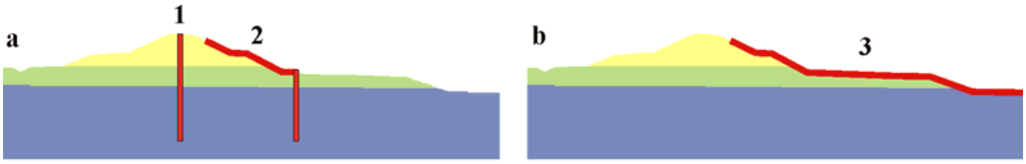

Figura 6. Examples of intervention proposed (for simplicity only left levee is shown) by the Administrator of the Channel in order to limit the water outflow from the uncoated bed: (a-1) vertical bentonite diaphragms from the top of the levees; (a-2) vertical bentonite diaphragms from the internal bank of the levees with partial coating of the banks; (b-3) concrete coatings of channel bed and internal banks.

MODELLING

Different technicians using simplified and complex methods have tried to face the problem of the under seepage hazard evaluation for the embankments of the Napoleonic Channel. The first estimates of the stability of the levees were made only by direct experiments after filling the channel. When the hydraulic head reached 9.00m or a few centimetres more (diagrams in Figure 4), the area around the channel started to reveal the first impoundment problems. Subsequently, an hydraulic head threshold was established at 9.70 m. After some more time the consolidation of the embankments and the underlying terrains have allowed the managers to increase the hydraulic head. The first mathematical methods were applied around the 1980s (STBR Archive) evaluating the under seepage risk with the empirical method proposed by Lane (1935). New thresholds were indicated for the maximum head of the channel, linking them to a specific new hydraulic management programme of the Cavo Napoleonico, and to a series of interventions, mainly by means of bentonite diaphragms and impermeable lining. At the moment, without these works the channel is used for the irrigation (augmentation of the Emilano-Romagnolo Channel) with a maximum head of 10.70 m, corresponding to one third of its maximum capacity, and it is always employed prudently during the River floods. Many other tests have been performed but the level has always been kept under the threshold. In 2004 and 2005 various numerical models were prepared using the transverse sections of the channel that had shown to be the most critical situations (sections 5 and 6 were the worst). The analyses were conducted with two-dimensional models with flow condition both stationary and transitory, using two codes: VS2DTI 3.0 (USGS 2000) e SEEP/W 4.0 (GEO-SLOPE 2004), respectively FDM and FEM numerical codes. Both allowed a more sophisticated analysis of hydraulic scenarios in comparison to the previous methods and the results obtained were comparable.

Modelling at present conditions

Using the hydraulic conductivity values summarised in Table 1, a numerical model analysis has been conducted on the sections considered the most representative for the seepage problems of the Napoleonic Channel. For example, the model of section 5 (localized in Figures 3 and 4) is shown in Figure 7 where it is sequentially reported: a) the geological model; b) the groundwater profile obtained in stationary conditions with the maximum head ever experienced (H = 10.70 m). The channel is constantly losing water, but it can only be found inside the lateral trench, as observed in reality; c) the same section in hypothetical transitory conditions, with the hydraulic head of the channel that reaches the maximum admissible level (14.50 m) with different time functions. The left side of the channel (d), the most critical one, shows impoundments with different combinations of time and hydraulic head. Those combinations are summarized in diagram (e) where the red area represents the location of critical conditions that must be avoided in order to prevent impounding phenomena.

Table 1. Synthetic average hydraulic conductivity characteristics of the terrains in the analysed section. Colours are referred to the geotechnical model shown in Figure 7a.

	USCS Classification	K_h sat (m/sec)	K_h/K_v
Embankments (artificial)	CL	$1.0 * 10^{-7}$	10
Superficial layers	CL	$2.0 * 10^{-8}$	10
Sandy layers	SP	$6.0 * 10^{-4}$	1

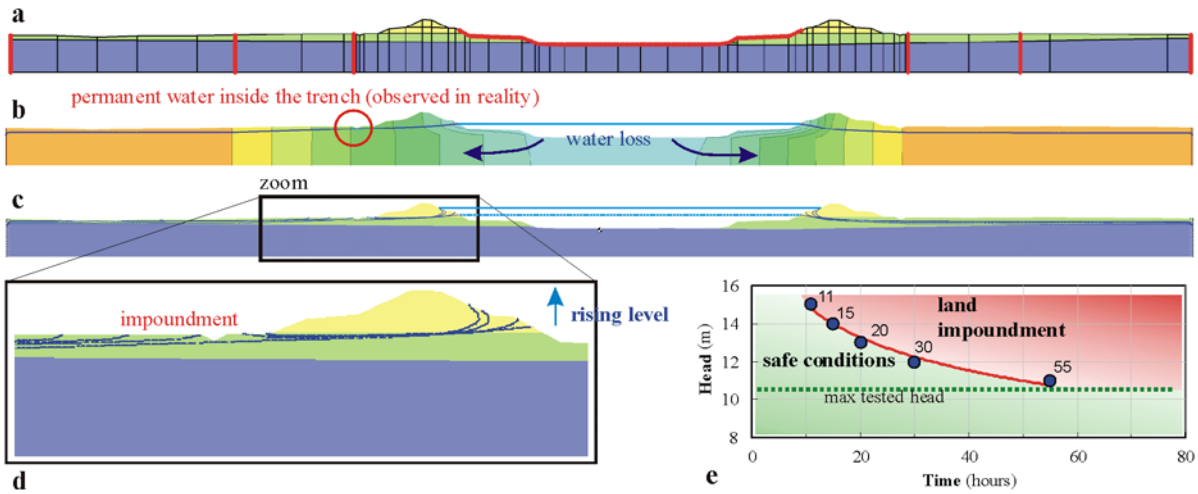

Figure 7. Modelling schemes of section 5: (a) element partition of the geological section for numerical analysis; (b) groundwater profile in stationary conditions with the hydraulic head at 10.70 m; (c) variations of the water table in transitory conditions. Water impoundment of the left side of the channel starts rising a few hours after the head reaches the maximum admissible head H_{max} = 14.50 (d, e).

Modelling with intervention works

The different hypothesis of intervention considered in Figure 6 have been taken into consideration and tested on the numerical model using the same starting hydraulic conditions described above. The use of diaphragms should be precluded because of the total absence of any impermeable layer inside the thick sandy complex under the channel.

The results obtained from models show a relevant decrease of the pressure head under the embankments, due to the presence of the vertical diaphragms, but this does not prevent the impoundment produced by the outflanking of the bentonite structures. Moreover, the presence of diaphragms create a sealing effect on the water accumulated inside the embankments during head dropping phases. The completion of the coating with concrete sheets or different impermeable materials, on the contrary, indicates an efficient action, even in the presence of holes, fractures, or other imperfections due to errors or deterioration. Such considerations have been taken into account because it is highly probable that the existing lining (made in the 1970s) could have been damaged over the last 30 years.

Discussion on the modelling

Among all the examined sections, number 5 is the most critical because it starts from the most penalising geotechnical conditions and furthermore it is located in proximity of the urban area of Bondeno (almost 15 700 inhabitants). The left embankment, the one that shows the highest rates of filtration, is also the flank that faces the most extensive part of the settlement. The analyses have proved that the only definitive solution to the hydraulic safety of the Napoleonic Channel is coating the bed with impermeable materials, in those segments where the under seepage could really endanger the embankment stability. The use of diaphragms does not seem suitable because it does not offer enough guarantees to prevent water impoundment around the channel, and in some cases even creates more dangerous situations, slowing the water flow from the embankments to the channel bed during the discharge of the filling water. In conclusion, the analyses demonstrate that the channel can be used with a higher capacity than those so far experimented; on condition that the hydraulic head must be fixed in relation to the time of permanence of the flood inside the Cavo, using diagrams like the one sketched on Figure 7e. However, this cannot be done without improving the real-time system of control, extending it also to the groundwater levels, at least in the most critical zones.

CONCLUSIONS

The Cavo Napoleonico Channel was originally designed with the purpose of diverting part of the floods of the Reno River into the River Po, or if needed to keep a considerable volume of water inside its own bed, in order to reduce the flooding (overbank spillage) risk along the artificial course of Reno River that starts from the village of Sant Agostino and extending eastward to the Adriatic Sea. The project, left unfinished at the beginning of the nineteenth century, had been modified substantially in its hydraulic and geotechnical characteristics. This has led to an increase of the flooding hazard in areas that have already experienced catastrophic events caused by the local streams in the past. The historical studies and reconstructions carried out and described in this paper demonstrate that the excessive attention of the designers to the hydraulic efficiency of the canal has generated important geotechnical drawbacks, such as the intersection of the waterway with abandoned channels. That lack of necessary awareness of geotechnical problems reflects attitudes in the 1950s. Finally, two different ways could be indicated to face the geotechnical problems. The first is to complete the coating of the channel segments that show excessive filtration phenomena. The second consists of reinforcing the remote control of the hydraulic levels so that the managers could be able to use the Naopleonic Channel respecting the thresholds established with the simulations obtained from numerical procedures. Although the first solution is at the moment impracticable, not having sufficient financial resources, the second one shows some weaknesses due to the uncertainty of measurements and to the eventual unpredictable events during the hydraulic management procedures. One more appropriate solution for the channel problems is represented by the realisation of a flood control reservoir in the upper course of the Reno River. Once completed, that structure would reduce the water discharge that needs to be diverted to the Cavo Napoleonico. Unfortunately, this artificial basin will need years to be completed, therefore, for the moment, the most practicable way is to modernize the remote control of groundwater and stream levels, while in the long term, to try to complete the impermeable lining in the critical sectors of the channel, choosing possibly a low impact solution for preserving the local groundwater circulation system.

Corresponding author: Dr Enrico Mazzini, Regione Emilia-Romagna - STBR, Viale Silvani 6, Bologna, 40122, Italy. Tel: +39 051 28 4347. Email: emazzini@regione.emilia-romagna.it.

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