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## THE PISA PLAIN (ITALY) AND ITS HYDROLOGICAL HAZARDS (\*\*\*)

**Abstract:** FEDERICI P.R. & MAZZANTI R. - *The Pisa plain (Italy) and its hydrological hazards.*

The Pisa plain, which is crossed by the lower sections of the Arno and the Serchio rivers, consists of a thick accumulation of marine and continental sediments of the Late Tertiary and the Quaternary. These sediments have filled in part of the Versilia graben and by their progradation the shoreline has been built forward farther and farther west and many kilometres away from the city of Pisa. Thus, besides the Holocene fluvial and palustrine sediments, we find that the surface of the plain consists of dune bar and coastal barrier beach sands.

The plain is very low, lying slightly above sea level, and shows only a very slight gradient (0,0005%). Thus, for centuries vast lakes and lagoons covered the plain surface and the courses of the rivers changed several times. Man has intervened since the period of the Roman Empire, attempting to modify the plain by reclaiming the marsh areas, building a network of drainage canals, and rectifying the courses of rivers, so that today drainage takes place through an entirely canalized system.

In spite of this, hydrological hazards are still present and they are represented mainly by *backwater* and *river overflow*.

The *backwater* hazard exists in less permeable areas after prolonged periods of rainfall. It should be kept in mind that the plain is undergoing subsidence and that the ground-water level is low due to excessive exploitation. These facts indirectly bring about another hazard: the *intrusion of salt water* inland, a hazard accentuated by major *coastal erosion* (a retreat of 1 km in 100 years). The coast is no longer replenished with the material that is removed from river beds by man.

A long list of overflows of the Arno and the Serchio rivers testifies to the *overflow hazard* affecting the countryside, cities and towns. A large artificial drainage canal, the Scolmatore, was built for the diversion and transport of the floodwater. From Pontedera, where the sluice-gates are located, the canal should transport the floodwater (900 m<sup>3</sup>/s) to the sea, following a route that is 28,300 km long. The structure has not yet been completed. Moreover, there is still no absolute certainty as to its efficiency in the event of a largescale overflow accompanied by sea-storm waves, which would obstruct the flow of the waters at the canal's sea outlet. The latter, like the mouths of the Serchio and the Morto rivers, is almost always obstructed by deposits.

**KEY WORDS:** Backwater hazard, Overflow hazard, Salt water intrusion, Coastal erosion, Pisa plain (Tuscany, Italy).

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**Riassunto:** FEDERICI P.R. & MAZZANTI R. - *La Pianura di Pisa (Italia) e il rischio idraulico.*

La pianura di Pisa, che è solcata dai tratti terminali dei fiumi Arno e Serchio, è costituita da un potente accumulo di sedimenti marini e continentali del tardo Terziario e del Quaternario. Questi hanno riempito una parte del graben della Versilia e con la loro progradazione hanno spostato la linea di riva sempre più a Ovest e molti km lontano dalla città di Pisa. Così in superficie, oltre che sedimenti fluviali e palustri olocenici, troviamo le sabbie dei cordoni dunari e dei lidi costieri.

La pianura è molto bassa sul livello del mare e ha una pendenza minima (0,0005%). Nel corso dei secoli è stata così occupata da vasti specchi lacustri e da lagune ed i fiumi hanno mutato più volte il loro tracciato. L'uomo è intervenuto fin da epoca romana imperiale a modificare l'aspetto della pianura bonificando le aree palustri, costruendo una rete di canali di scolo delle acque e rettificando i fiumi, cosicché il drenaggio è oggi tutto artificiale.

Nonostante ciò la pianura è ancora sotto il rischio idraulico soprattutto per il *ristagno delle acque* e per le *esondazioni fluviali*.

Il rischio di *ristagno delle acque*, nelle zone meno permeabili, si verifica dopo piogge prolungate. Bisogna tener conto che la pianura è in subsidenza e che la falda freatica è depressa per il suo eccessivo sfruttamento. Questi fatti provocano di riflesso anche il rischio di *intrusione dell'acqua marina* in terraferma, rischio accentuato dalla grande *erosione del litorale* (1 km di arretramento in 100 anni), non più rifornito dei materiali prelevati dall'uomo negli alvei fluviali.

Un lungo elenco di inondazioni dell'Arno e del Serchio testimonia il *rischio di inondazione* delle campagne e delle città. Per lo smaltimento delle piene, è stato costruito un grande Canale Scolmatore d'Arno, che da Pontedera, ove sono le cateratte, dovrebbe portare le acque di piena (900 m<sup>3</sup>/sec) al mare dopo un percorso di 28,300 km. L'opera non è completa e non vi è ancora assoluta sicurezza sul suo buon funzionamento nel caso si verificasse una grande piena in concomitanza di mareggiate. Queste ostacolerebbero il deflusso delle acque alla foce del canale, che, come le bocche del Serchio e del Fiume Morto, è quasi sempre ostruito da depositi.

**TERMINI CHIAVE:** Rischio da ristagno d'acque, Esondazioni fluviali, Intrusione salina, Erosione costiera, Pianura di Pisa (Italia).

The Pisa plain corresponds to the area crossed by the lower section of the Arno river, below the confluence of the Era river. The plain is fairly well-defined to the South by the Colline Pisane and the terrace bordering the Monti di Livorno. To the North, beyond Monte Pisano, the plain merges into the Versilia plain without any distinct boundaries, due to the uncertain drainage of the lower course of the Serchio river. The Lake of Massaciuccoli, however,

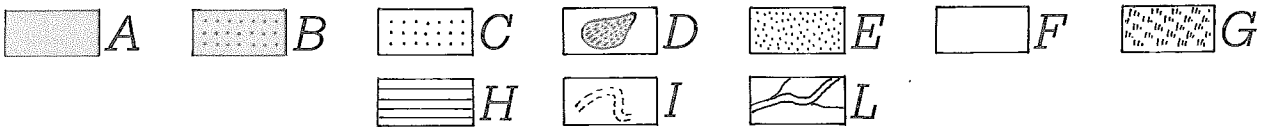
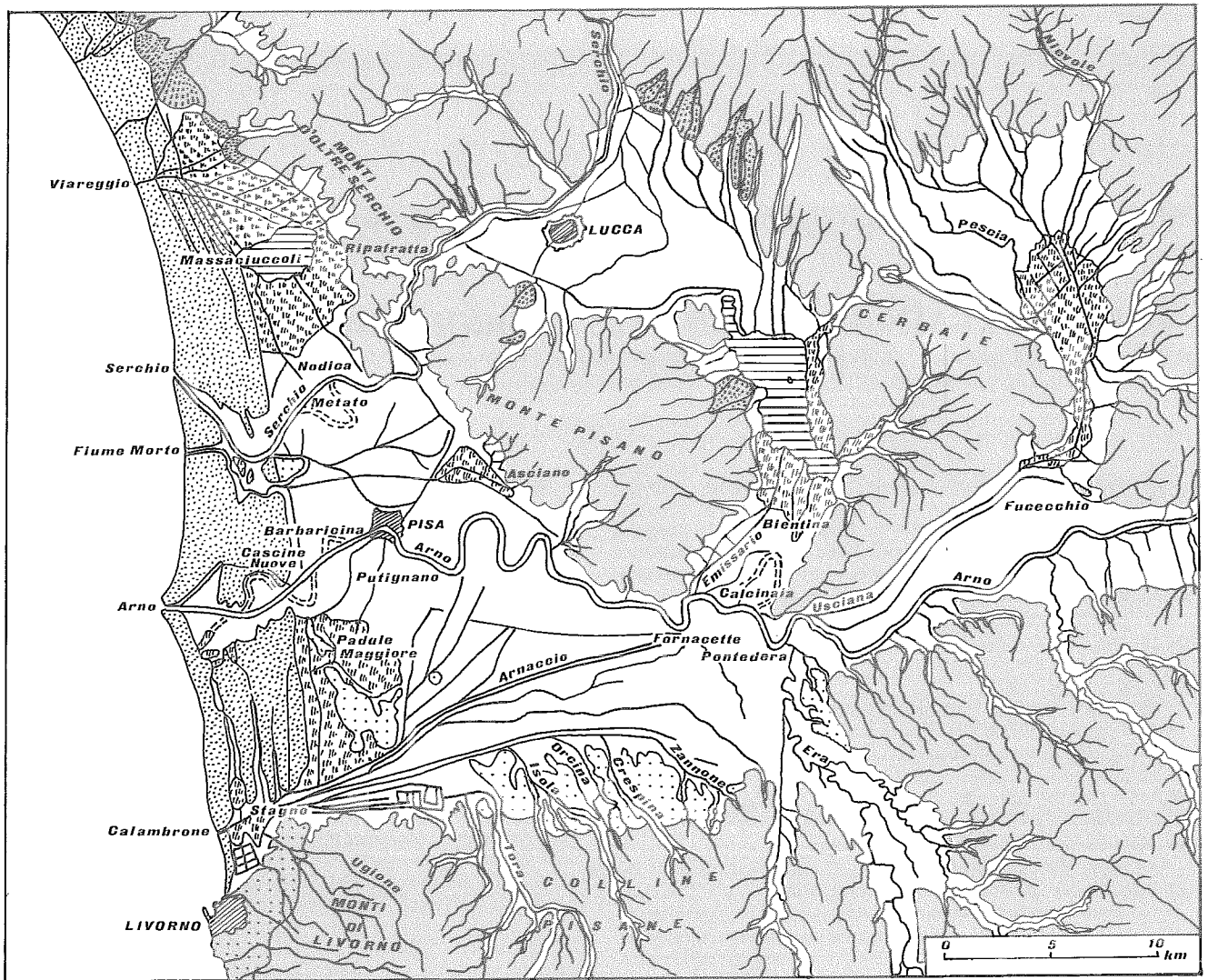


FIG. 1 - The Pisa plain within the framework of the other physiographical features and forms that border it. The shoreline and drainage pattern are from the map by G. INGHIRAMI (1830).

- A = Pre-Upper Pleistocene formations
- B = The Upper Pleistocene Livorno terrace
- C = Aeolian Isola di Coltano sands and Vicarello sands, both of the Upper Pleistocene, but morphologically related to the Pisa plain.
- D = Pleistocene talus cones
- E = Holocene dune, barrier beach and beach sands
- F = Alluvial deposits
- G = Marsh areas
- H = Lacustrine areas
- I = Abandoned river meanders
- L = Watercourses

\*All place-names cited in the text are shown on the maps (figs. 1 and 2).

represents the furthestmost limit of the delta plain of the Arno (see fig. 1).

There is a clear-cut contrast between the Monti di Livorno, Monte Pisano, Monti d'oltre Serchio, which are folded structures, and the plain that they delimit. This is

due to a complex series of events in the area's most recent history. This history is characterised by slow, generalised uplift, but in several areas, there was major tectonic sinking related to the appearance of normal faults in a regimen of crustal extension. From this point of view, the Pisa plain

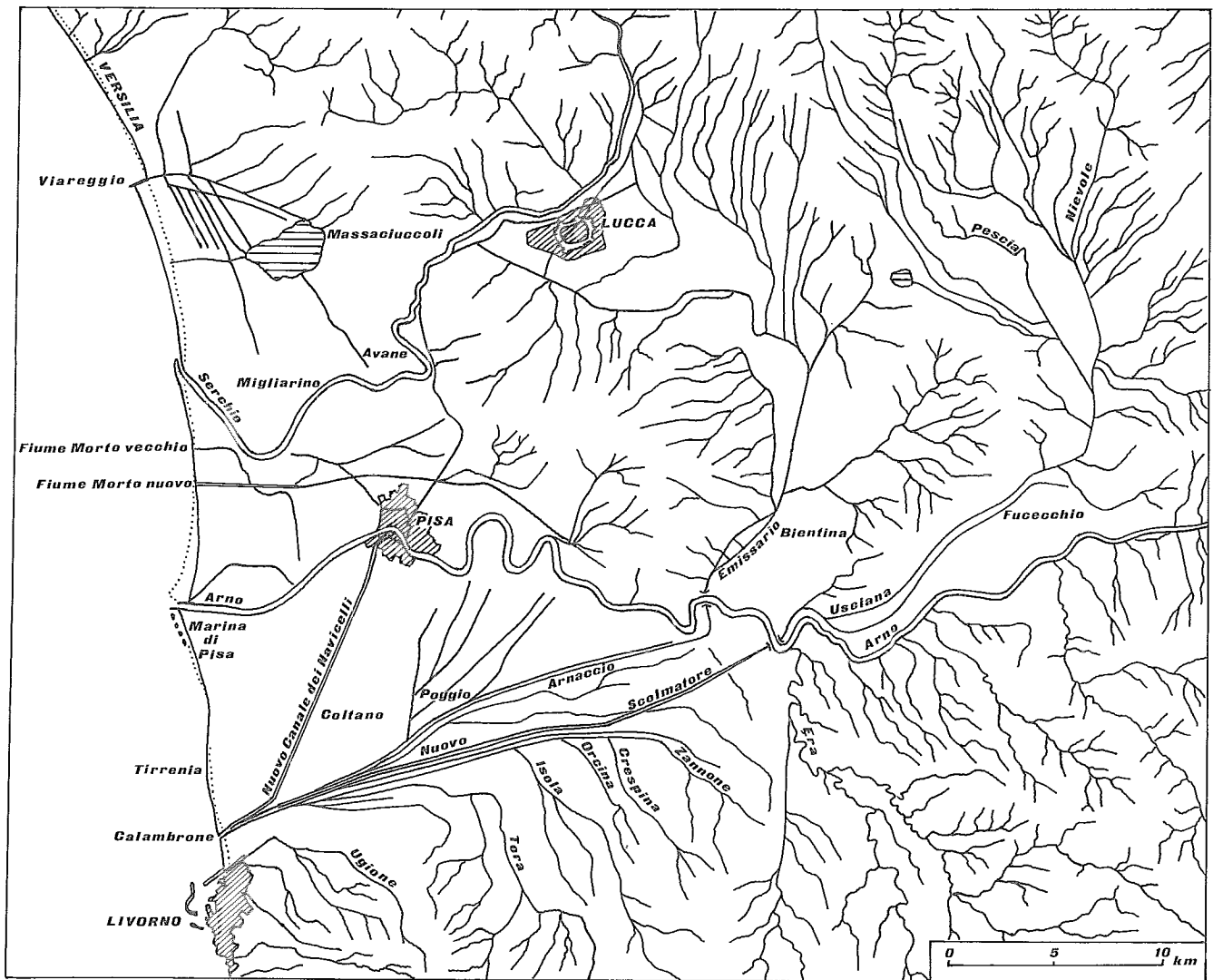


FIG. 2 - Map of the present Pisa plain drainage system and the physiographic features and forms bordering it. The dotted line indicates the shoreline in 1830, reproduced from the map by G. INGHIRAMI.

is part of the Versilia graben that extends NW-SE, the westernmost section of which is submerged by the sea.

If one considers that the top of the pre-Miocene basement was found at depths ranging from 500 to 2000 m according to drillings, one can then comprehend the vast scope of the sedimentation processes involved in the infilling of the depression. The Poggio drill-hole carried out by the Larderello firm engaged by Dalmine, SSE of Pisa in the vicinity of Arnaccio, reached the basement at a depth of approximately -700 m. The basement was found to support a series of clayey sediments of the Pliocene, a series of sandy clays and marine sands of the Quaternary, and then a series of gravels, sands and peats of brackish and continental environments. According to GHELARDONI & *alii.*, there may be a small morphological step at -500 to -700 m near Monte Pisano, a level zone at -700 to -800 m extending as far as Pisa, and then a rapid lowering of the basement down to more than -2000m between Tirrenia and Marina di Pisa. The

plain is therefore the result of a thick aggradation of marine and continental sediments, as well as periodic progradation that has brought the shoreline farther West and farther away from the city of Pisa.

Besides the Holocene fluvial and palustrine deposits, the surface of the plain consists of dune bars and barrier beaches, which also date from the Holocene and separate it from the sea to the West and from the aeolian sands of the last-glaciation that outcrop from the substratum (like nuclei spared from the pre-Holocene erosion) in several central areas and areas bordering the Colline Pisane. For an in-depth outline of the geomorphology of the Pisa plain, the reader is referred to the study on the drainage pattern and paleogeography of the lower Arno valley (FEDERICI & MAZZANTI, 1988).

Attempts by man to modify the plain probably began in the late Middle Ages with the rectification of natural watercourses and the building of a network of drainage

canals. Thus the Arno and Serchio rivers, the lower sections of which cross this plain and which find their outlets to the sea there, are contained within considerable embankments. In addition, having been deprived of their high-water bed areas, they now flow as hanging rivers over almost the entire plain. For this reason they are, in one sense, extraneous to the plain, except during the episodes of overflow.

Drainage of the area north of the Serchio takes place through a network of canals that conducts the waters into the Lake of Massaciuccoli and from there to the sea near Viareggio. Drainage of the area between the Serchio and the Arno is based on a network of canals that flow into the Morto river, which was in part derived from an abandoned former section of the Serchio, and then to the sea. Drainage of the area south of the Arno relies on numerous canals, all of which lead into the Calambrone canal and then to the sea slightly North of Livorno.

The waters that carve the northern part of the Livorno Terrace (the Ugione torrent) and the Colline Pisane (the Tora, Isola, Orcina, Zannone torrents) also flow into the Calambrone canal, as do the waters from the drained area of what was once the Bientina Lake in the plain between Mt. Pisano and the Cerbaie Hills, situated farther east. This latter supply takes place through the Arnaccio canal that was connected with the Emissario Canal from the former Bientina lake, in 1859, through a conduit passing beneath the Arno. This operation permitted the lake itself to be drained and shifted the drainage of the plain, situated between Mt. Pisano and the Cerbaie Hills, south of the Arno and to the mouth of the Calambrone canal (for details on these aspects, see FEDERICI, 1987). Drainage of the former Sesto or Bientina swamp-lake was a grandiose operation which was to bring the modern epoch of hydraulics in Tuscany to a close. It had been preceded mainly by large-scale works attempted especially in the 18th century to reduce the most depressed areas by means of reclamation. In fact, being the product of lengthy periods of fluvial and marine sedimentation, including episodes that overlapped, occurred simultaneously or alternated with erosion phases, some of which were quite significant, the plain did not take on, as is natural, a uniform upper surface, but one that is very irregular, along with the presence of morphological depressions and rises.

## THE MAIN CAUSES OF HAZARDS

Near the confluence of the Era river with the Arno, approximately 30 km from the sea, the plain is already very low, showing heights of about 15 m with a gradient of only 0.0005%. In addition, such gradients are only found near the course of the Arno river, whereas other areas of the plain actually lie below sea level due to the effect of the pre-Holocene phases of erosion. Obstructions to the free flow of water are presented by the shoreline sandbar accumulations and by the remnants of last-glaciation aeolian deposits outcropping from the substratum and which are slightly higher than the Holocene sediments. The draining of these lower areas and of the reversed slope areas was possible only after the introduction of modern water-scooping machines.

The latter are constantly in operation to prevent reflooding, which, however, recurs unfailingly, for example in the Asciano area, in vast sections of the bed of the former Bientina lake, and also in the areas surrounding Pisa, following prolonged periods of rain.

The configuration of the surface of the plain is not the sole reason for the difficulties that have always been encountered in attempts to obtain an even discharge of water. Subsidence, the other factor of considerable importance, must be given special attention. From a geological point of view, its presence is normal in an area such as that of the low plains of the Arno and Serchio, set in a graben delimited by faults. Tongiorgi (1978) has estimated the subsidence at approximately 1 mm/year from the Miocene to the present. This estimate can essentially be attributed to normal compaction of the sediments, even if a tectonic component cannot be excluded. For the Holocene, the estimates range from 0.7 to 4 mm/year in the part of the plain that extends southwest merging into the Livorno plain (TONGIORGI, 1978). Very recent data on the subsidence in progress have revealed much higher values. For some areas, they reach and sometimes surpass 1 cm/year (PALLA, 1973; PALLA & POLI, 1978). Examples may be found on the Salviati estate in Migliarino Pisano and in Coltano. There are also areas showing anomalous subsidence, such as those bordering the Strada Statale Aurelia or near Ripafratta. In these cases, the effects of human activities must play a part, such as the excessive pumping of the groundwater.

One aspect of hydrological hazards in the Pisa plain is precisely the situation created by the extreme exploitation of the groundwater. This tendency has become increasingly more evident and particularly insidious in the last twenty years.

As regards the nature of these water resources, we shall briefly mention that the Pisa plain contains poor and infrequent phreatic strata and artesian water. The phreatic strata are located in the «Clayey Sands of Le Rene» (DELLA ROCCA & *alii.*, 1987), a surface deposit alongside the present course of the Arno. This deposit marks the position of several older riverbeds which are completely abandoned today. Phreatic strata are also present in the dune sands on the coast. Both of these sandy formations are lenticular and are mixed with silts and clays so that they do not contain significant groundwater reservoirs. Though revealing supply characteristics at a depth great enough to have brought about springs, another phreatic stratum is found in the «Sands of the Isola di Coltano» formation (FANCELLI & *alii.*, 1986). The outcrops of this formation are pre-Holocene fluvial relicts and they are scattered in the middle of the plain and along the plain's southern edge at the foot of the Colline Pisane, where they have been referred to as the «Vicarello Sands» (DELLA ROCCA & *alii.*, 1987). Artesian water is found in the «Arno and Serchio from Bientina Conglomerates» starting from a depth of -40 m (SEGRE, 1955). The «Conglomerates» mark an older course of the two rivers (the Arno and the Serchio from Bientina) below their confluence SE of Monte Pisano.

Thousands of wells draw from the meagre groundwater

resources of the strata mentioned previously. The groundwater level is thus lowered to the point of triggering-off a series of consequences, some of which are easily understood, others that are perhaps less clear, but not to be overlooked as both are the source of many problems.

The first such problem concerns the stability of many buildings and structures threatened by the depletion of the surface water. This fact is well-known principally because of the heated debate that broke out over a deliberation by the city government of Pisa that was promptly revoked. The deliberation had prohibited drawing from all wells over a wide area around the famous Leaning Tower in order to counteract its progressively increasing inclination. Actually, there are many other leaning towers and bell-towers in Pisa, even if they do not share the fame of Bonanno's monument.

Another problem that arose with the concentrated construction along the coast, is the excessive exploitation of the phreatic waters in an area extending inland for several kilometres from the shoreline. It is well-known that this causes the rise of the salt-water wedge underlying the fresh water, which results in effects that are detrimental to the belt of coastal woods that have managed to escape felling. This threat is that much greater along the Pisan coast, in that there exists the additional complication brought about by the widespread use of water-scooping machines since the 1930s to drain swamps. The use of water-scooping machines depletes fresh-water levels and leads to salt-water encroachment. All of this is taking place within the framework of a shoreline which, starting from the end of the 19th century, has retreated considerably in many tracts (1 km on the right side of the Arno) (VITTORINI, 1980; MAZZANTI & PASQUINUCCI, 1983). On the other hand, development of the coast, even when respecting the standards devised to pro-

vide for the harmonious insertion of construction works within the original environment (for example, some parts of Tirrenia), always involves dumping, waste, and leakage of polluted liquids. This is because of sewer leakage, and these substances thus escape the purification processes even in those localities where purification plants exist. The leakage of polluting liquids, mixed in differing degrees with water, probably takes place in large quantities over the entire southern part of the Pisa plain that is in contact with the industrial port of Livorno. The use of insecticides in agriculture completes the picture of the agents polluting the fresh water. In the Pisa plain, exposure of the groundwater, which is separated from the surface by substantial clay banks, to the polluting agents should not occur by direct vertical descent. However, the groundwater is obviously exposed to polluting agents from replenishment areas such as the Lucca plain (a highly developed industrial and agricultural area) and the Colline Pisane torrents. With their poor-quality water due to the excessive iron salt content, if these water-bearing strata were to become polluted, they would be difficult to purify considering the slowness of their drainage.

It is simple to conclude from the above that the Pisa plain must be considered at risk as regards the backwater drainage and pollution (fig. 3).

The swamp areas that were in existence in 1830, that is, before the introduction of the modern water-scooping machines and drainage of the Bientina lake, are shown in figure 1. This provides an idea of the hydrological conditions of the plain. One should keep in mind that the figure does not show the numerous «lame» or marshy ground areas that extended among the dunes throughout the entire coastal belt, the swamps that surrounded Pisa which were reclaimed in the Middle Ages, nor those that were located where the

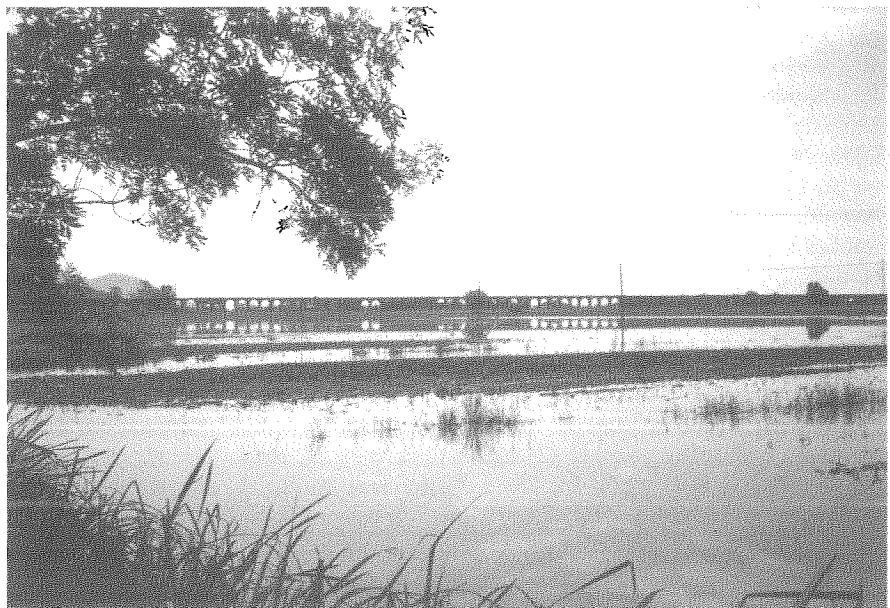


FIG. 3 - Extensive backwaters in the Asciano area after heavy rainfall in the winter of 1987; in the background the aqueduct of the Medici (1596-1611).

Colline Pisane torrents reached the plain, and which were drained through canalization and reclamation in the 17th and 18th centuries.

As was discussed previously, the present situation reflects an area that has been intensely changed by the intervention of man. On one hand, it no longer presents those features of the marshy plains of the past. On the other hand, one cannot claim that the situation is a comforting one. For added to several still unresolved classic problems, there are those created by unregulated urbanisation and the unchecked exploitation of the water resources.

The most potentially damaging geomorphological hazard is certainly that of river overflow and there is virtually no region in Italy immune from it (FEDERICI, 1980). From this point of view, the Arno valley is no exception. For example, memories of the disastrous flood of November 4th, 1966, are still very vivid. Overflows of the Arno are not the only ones in the Pisa plain, which is also affected by the overflows of the torrents flowing from the Colline Pisane and those of the Serchio river.

At present, the Serchio river represents a hazard because of its damaging overflows to the West and floods in the Ripafratta area, after the «forced» and artificial passage of the watercourse North of Lucca. A considerable flood took place in 1949 and other less extensive, though economically devastating floods are frequent in the Avane-Nodica area, as well as in the Migliarino Pisano area, despite high embankments. In the past, before the construction of the Emissario canal in the Bientina area mentioned previously, the Serchio river was able to spread into even the innermost part of the Pisa plain (MASINI, 1956; FEDERICI, 1987).

The Arno river, however, naturally requires the most attention. The list of floods of the Arno for which reliable historical documentation exists, has been taken from CACIAGLI (1970). It should suffice to provide an idea of the gravity of this hydrological hazard.

List of floods, classified as medium (M), large-scale (L) or exceptional (E).

November 4, 1177 L; October 1261 M; October 1, 1269 L; December 15, 1282 L; April 2, 1284 L; January 1305; November 1, 1333 E; December 5, 1334 L; November 6, 1345 L; November 1362 M; November 1, 1368 M; July 21, 1378 M; October 20, 1380 L; May 1406 M; December 1434 M; October 18, 1456 L; January 16, 1465 L; January 19, 1490 M; June 10, 1491 M; January 8, 1515 L; August 28, 1520 M; December 15, 1532 L; December 1538 M; November 6, 1539 L; November 15, 1544 L; August 13, 1547 E; November 8, 1550 M; September 13, 1557 E; October 31, 1589 E; January 1621 M; November 9, 1641 M; November 6, 1646 L; January 1651 M; November 4, 1660 M; May 11, 1674 M; October 11, 1676 L; February 19, 1677 L; May 18, 1680 L; April 20, 1683 M; January 26, 1687 L; December 8, 1688 L; June 2, 1695 M; January 1698 M; October 11, 1705 L; February 28, 1709 L; October 22, 1714 L; September 6, 1715 M; November 1719 L; December 3, 1740 E; October 19, 1745 M; December 1, 1758 E; Novem-

ber 14, 1761 M; November 3, 1844 E; March 1866 M; February 18, 1904 M; January 10, 1916 M; November 26, 1949 M; November 1966 E.

Areas of highest risk for overflows of the Arno have been and in part still are represented by a) the narrowing of the river tract that traverses the city of Pisa, b) the tight curves of several meander bends, c) the orientation of the mouth with respect to direction from which prevailing sea-storms come, and d) the confluence of the tributaries.

a) The tract of the river that traverses the city is a genuine bottleneck and it is also supplied with bridges. Moreover, the course in this tract is a rather artificial one, given that it has been kept the same since the Roman period. Elimination of this hazard has never been seriously considered by city officials because the presence of the Arno in Pisa is considered a vital element of the city's basis characteristics. The only known project for the complete diversion of the Arno out of Pisa was attempted by the Florentine troops during the second siege of Pisa in the early 16th century. The attempt failed, despite the fact that LEONARDO da Vinci was amongst the planners. On the other hand, their intentions were certainly not aimed at safeguarding Pisa from the overflows of the Arno, but rather, at preventing even the most precarious means of provisioning the city!

b) Reviewing the other areas at high risk for floods, we should note that the tight curves of the meander bends were straightened in the case of both the Arno and the Serchio rivers. In the case of the Arno, information is available starting from the two cut-off channels built near Cascine Nuove in 1338 (REDI, 1986). They were followed by the Calcinaia cut-offs in 1563-64 (MAZZONI & PARDINI, 1980) and the Barbaricina cut-off dating from 1771-74 (FIASCHI, 1938). As for the Serchio river, it is known that the Metato meander cut-off was constructed in 1579 (PARDINI, 1980).

c) The hydraulic projects attempted at the mouths of the two principal rivers of the Pisa plain are also known. They were planned to facilitate the discharge of flood waves into the sea even during onshore storms.

The most successful operation was undoubtedly the cut-off of the mouth of the Arno in 1606, with the shifting of the SW orientation to a NW orientation. This was done to shelter it with respect to the source of the south-westerly storm waves. The libeccio, in fact, is the prevailing wind. Other outlet deviations were attempted for the Morto river which was diverted into the Serchio river in 1560 and 1612 and then re-routed to the sea in 1588 and 1623, after the previous operations had been recognised as unsuccessful (PARDINI, 1980).

The problem has never been completely resolved. At present, for example, the mouth of the Morto river is completely obstructed and one cannot claim that the Serchio outlet is free to a degree that allows for the free-flow of the waters in the case of a dangerous flood. The most recent overflows of the Serchio found in this obstruction a significant factor in facilitating the flooding of the surrounding countryside. As will be shown later, the problem of the open-

ing of the outlet to the sea also remains unresolved for the mouth of the Calambrone, the terminal section of the Scolmatore drainage canal from the Arno.

d) Concerning the areas at high risk for flooding represented by the confluences of the Arno with other watercourses, the major hazard in the Pisa plain is that of the Era river, near the town of Pontedera. This confluence is one of the most critical points in the entire Arno basin, in that the two rivers join where the embankments are high and, during overflows, the waters reach levels higher than the plain and the town of Pontedera. The unfortunate position of the latter was made evident in the flood of November 4th, 1966, when the two rivers burst their banks at the point

of their confluence, and flooded the countryside and the town as the floodwaters reached the height of 2 m;

To facilitate diversion of floodwaters of the Arno in the Pisa plain, the Consiglio Superiore dei Lavori Pubblici (Supreme Council on Public Works) approved a construction project in 1951 for an artificial drainage canal, the Scolmatore Canal, from the Arno. It is being built slightly downstream from Pontedera, as far as the Calambrone near Livorno, for a length of 28.3 km. It is planned that drainage will automatically begin whenever the waters reach a certain level, by opening the sluice-gates built on the left side (fig. 4).

The discharge capacity has been calculated for a maxi-



FIG. 4 a - The flow-regulation system of the Scolmatore, near Pontedera.

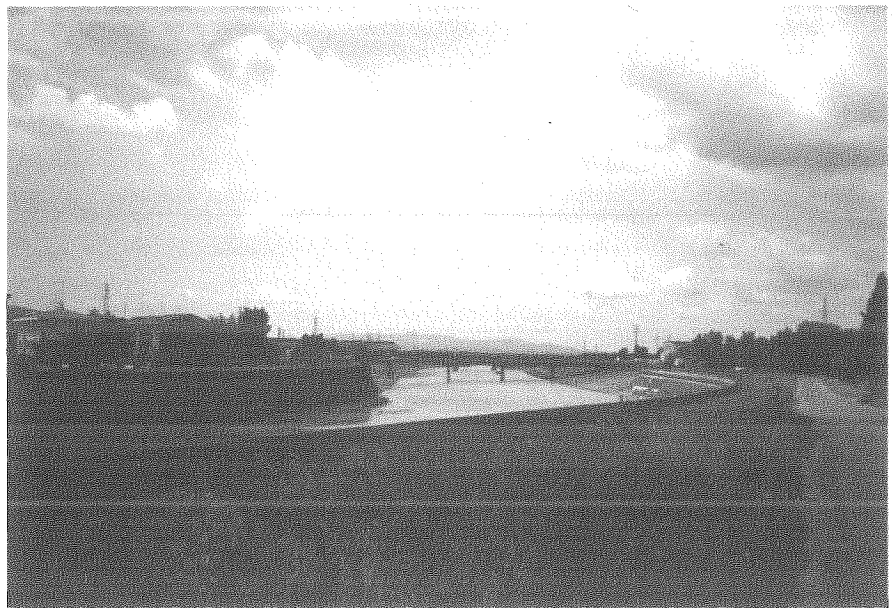


FIG. 4 b - The modern Arno drainage canal, the Scolmatore, near Pontedera.

imum of 900 m<sup>3</sup>/s and represents a considerable guarantee to safeguard the remaining course of the Arno from overflow, obviously including the segment through the city of Pisa. As foreseen by the project, the Usciana Canal also flows into the Scolmatore through a tunnel under the Arno river. The Usciana Canal drains the once swampy Fucecchio waters and the Nievole and Pescia basins. Although it is now a completely channelled watercourse, the Usciana is subject to overflows of considerable proportions. At present, whenever the level of the Arno surpasses that of the Usciana, the sluice-gates at the confluence of the two watercourses are closed in order to prevent the Arno from flooding the countryside. By preventing any release of the Usciana waters, this operation does, however, cause dangerous overflows if prolonged for too long a time. The new structure should overcome these problems as it has been designed to receive up to 500 m<sup>3</sup>/s of water from the Usciana basin. This water will no longer swell the course of the Arno, but will converge with the 900 m<sup>3</sup>/s of water that could be drained from the Arno when it too is overflowing (see fig. 2).

Although storage basins on the Arno and the tunnel underground for the Usciana were built some time ago, the Scolmatore is not yet in operation. This is because a completed middle section of the canal proved to be narrower than the initial and terminal sections. In addition, it appears that correction of the bed depth is necessary in several places.

At this point, a continuing commitment to finish the structure according to the plans is to be hoped for, so that an evaluation of its success and any corrections needed will be possible. At any rate, the moment it is put into operation during an overflow could not but be a moving experience for the technicians and political representatives who have worked on it for so many years, as well as for the population that expects greater safety and peace of mind from it! We do not deny that there are valid reasons for quite a few uncertainties as to the efficiency of the entire system. The

sea outlet at present is blocked by beach deposits that should be swept away by the first flood wave when the system is put into operation. However, will the mouth actually become unobstructed when the first major overflow arises? And if there are south-westerly waves, as often happens in Tuscany, will such a channel manage to cope with the large quantities of water that will be conducted toward the mouth?

An alternative possibility in the event of failure is the flooding of the coastal area north of Livorno, which would function as a storage basin. However, considering the industrial development and port activities that have expanded in the last fifty years, this could cause very serious damage. And then, is it possible to «reinforce» the mouth of the Calambrone by means of jetties so that the flow of large quantities of water into the sea could be ensured without damaging the Tirrenia beach? Such reinforcement would need deep foundations and the construction of very long jetties.

In conclusion, we hope that the new Scolmatore does not end up like the two drainage canals built by the Medici's! The first one was built in 1558 in Putignano and was used briefly to transport the turbid waters of the Arno into the Fosso delle Bocchette and from that channel to replenish the reclaimed Padule Maggiore swamps (FIASCHI, 1938) (fig. 5), the second canal was built in 1568 in Fornacette and flowed into the Arnaccio canal to conduct the waters of the Arno to the warp-land of Stagno. It was in operation very briefly because as early as 1632 the neighbouring communities had already been granted pasture privileges in the bed of the Arnaccio canal, after crop cultivation had already been attempted there (MAZZANTI & PULT QUAGLIA, 1986). In the second part of the 18th century, it was used as the shortest route between Livorno and Florence (TARGIONI TOZZETTI, 1768). It remains certain that neither one was successful in appreciably impeding the Arno from flooding Pisa and the surrounding countryside.

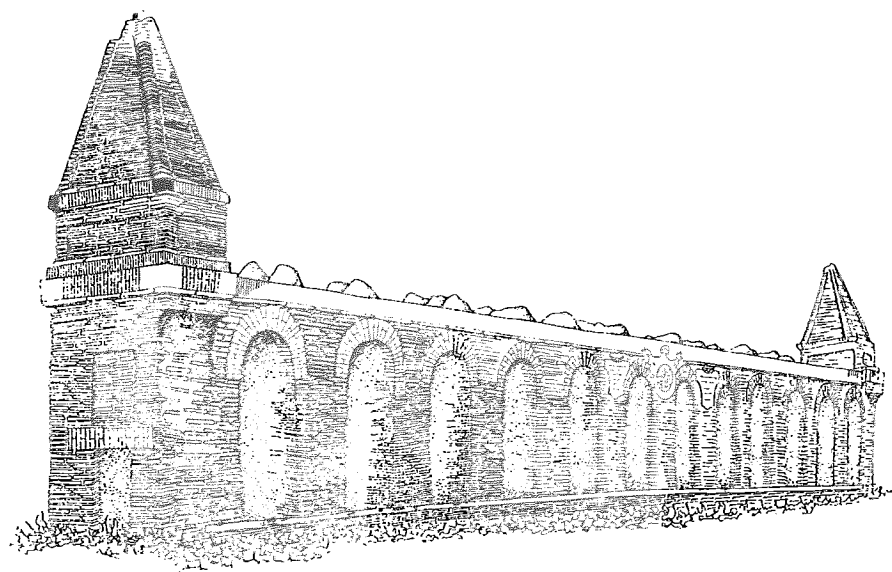


FIG. 5 - The floodgates of a drainage canal from the Arno, built in the Renaissance period near Putignano (Actual drawing by FEDERICI, 1983).

## CONCLUSIONS

The Arno drainage canal is the culminating project in centuries of man's attempts to control the hydrogeomorphological hazards in a region that is densely populated and that has great economic interests and an artistic heritage at stake. However, the overall picture of the hydrological situation in the Pisa plain is anything but reassuring. The flood hazards are still not completely under control and although technical advances have permitted basic swamp-draining operations, it is also true that the danger of backwaters still persists in various sectors of the plain.

Moreover, new industrial processes and agricultural practices create polluting substances that are increasingly less soluble by natural processes. They represent a threat to the quality of the water resources precisely at a time when the water demand has greatly increased due to the increase in population and advances in hygiene and the economy. The shoreline retreat along the coastal fringe, which is still in progress, and the excessive exploitation of the fresh water-bearing strata are also creating the intrusion of a small salt-water wedge in the substratum inland.

In this context various schools of thought and political factions have arisen. They are petitioning for radical solutions aimed at protecting the environment and its ancient equilibrium, opposing and even rejecting the rapid, but often unbalanced advances offered by modern land-use. Among the proposals for a return, even if only a partial return, to conditions closer to the older and more «natural» ones, one must mention the proposal to allow some of the previous swamp areas, such as sections of the bed of the former Bientina lake or the reclaimed area of Coltano, to be reflooded.

These proposals are characteristic of an urbanised and modern society. From a conservationist point of view, these operations could be useful in restoring the existing wood land and replenishing the water-bearing strata. They require great prudence from a geological and hydrological point of view, because they would have to be carried out with the guarantee of restoring the wetlands with good-quality (i.e. unpolluted) water and with sufficient replacement.

No attempt at solutions can dismiss the fact that the Pisa plain is only the terminal part of a large fluvial basin. The basin originated and develops in geomorphological and geographical environments that are extremely varied and complex. For this reason, the hydrological hazards and the

attempt to mitigate them must also be considered within the larger systematic context in which man and nature have worked together or been in conflict since the remotest past.

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