Drainage in Spanish land reclamation projects

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1 Introduction

In 1983 arable land in Spain covered an area of 20.5 million ha, from which approximately 2.9 million were under irrigation (MAPA 1985). Although only 14% of the total cultivated land was under irrigation, production of irrigated land amounted to half of the total agricultural production. Therefore productivity of irrigated agriculture was six times that of dry farming.

These data show the importance if irrigation in Spanish agriculture, and why irrigation was the first water management practice applied in Spanish land reclamation projects. However, land drainage became a need as some irrigated areas were affected by waterlogging and secondary salinization. Moreover, drainage was needed to reclaim problematic soils, since the best lands are nowadays irrigated and to intensify irrigated agriculture, for instance by changing rice fields into horticultural production.

The experience achieved in drainage of heavy soils in the Marismas Plain, salt affected soils in the Ebro basin, and organic soils in polder areas of Eastern Spain is described in this paper. Prospects for draining sandy soils in the Ebro delta and planosols in Central Spain are also indicated. The Spanish river basins are shown in Figure 1, which can be used as a reference map for the forthcoming figures.

2 Drainage of heavy soils in the Marismas

2.1 Natural conditions

The Marismas area is located in the Guadalquivir estuary in Southern Spain. The total area covers 136 000 ha, of which 33 000 ha are irrigated on the left bank by the Lower Guadalquivir Irrigation Canal, 6 600 ha are included in the Almonte-Marismas Project and 30 000 ha are rice fields (Figure 2).

The climate is Mediterranean with Atlantic influence. The rainy season is lasting from October to April with an average rainfall of 570 mm. Soils are fine-textured, with a clay fraction higher than 65%. Soil structure is good in the top 15 cm, the subsurface horizon is prismatic with crack development, and below 60 cm the soil is structureless. Hydraulic conductivity depends on soil structure and therefore decreases with depth; below 70-80 cm the soil is almost impervious. There is a shallow groundwater table which under natural conditions is strongly saline.

Cereals and sugar beet are the main winter crops. Summer crops are irrigated with

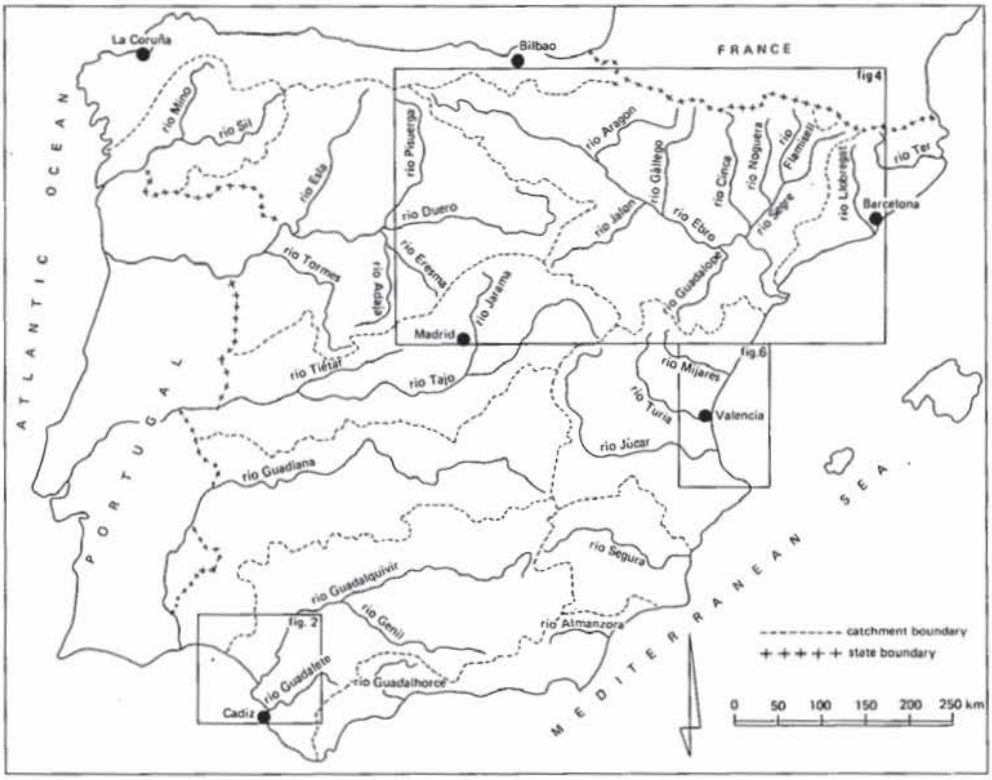

Fig. 1 Spanish river basins

water of good quality by means of furrows, but sprinkler irrigation is used in the earlier growth stages of cotton, which is the main crop.

2.2 The drainage system

2.2.1 Engineering characteristics

On the left bank three polders were reclaimed, protected by a dike to avoid the entrance of surface water. The subsurface drainage system consists of tile drains at spacings of 10 m running with a $1^0/_{00}$ slope at an average depth of 1 m. The laterals discharge in secondary collector drains spaced each 500 m and these into primary collectors constructed at spacings of 2000 m. The main drains discharge in the river through a gate, which is closed at high tide, and also by means of pumping stations (Figure 3).

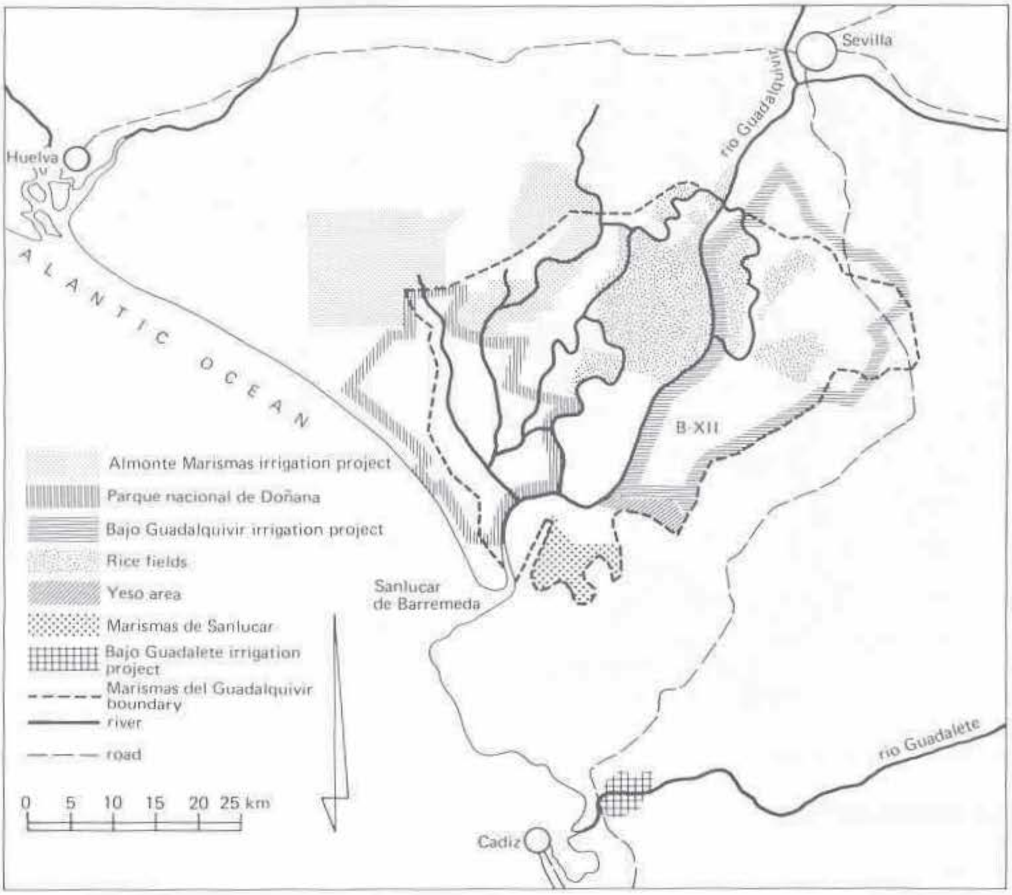

Figure 2 Land reclamation projects in the Marismas del Guadalquivir

Fields drains were laid during the dry season with trencher machines. The trench remained open for some time to allow the spoil to become structured. Thus the backfill is permeable and the entrance of subsurface flow increases in spite of the drain being placed in a layer of low hydraulic conductivity. After drainage subsoiling was carried out to increase topsoil permeability.

Drainage with trenchless machines was experimented with unsatisfactory results, probably because the pipe was installed in a layer of very low permeability and no permeable backfill was used to connect the drain with the upper layers of the soil profile. In 1978 the relation between drainage costs with trenchless machine and with trencher machine was 0.75.

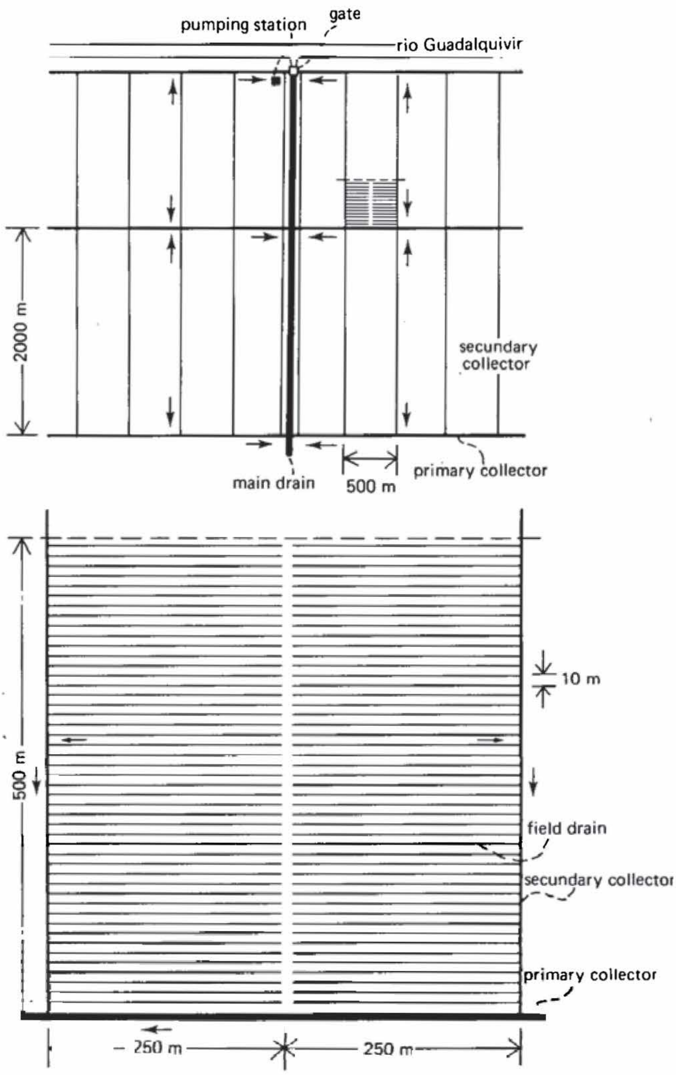

Figure 3 Drainage system in B XII of the Lower area

2.2.2 Drainage materials and costs

Drainage costs for both PVC and clay tiles are shown in Table 1. Since the cost difference is small, clay pipes were preferred by farmers because of their greater diameter. Therefore, only 600 ha have been drained with PVC.

Table 1 Drainage costs in pesetas per ha in 1985*

	PVC Ø 50 mm	Clay Ø 80 mm
Drainage machines (220 m/h)	52864	56697
Labour cost	10761	14899
Pipe (1000 m) and lateral outlets	47000	43000
Filling of the trench	1481	1481
Subsoiling	7000	7000
	119106	123077

* Average currency rate in 1985: US$ 1.00 = 170 pts

2.2.3 Maintenance and costs

Operation and maintenance of an irrigation area of 14 000 ha is the responsibility of a division of the Bajo Guadalquivir Water Management Organization. Maintenance of collector and main drains is done on demand of individual farmers every two or three years; on average the annual cost is 1000 pts/ha. Mean annual pumping costs, including operation and maintenance of the pumping stations, are 1050 pts/ha.

2.3 Drainage system evaluation

Since 1983 the drainage system in Sector B-XII is being evaluated, as the farmers demand drain spacings of 5 m that would allow a faster desalinization. It was also monitored on an experimental farm on the right bank from 1972 to 1974.

Field observations show that during winter and the irrigation season in summer non-steady state flow conditions occur. Before a water application the water level is just above the drain depth, and discharge is negligible because drains are located in a layer with low hydraulic conductivity. After a watering the watertable rises everywhere to the toplayer. Then water flows directly through the drain trench and through the permeable layer. During tail recession the drawdown observed in piezometers agrees fairly well with that obtained by applying the Boussinesq theory. In areas where drip irrigation is used, steady state conditions occur; the drain discharge is very low due to the low hydraulic conductivity of a soil that is kept continuously wet.

Drainable pore space and hydraulic conductivity depend on crack development in the horizon with prismatic structure. If cracking is obtained by means of sound water management, the hydraulic conductivity varies from 0.4 to 0.6 m/d in the upper 65 cm and the pore space decreases with depth from 0.03 to 0.01. Where the soil is closed due to continuous wetting, the hydraulic conductivity is low from the soil surface downward (from 0.1 to 0.05 m/d).

If the hydraulic conductivity is kept at about 0.5 m/d, a drawdown of the watertable from the soil surface to 30 cm occurs in one day and to 50 cm in two days. Below this depth tail recession is very slow; nevertheless the water level is close to drain depth before the next water application. These conditions are suitable for summer crops, and they can be used as non-steady state drainage criteria.

During winter surface run-off after heavy rainfall is rapidly discharged by surface drains if the land has been smoothed.

No silting up was observed in drains after several years of service if they were properly installed and the tile outlets were maintained clean. There were no differences in performance between PVC and clay pipes besides a difference owing to the diameter.

The main maintenance problem is bank erosion when surface run-off flows directly towards the ditch instead of flowing through a surface pipe. If erosion occurs, water flow through the collector is impeded, the water level rises above the outlets of the laterals and the whole system does not work. Besides, where saline shrubs (suaeda fructicosa) grow on the ditch banks, very fine roots enter the pipe and clog the lateral.

In summary, the key points to keep the system working are firstly to maintain the hydraulic conductivity of the soil by introducing winter cereals in the crop rotation, which allows periodical subsoiling, alternate wetting and drying and maintaining hydraulic conductivity. Secondly, to keep the tile outlets clean and to avoid water losses due to surface run-off during the irrigation season, which increase the irrigation efficiency.

2.4 Prospects for the future

The findings obtained from the drainage evaluation of Sector B-XII were divulgated through the water management organization resulting in a conspicuous improvement of the water management in this sector. This achievement encourages continuous monitoring of presently drained lands. An increase of the irrigated acreage on the left bank depends on water saving achieved by improving the water management in the presently irrigated areas. So the Marismas de Sanlucar Project, which has already been drained, could be finished. On the right bank new reclamation projects are not foreseen since there is a need to preserve the Coto de Doñana wildlife park (Figure 2).

However, there is a need to improve leaching of non-irrigated soils that allows the cultivation of winter crops. For that purpose a cheaper drainage system is required, since the present cost of a standard drainage system is only economically feasible for irrigated soils. For this reason a mole drainage experimental programme has been carried out. Only results of one year of experience are available but they are very promising. If they are confirmed in the next years, mole drainage will be applied on non-irrigated soils of the Marismas.

3 Drainage of salt affected soils in the Ebro basin

3.1 Hydrological and soil conditions

The Bardenas – Alto Aragón irrigation scheme uses the hydraulic resources of three

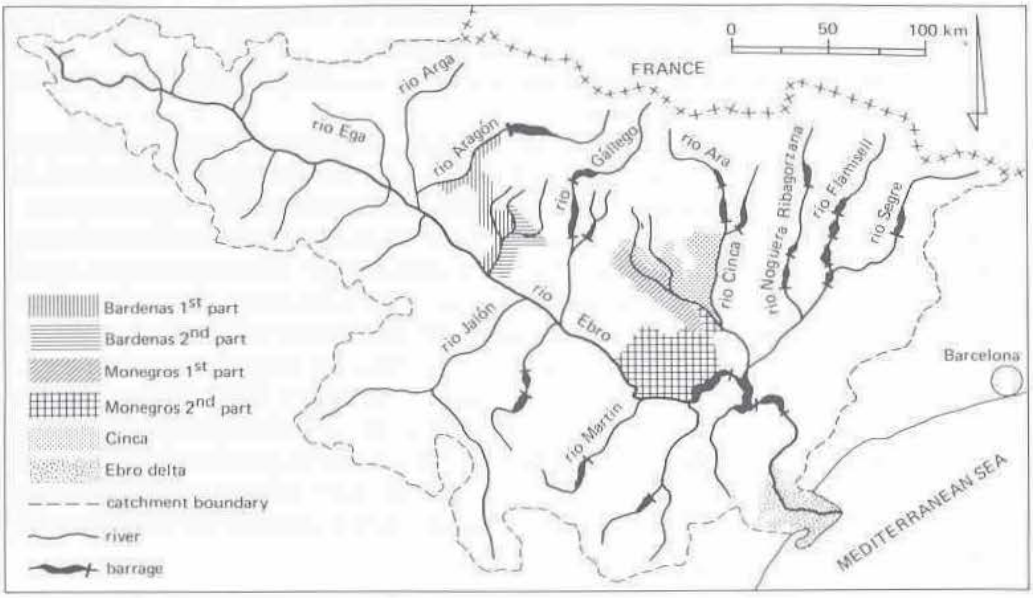

Figure 4 The Bardebas.Alto Aragon irrigation project

main tributaries of the Ebro river along its middle reach. The project includes a total area of approximately 260 000 ha (Figure 4).

About 90 000 ha of the presently irrigated area are affected by salinity, although irrigation water is of good quality. Primary salinity is inherent to soil parent materials derived from Tertiary saline rocks. Besides, secondary salinization occurs due to the existence of saline groundwater, recharged in part by seepage from adjacent uplands (Martínez Beltrán 1978).

Drainage requirements depend on topographical, hydrological and soil conditions which are closely related to the geomorphology of the region.

There are fluvio-colluvial valleys and alluvial plains with silty clay soils, where hydraulic conductivity decreases with depth down to an impervious layer located at a depth between 1 and 1.5 m. In these soils there is a shallow groundwater table recharged by rainfall, irrigation and seepage from the surrounding hills (Figure 5).

There are also silty loam and silty clay loam alluvial soils with a very fine stratification in the subsurface layer. Internal drainage is impeded since hydraulic conductivity for vertical flow is almost zero. Sometimes coarse alluvium is present underneath the stratified layer. There is not a continuous water body but discontinuous confined aquifers in the coarse deep layers. Rainfall or irrigation water remains on the soil surface until it evaporates and surface run-off is common even on levelled soils (Figure 6).

Between residual mesas, situated in the highest position, and low-lying valleys and plains, transitional glacis occur. Slopes are eroded in their upper part and the saline

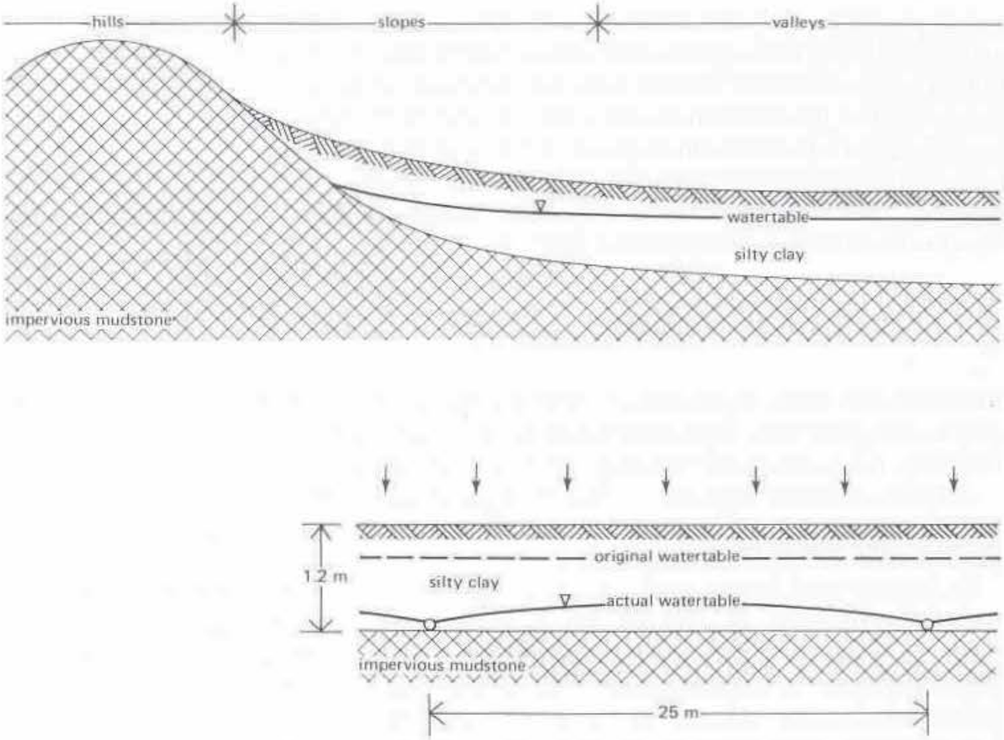

Figure 5 Subsurface drainage in fluvio-colluvial valleys and plains

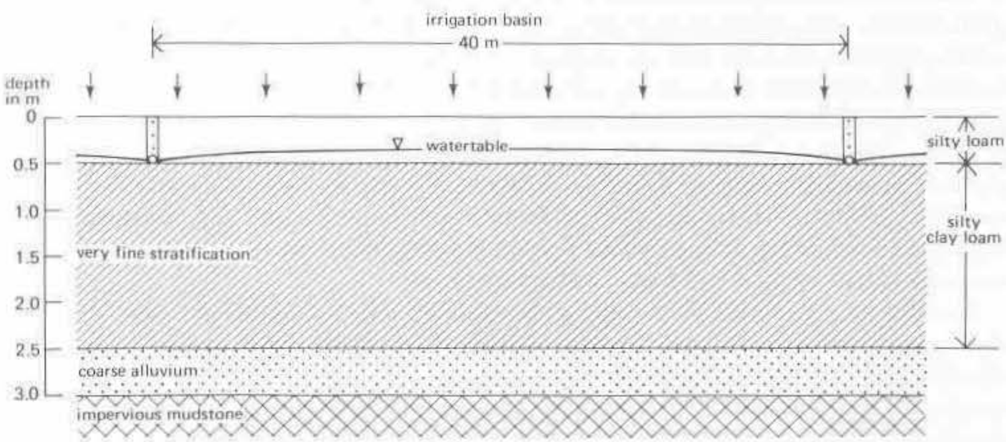

Figure 6 Alluvial soils with restricted internal drainage

and impervious sediments reach the soil surface. The soils become gradually colluvial in the middle and lower parts of the slopes. Under natural conditions there is no indication of a real watertable in these soils, but only local seepage coming from the adjacent mesas where a perched watertable is present during the irrigation season. Where land levelling has caused the outcropping of fine-grained sediments, the surface layer becomes saline and impervious and leaching is extremely difficult. Moreover, natural drainage is altered and local seepage occurs from the upper irrigated basins to the lower ones when water is applied (Figure 7).

3.2 Present drainage systems

The soils with saline groundwater table are drained by means of open ditches spaced on an average at 50 m. This system matches drainage requirements for barley irrigated in spring, but is unsuitable for irrigated crops such as lucerne and maize.

Alluvial soils with impeded internal drainage remain undrained. Salinity is still high because water percolation and leaching is restricted to the topsoil improved by subsoiling. Therefore soil productivity is very low.

In sloping lands of the Monegros area where levelling altered natural drainage, a reclamation project was carried out in the late seventies. An expensive composite drainage system was laid out with 2 or 3 laterals per irrigation basin and a collector pipe running in the slope direction. The design of this system was based on drainage principles for flat areas with an extensive aquifer. Monitoring of the drainage system has shown that only those drains which intercept local seepage, work, but the laterals laid in the impervious layer usually run dry.

3.3 Drainage solutions

A subsurface drainage system was evaluated on an experimental field established on alluvial soils with a saline watertable (Figure 5). The results obtained after four years of investigation showed that spacings of 25 m for tile drains laid on the impervious barrier are sufficient to lower the watertable rise of about 0.7 m caused by irrigation losses in about 12 days between two consecutive waterings. After 4 days the watertable is deeper than 0.5 m. This system also allows a watertable drawdown in winter from the soil surface to a depth of 0.65 m in about 8 days, which is adequate for winter cereals. After an initial leaching period of nine months moderately salt resistant crops, such as barley and sugar beet, were irrigated. As desalinization continued, less tolerant crops as wheat, lucerne and finally maize were grown.

In a drainage experiment on soils with restricted internal drainage it was observed that water flows directly into the drain trench through the upper layer, in which the stratification was disrupted by levelling and subsoiling. Therefore subsurface drains worked in fact as covered surface drains (Figure 6). There is no deep percolation and therefore no desalinization. Improvement of these soils should be based on deep subsoiling to increase percolation, leaching and desalinization of the top layer. Drainage

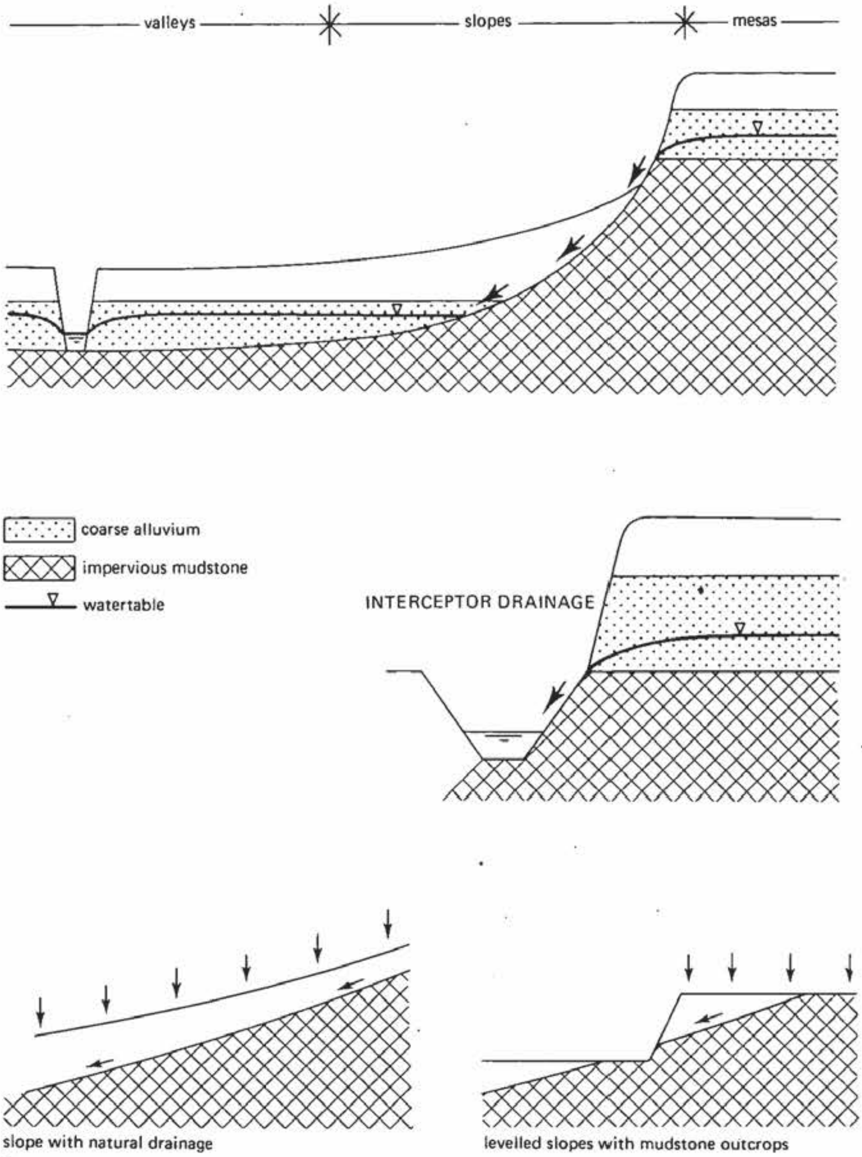

Figure 7 Interceptor drainage on eroded and colluvial slopes

only requires shallow covered tiles to allow interflow through the upper layer disrupted by subsoiling. Since the suitability of these soils for irrigation is limited, they should be excluded from new irrigation projects.

On sloping lands with a saline subsoil selection of a suitable irrigation method such as sprinkling or contour furrows for preserving good natural drainage, in addition to interceptor drainage will prevent secondary salinization of the topsoil (Figure 7). In areas presently levelled a shallow interceptor drain is needed between every two irrigation basins.

3.4 Conclusions

The results obtained from the experimental fields have not been properly diffused. Therefore a link between drainage engineers and water management organizations is urgently needed.

Moreover, drainage costs of levelled sloping lands were in 1978 from 1.75 to 2.25 times those of the Marismas Project. These costs discouraged the farmers and together with the lack of information, these were the major causes why reclamation of saline soils has slowly progressed in the last years.

However, better knowledge of drainage for reclaiming salt affected soils has been helpful in land evaluation surveys to deliminate new irrigation projects, where soils with less salinization hazard were selected.

4 Drainage of organic and sandy soils and polder areas of Eastern Spain

4.1 Natural conditions

In Eastern Spain lowlying areas exist along the Mediterranean coast from Northern Alicante up to the Ebro delta (Figure 8). Here rice was grown in 1982 on 20 000 ha, horticultural crops on about 5600 ha and 6200 ha of former rice fields remained uncultivated and covered by reed (Gil 1982). In the Ebro delta from a total area of 25 000 ha about 15 000 ha are rice fields (Figure 4).

In these coastal areas soil variability is great since sandy soils occur jointly with peat and clay soils, but a watertable is always present. Although rice is the most suitable crop for undrained land, there is a trend to transform rice fields into horticultural production by means of polder development, including irrigation and drainage.

In the Ebro delta a drainage system was designed in 1969. The main drainage network including pumping stations was constructed. Composite drainage systems have been installed on a few farms with drain spacings between 80 and 100 m in sandy soils. A systematic field drainage evaluation has not yet been carried out.

The experience obtained in a pilot polder of 1000 ha will now be presented. The project is situated in a lacustrine formation between a sandy coastal fringe and inland colluvial soils. Most soils consist of a clay toplayer of 40 cm covering a raw peat layer. Underneath a fine sandy layer saturated with water is found at variable depth. This aquifer is semi-confined by the upper layers of peat and clay and is limited by an impervious barrier at a depth between 5 and 15 m. Under natural conditions the aquifer is mainly recharged by seepage from the adjacent highlying areas. Besides surface water enters the area during heavy autumn rainfall, when high water levels occur in the drainage outlets.

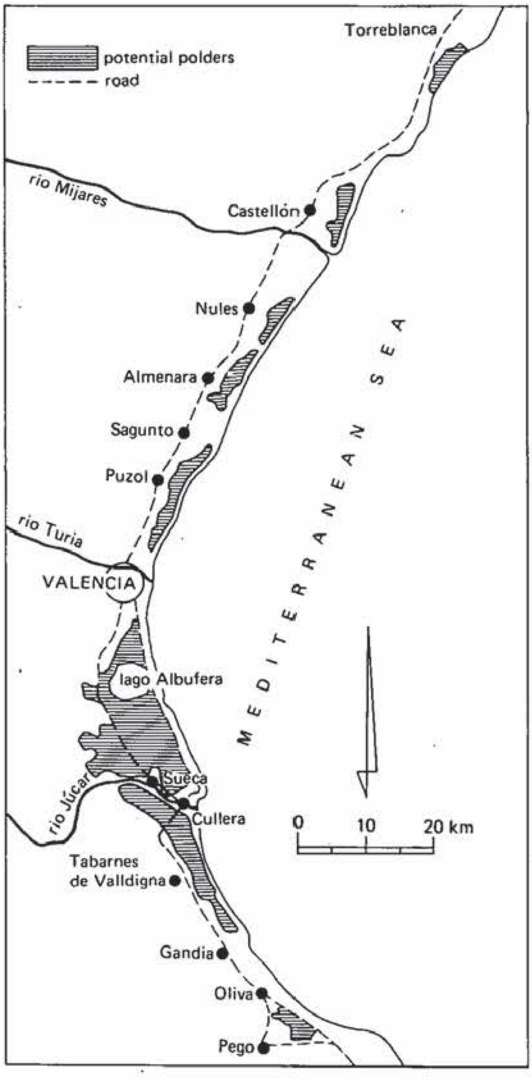

Figure 8 Potential polders in Eastern Spain

4.2 The drainage system

The drainage system consists of primary and secondary collector drains, and two main canals which conduct water towards two pumping stations, from where the drainage flow is discharged into two watercourses (Figure 9). The design discharge of the pumping stations was 60 mm/d which covers the drainage requirement of horticultural crops for a rainfall return period of 10 years.

4.3 Field drainage investigations

The field drainage system has been tested on an experimental plot. The first approach consisted of laterals at 25 m spacings laid at a depth of 1.2 m in the peat layer. This appeared unsatisfactory since many problems occurred to achieve the required pipe slope, and moreover the radial resistance was high, due to the low permeability of the peat. As a result, the watertable depth was unsuitable for the crops.

Entrance resistance was totally eliminated by stabilizing the drain trench with gravel. In order to reduce the radial resistance the drain depth was lowered to reach the sandy permeable layer. With field drains at 50 m spacing laid at a depth of 1.8 m, the watertable remained fairly constant at a depth of 1 m for a steady discharge of about 22 m/d. Transmissivity, experimentally derived with the Ernst equation was about $60 m^2/d$, the aquifer thickness being 8 m and the hydraulic conductivity of the sand 7.5 m/d.

The drainage criterion for steady state flow to be applied in the final design could be a watertable depth of 0.7 m. Then drain spacings could be wider than 50 m if the transmissivity is similar to that of the experimental plot.

It should be noted that estimation of the hydraulic conductivity of the raw peat layer caused a wrong design. The mistake was due to the fact that the hydraulic conductivity was measured by the auger hole method when the watertable was close to the soil surface. Surface flow and interflow towards the auger hole occurred and the water level rose very fast, not corresponding with the permeability of the peat. Measurements made later at lower watertables gave results in accordance with the value of 0.09 m/d that was derived from the relationship between hydraulic head and discharge on the experimental plot.

4.4 Prospects for the future

Future drainage development in these coastal areas will depend on the trend to convert present rice fields into horticultural projects and on the tendency for conservation of wet areas presently uncultivated.

In the Ebro delta a programme of field drainage evaluation under different soil conditions is being scheduled and results are expected for the next year.

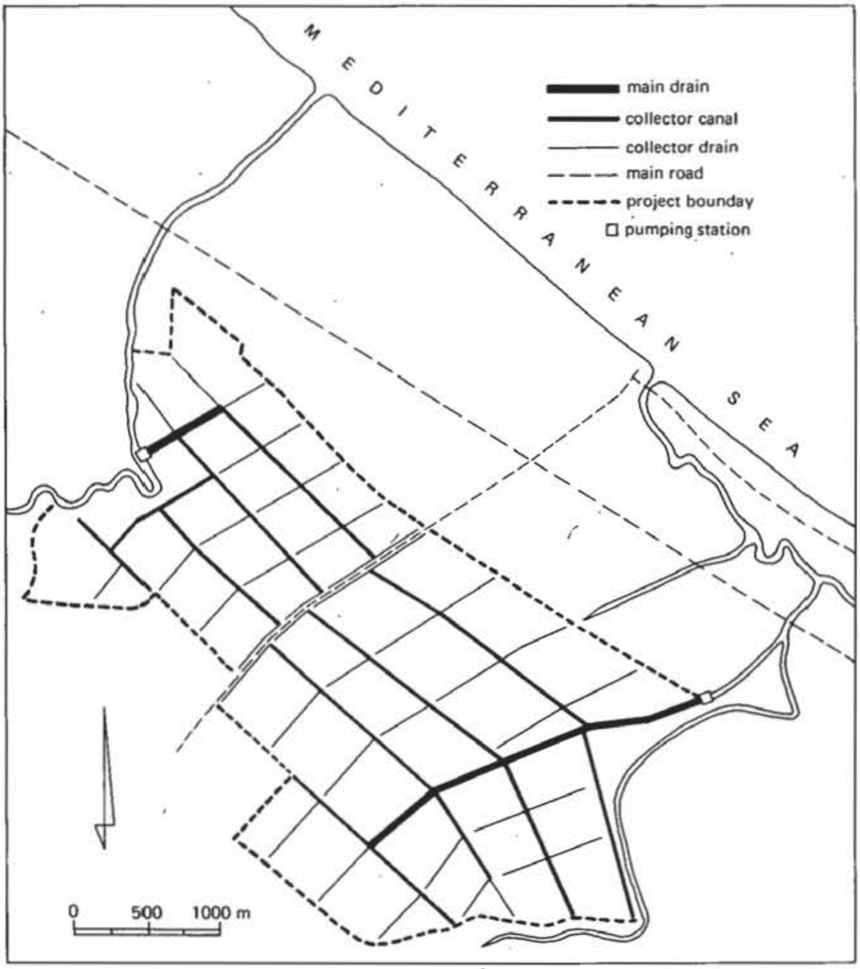

Figure 9 Drainage system in polder area Pego-Oliva

5 Programme for draining planosols in Central Spain

The Tiétar river is a Tajo tributary which is located in Central Spain south of the Gredos Mountains (Figure 1). In the Tiétar basin there is a great plain where planosols and sandy soils with a gentle slope occupy about 150 000 ha.

In this area winter crops cannot be grown due to a perched watertable on an impervious clay layer. In summer tobacco and asparagus are grown in the deepest planosols by irrigating with water from the Tiétar river.

If no drainage facilities are provided, salinity problems are expected in new irrigation projects, where water from the Tajo river will be used. Moreover, the drainage of planosols can increase the agricultural production of this region by growing winter crops in areas with a more favourable texture of the topsoil.

Therefore, next year drainage investigations will start in this plain, once soil surveys have been completed.

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