Water for agriculture, environment and human needs in the Fucino area (central Italy)

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Abstract Lake Fucino was the third largest Italian lake. In the 1st century AD an underground canal was built to prevent it from causing devastating floods. After the initial success, the efficiency of the canal rapidly deteriorated and the ancient lake surface was restored. In the mid 1800s, the construction of a new underground canal led to the complete disappearance of the lake and to the reclamation of its basin. Thus, an ancient conflict between local communities and a water surplus appeared to be finally solved. However, the initial farm crops, mostly wheat, maize and sugar beet, were progressively replaced with much more profitable horticultural crops, especially over the past 15 years. This change was accompanied by rising demand for water. Consequently, groundwater withdrawal has increased, and flows in streams and from springs have decreased, causing many environmental problems. These problems have to be solved by the application of water science, in terms of scientific knowledge, technical tools and regulatory efforts.

Key words agriculture; central Italy; groundwater management; hydrogeology; irrigation; reclamation

ROMAN LAND RECLAMATION

Lake Fucino is an endorheic basin without a natural outlet, and is the third largest Italian lake. Given its geological and geomorphological configuration (Burri & Petitta, 1998), flood control was effected by karst swallow-holes, albeit on a discontinuous basis. Since the 1st century AD surface canals had been built near the largest of the holes, known as Petogna, in order to facilitate infiltration of water (Burri, 1990). Human settlement around the lake started in the Bronze Age. As testified by hiatuses in the local stratigraphical sequence, rising lake levels caused repeated flooding of these settlements, which led to many attempts to control flows. In ancient Latium there were numerous volcanic lakes with no outlets and a similar morphology (Albano, Nemi, Ariccia, Gabi/Pantano Borghese, Turno/Pavona, Regillo/Pantano Secco, Giulianello), where underground canals had been dug for flood control and, in some cases, for land reclamation. Lake Fucino, relied on these well-established techniques.

The date of AD 41 marks the beginning of the construction of the underground canal under the Emperor Claudius. However, the works were completed and became fully operational only some decades later, under the Emperor Hadrian. A 5647 m-long tunnel and surface drainage structures were built. With the supporting structures (wells, either vertical or inclined, and diversions), the total length of the tunnel was close to 7 km. Among ancient hydraulic structures, this “main canal” is unquestionably
one of the most impressive historically, artistically, archaeologically and architecturally. The application of Roman water sciences appeared to solve the "Fucino Issue".

After a few centuries (at least by the 6th century AD), for reasons that will not be dealt with in this paper, the efficiency of the tunnel slowly decreased, thus restoring the ancient water body. It was not until the mid-19th century that Alessandro Torlonia built a new main canal and drained Lake Fucino completely (Brisse & De Rotrou, 1876).

FROM THE TORLONIA TUNNEL TO THE FUCINO DEVELOPMENT AGENCY

This background describes the "Fucino Issue" and its evolution in space and time. Restoration of the water body and the consequent floods would no longer be regarded as inevitable, since a solution had already been designed, implemented and was considered to be efficient until its deterioration. This was due to carelessness rather than to errors in its construction. Thus, for the local communities, the project for the drainage of Lake Fucino became a yardstick to measure the commitment of the rulers’ to partial or complete rehabilitation of the ancient main canal. Thus the canal itself became a landmark. Unfortunately, any major variation in the climate involving an increase in rainfall would make the flood problem more critical, stimulating the protests of the local communities which, especially during periods of higher political stability, urged rulers to rehabilitate the ancient main canal. It was not until the 18th century, however, that steps were taken, i.e. the setting up of a company with the mission of restoring the efficiency of the ancient tunnel, draining Lake Fucino completely, and using the reclaimed land under lease agreements. Faced with the uncertainties of his partners, Alessandro Torlonia, a wealthy and far-sighted Roman banker, purchased all the shares of the company and adopted a novel solution, i.e. the construction of a wider and longer new tunnel, radically solving the ancient issue. In terms of scientific and technical solutions, the project and the realization of the new tunnel testify to the significant role of the water sciences, especially in relation to drainage and reclamation technology.

After the reclamation of the land, there was the expectation of a new golden age for Marsica and its communities. But this expectation did not materialize and the situation remained unaltered. Most of the local communities remained poor, simply because their needs did not match those of Torlonia (Arpea, 1959). Once again, poverty and wealth co-existed and, at the end of the 19th century, the local situation was gloomy and dominated by an economic and social system, which was increasingly reflective of the one preceding the disappearance of the lake.

The main problems that Torlonia’s land reclamation had to address were of a technical and social nature:

(a) Infrastructures and Farming Models in the Reclaimed Area. By the end of 1875, the ancient lake had turned into an extensive swamp, making it necessary to build 210 km of roads, 100 km of canals and 648 km of drainage ditches, in addition to the usual agricultural buildings, such as farm-houses, store-houses and stables. In the ensuing decades of the late 19th century, the large Torlonia estate (over 13 000 ha of farm-land) was distributed as follows: 2800 ha to farmers, 900 ha to
share-croppers and the remaining and most substantial part (9300 ha) to leaseholders, especially those coming from Romagna, Marche and Val Vomano (Abruzzi). To obtain an immediate return on its investment, the Torlonia Administration had preferred to lease 25-ha plots of land to many of the influential local families, instead of entering into direct agreements with applicants. These families would in turn split these plots into much smaller plots, generally of 10, 20 or 30 “coppe” (each “coppa”, the local measurement unit, was equivalent to the 20th part of 1 ha), subleasing them at much higher prices and making considerable profits. Unfortunately, this strategy led to the fragmentation of the property and a serious reduction of the income therefrom (Giarrizzo, 1971). In the early decades of the next century, the situation did not improve and, in 1930, the Fucino Plain had a farm-land area of 34 119 ha, managed by: farmers (16 013 ha), lease-holders (4454 ha), share-croppers (1166 ha) and combinations thereof (12 486 ha). As regards holdings (8507), most of them (77.48%) were very small (0–3 ha) and they used only 27.10% of the land. The proportion of small (3–5 ha) and medium (5–10 ha) size holdings was large. As a consequence, the percentage of medium-large (10–50 ha) and large (>50 ha) holdings was low (<2%). It should be pointed out that, although the microholdings were many, they managed a total surface area smaller than the one occupied by the few macroholdings.

(b) Lack of Farming Tradition. Perhaps the most anthropologically and culturally problematic aspect of the Fucino Plain lies in the fact that, in a matter of a few decades after the start of the drainage of the lake, a community of shepherds and fishermen had to turn into farmers. As Prince Torlonia had also initiated the construction of distilleries, the crops grown on the reclaimed land were only those that responded to the Prince’s business requirements, i.e. sorghum and sugar beet, while crop rotation and application of fertilizer were reduced to a minimum.

c) Lack of a Water Management Policy. Since the original flood control project implemented by the Romans, the “bacinetto (i.e. the lowest part of the lake) had been spared and was used as a surge tank for severe floods and as a fish farm. In Torlonia’s original project, the “bacinetto” was planned to be retained. However, it was subsequently drained. This move marked the beginning of hydraulic problems in the Fucino Plain, because the main canal soon showed signs of instability and its waters flooded the Plain, depriving it of a precious reserve for irrigation (and thus of an abundant harvest) in the summer months. Consequently, as the drainage canals were not always useable for water withdrawal, wells were dug. This practice has continued to date, without any control.

The fragmentation of property is one of the factors contributing to water shortages in the Fucino Plain. However, over the years, this phenomenon worsened. In 1947, the more and more numerous microholdings (0–5 ha) utilized a smaller and smaller area, whereas the few large holdings (>100 ha) exploited a larger area: in the Fucino Plain; microholdings (95%) covered 17.5% of the land, while macroholdings (about 0.15%) occupied 68% of it. These were the most critical years, with many strikes and protests by farmers which led to the setting up (28 February 1951) of the “Ente per la Colonizzazione della Maremma Tosco-Laziale e del territorio del Fucino” (Agency for Development of the Tuscan-Latian Maremma and of the Fucino Plain), later called “Ente Fucino” (Fucino Development Agency).
In the early years of agricultural reform, the Fucino Development Agency had to raise the peasants’ awareness of the need to change their customs and to adapt to the post-Torlonia situation (Burri & Petitta, 2002). The task of the Agency was particularly difficult because there were 9918 formal lease agreements as opposed to at least 15 800 informal ones. In effect, each agreement covered holdings consisting of multiple farms, and each farm (73% of which did not exceed 0.5 ha) included multiple plots of land. The approximately 29 000 original plots of land were aggregated into slightly more than 10 000 units. This effort recovered about 200 ha of farmland. Obviously, the change with respect to the previous organisational model was dramatic: the average size of holdings increased from 1 ha to almost 1.5 ha (about 50% of the existing plots were re-aggregated) and half of the new holdings became fairly autonomous. In this way, property fragmentation was eliminated and 10% of leaseholders finally had a single-unit holding located in their municipality of residence.

The reform also had an impact on crops, because it intensified the rotation of the three main ones (wheat, potato and beet) and induced the progressive replacement of the less productive varieties. In as little as 10 years (from 1948 to 1958), yields considerably improved: wheat production rose from 26 to 36 quintals ha\(^{-1}\), beet from 260 to 388 quintals ha\(^{-1}\) and potatoes from 140 to 230 quintals ha\(^{-1}\). Comparing the three years before (1948–1951) to three years after the reform (1955–1958), the area of farmland was almost the same, but the gross saleable production mounted significantly (ARSSA, 1948–2003). From the 1980s there was another change: the three main crops were replaced by much more profitable horticultural crops, especially over the past 15 years (Fig. 1). This new trend required larger volumes of water, taking into account the possibility of having 2–3 harvests a year.

Despite the Reform, the 1961 and 1970 Agricultural Censuses revealed a situation not very different from the previous one, with dominance of microholdings. Nonetheless, by the 1980s, the situation had become more balanced: the Fucino farmland is now occupied by numerous holdings of small size and low profitability. Nonetheless, they represent a meaningful reality, because they are much more numerous than the large holdings. Indeed, for most owners or leaseholders in the Fucino Plain, farming is not the main source of income, but only a secondary activity which, as such, cannot adequately harness local resources. To overcome this obstacle and reach an optimum situation, large portions of farmland should be consolidated and

**Fig. 1** Evolution of farming in the Fucino Plain: comparison of crop distribution in: (a) 1958–1988 and (b) 1989–2003.
allocated to a single owner or to co-operatives. Unfortunately, however, the Fucino Plain lacks both a co-operative mentality and a capitalist force capable of reunifying the land of Fucino.

PRESENT WATER DEMAND AND CONSUMPTION

Until about 1950, the demand for water for agriculture and domestic use was very limited and covered by flows in canals, runoff and especially by numerous piedmont springs (Burri & Petitta, 1999). In the 1950s and 1960s, to meet the demand for agricultural development, the Fucino Development Agency (now ARSSA, “Agenzia Regionale per i Servizi di Sviluppo Agricolo”, Regional Agency for Agricultural Development) bored about 200 wells, part of which are currently exploited by land owners in periods of water shortage. The most important wells, some of which are artesian, have been directly exploited by ARSSA since 1989, with a view to keeping the minimum in-stream flow in the canals, thereby preventing their drying-up and related consequences (Fig. 2).

Consumption by agriculture is concentrated in the period from May to September. Water is withdrawn from surface canals by pumping, i.e. with mobile pumps connected to tractors. Both ARSSA and the Land Reclamation Consortium (having jurisdiction over irrigation matters) abstract groundwater from well fields and feed it to the network of canals, where it is withdrawn by consumers.

Fig. 2 Hydrogeological map and water management of the Fucino Basin: (1) main springs; (2) main streambed springs; (3) public irrigation well-fields; (4) drinking water well-fields; (5) Plain aquifer; (6) fan and detrital deposits connecting carbonate aquifers to the Plain aquifer; (7) ancient alluvial deposits, constituting an aquitard; (8) terrigenous deposits representing the regional aquiclude; and (9) carbonate aquifers (recharge area of springs) (from Burri & Petitta, 2004).
Local water resources are also exploited by a third consortium (the Aqueduct Consortium) for domestic use. Recently the development of industrial settlements (Avezzano Industrial Consortium) has required additional amounts of water and these have been covered by diversions from streams. In future, they will be met by a new well field (expected to become operational soon).

The overlapping roles of the different water management authorities and uncontrolled abstractions from canals and often from unauthorized wells, make it extremely difficult to compute the total water consumption and, above all, to distinguish between the consumption of naturally available water and of groundwater. As a consequence, it is very hard to determine the actual extent of abstractions.

A quantitative assessment of discharge and abstractions was carried out on the basis of recent research (Burri & Petitta, 1998). The collected data point to a progressive decrease of the total discharge through the outlets from the Fucino basin since the 1960s (Fig. 3). The total discharge of the Fucino basin, measured in the main canal, amounts to 6 m$^3$ s$^{-1}$ year$^{-1}$ on average. However, this value has declined significantly in recent decades, passing from a yearly average of 7 m$^3$ s$^{-1}$ in 1968–1987 to as little as 3.3 m$^3$ s$^{-1}$ in the 1988–1998 decade (with a minimum of 1.5 m$^3$ s$^{-1}$ in 1990). The summer (June–September) values shrank from 4.4 m$^3$ s$^{-1}$ in 1968–1987 to 0.9 m$^3$ s$^{-1}$ in the last decade, i.e. to as little as $9 \times 10^6$ m$^3$ in total over the four summer months.

Actually, during the last decade, the summer discharge in the Fucino basin was almost exclusively sustained by abstractions of groundwater, without which the canals would be practically dry, as happened in 1990. This situation is due not only to the natural decrease of precipitation in different parts of central Italy (Dragoni, 1996), but also to the increased water requirements for irrigation (more intensive farming and more water-demanding crops).

Until the mid 1980s, the water pumped from wells and used for drinking (Marsica Aqueduct Consortium) was limited to $1 \times 10^6$ m$^3$ year$^{-1}$ ($0.4 \times 10^6$ m$^3$ in the summer quarter).

![Graph](image)

**Fig. 3** Monthly water levels of the Fucino outlet (Incile) from 1960 to 1991: the negative trend is shown.
At present, this abstraction is in the range of $10 \times 10^6 \text{ m}^3 \text{ year}^{-1}$, of which at least 4 are in the summer quarter; additional volumes are expected to be pumped in the current season. ARSSA abstracts about 500 $\text{l s}^{-1}$ from its well fields, but only during the irrigation season (1998: 23 June–31 August), when the canals may dry up owing to high water consumption by farmers (ARSSA, 1988–2003). Since 1989 (when pumping of water from the subsoil started), water abstractions have risen from $<1 \times 10^6 \text{ m}^3 \text{ year}^{-1}$ in 1997, to the present figure of $2 \times 10^6 \text{ m}^3 \text{ year}^{-1}$. Furthermore, from May to September, the Fucino Land Reclamation Consortium abstracts about 200 $\text{l s}^{-1}$ from the Giovenco River and about 250 $\text{l s}^{-1}$ from its well fields (about $0.7 \times 10^6 \text{ m}^3$ per season in total). The activity of the Consortium is expanding rapidly and approximately $4-5 \times 10^6 \text{ m}^3$ are planned to be abstracted from new wells, some of which have been in operation since 1999.

Hence, total groundwater usage exceeds $6 \times 10^6 \text{ m}^3$ per summer season. In practice, water requirements for farm crops and drinking uses have reached and exceeded the amount of water naturally available in the canals. Under these circumstances, the continuing increase of abstractions, especially of groundwater, causes an environmental problem. This problem has not yet reached the level of an emergency. However, given its future implications, this level must soon be reached and, consequently, it must be adequately addressed.

Figure 4 summarizes the above data, showing the trends of summer precipitation, potential evapotranspiration, abstractions from wells, theoretical water requirements by farm crops and the spring discharge during the past decade. Clearly, owing to the decreasing precipitation, especially in summer, and to the sharp increase in the use of crops which need more water, groundwater abstractions are not sufficient to cover water demand. The problem is compounded by losses by evapotranspiration, owing to the use of obsolete sprinkler irrigation systems.

![Fig. 4 Trends of the variables affecting water resources in the Fucino Plain: (A) summer evapotranspiration; (B) summer rainfall; (C) agricultural water requirements; (D) abstractions from wells for agricultural use; (E) summer spring discharge.](image-url)
Again the solution of the "Fucino Issue" has been directed towards the water sciences, in a new perspective: the past abundance of surface waters has been changed into a groundwater shortage.

CURRENT AND FUTURE ISSUES

Some issues concern the water supply and thus fall under the responsibility of the various water management authorities. In the irrigation season, abstraction of groundwater is intense and concentrated at the margins of the Plain, in the wells bored in the carbonate aquifers. Recharge of the regional aquifer is practically non-existent and the discharges in the canals are scanty owing to drought, pumping from wells and abstractions by farmers. The intense farming activity may release pollutants into the soils of the Plain. These pollutants may be entrained by the irrigation waters and reach the canals and as far as the Incile River and then flow into the Liri basin. The pollutants may also infiltrate into the aquifer below the Plain and reach the wells lying at its margins, if their piezometric surface falls below the piezometric level of the Plain. The first findings from the relevant investigations indicated that pollution of groundwater is low with respect to the more significant pollution episodes which have been recorded in surface waters (Petitta et al., 2003).

Especially at the southern margin of the Fucino Plain, abstraction of groundwater decreased the discharge or, in many cases, caused the disappearance of natural springs. Piezometric levels in the wells showed a general decrease, as against the 1970s; these levels have been continuously monitored since 1998 (Fig. 5), in order to determine variations, whether of natural origin or induced by seasonal pumping. At present, after an improvement in 2000–2001, piezometric levels are sharply dropping, also owing to climate conditions (Burri & Petitta, 2004). Currently, after a period of rise in 2000–2001, water levels are falling, because of abstractions and climatic changes.

Fig. 5 Water table monitoring at the southern border of the Fucino Plain (Trasacco well field, see Fig. 2 for location). Water level changes during the year show the aquifer recharge period from January–February to May. Negative peaks identify the summer pumping periods.
Other environmental problems, which also involve nearby areas, cannot be neglected:

(a) Interaction between the carbonate aquifers encircling the Plain and the Quaternary deposits. Groundwater mining in the Plain might result into a generalized depletion of aquifers, also reducing the available of water for springs and streams in the mountain areas (including protected ones), such as the Sirente-Velino Regional Park to the north and the Abruzzi National Park to the south. A similar but more macroscopic case is represented by the high-altitude springs of the Gran Sasso massif, whose discharges dropped significantly as a consequence of underground drainage caused by the Gran Sasso motorway tunnel;

(b) decrease of runoff towards the Liri basin, through the Torlonia canal. This fact might create environmental emergencies owing to the higher concentration of wastewaters, which are released (after being purified) into the Fucino canal network;

(c) inadequate use (massive irrigation) of high-quality groundwater, including groundwater derived from protected areas.

Achieving the target of the correct management of agricultural and water resources in the Fucino Plain questions the current modes of withdrawal and distribution of local water resources and calls for the planning of protection measures. These measures should be paralleled by a revision of the current types of farm crops and the modernization of irrigation techniques.

In conclusion, the final solution of the “Fucino Issue” could be related to different actions, concerning the water sciences:

(a) introduction of modern techniques of irrigation;
(b) regulatory efforts to control water use and the introduction of taxes;
(c) development and operation of a hydrological model to forecast seasonal water availability starting from precipitation and groundwater levels.

This case-history shows the great importance of the water sciences, in terms of scientific knowledge and technical improvements, in order to achieve the correct management of land, both where water is in surplus as a resource and where it is under stress and is a valuable resource that has to be protected.

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