To the Graduate Council:

I am submitting herewith a thesis written by Gilles Michel Thèret entitled "Irrigation and Agricultural Development in the Crau of Southern France." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

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IRRIGATION AND AGRICULTURAL DEVELOPMENT
IN THE CRAU OF SOUTHERN FRANCE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Gilles Michel Théret

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To My Friend

Renaud Dyèvre

(1955-1974)

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I would like to express my sincere gratitude for the guidance and support offered by Dr. Theodore Schmudde who served as my major professor and had to deal with my numerous successive drafts. Thanks are also extended to Dr. John Rehder and James Carter for their critical reading of the document and helpful suggestions.

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ABSTRACT

The natural environment of the Crau of southern France is a plain covered with stony, porous soils and the climate has a long dry summer. This study is an investigation of the process that overcame the natural liabilities of drought and poor soils to make the Crau into an area of productive agriculture. The historical development of irrigation is investigated along with the corresponding agricultural practices, the water management techniques, the role of private and public financing and the ecological consequences.

Although it was not his primary goal, irrigation was first developed by Adam de Craponne who diverted the Durance River waters for water power. From that beginning, the water and silt of the Durance River have been used to develop the Crau. The silt sediment of the Durance River waters was used by farmers to create soils on their land (warping) and transform them into productive areas. The Crau was so successful that other areas along the lower Durance River turned to irrigation. This lead to the appearance of periodic summer droughts early in this century because the natural summer flow of the Durance was inadequate. To solve this problem, the Durance River was regulated by a series of reservoirs and canals built after World War II and financed by the national government. The result has been a guaranteed water supply adequate to meet current and expected irrigation demands of the Crau.

Hay production combined with sheep raising was the traditional agricultural system of the Crau and is still dominant. However, a decline in hay production occurred with the loss of the Algerian market after

after its independence in 1962. In this same period displaced French nationals from Algeria as well as fruit and vegetable growers from nearby cities took up land in the Crau and introduced new irrigation techniques, such as spray and drip, and new types of agriculture. Spray and drip irrigation could not use the water from the Durance River with its high silt content and so farmers using these practices turned to the clearer water available in the ground. These new irrigation practices were more costly, but they used small areas much more intensively to compensate.

Today the Crau is one of the richest agricultural regions of the country because it produces earlier than any other region. However, the development of the new techniques created a new equilibrium which may have negative effects. Due to the regulation of the Durance River much of the silt is deposited behind the dams and building better soil by warping is no longer possible. There is also a concern that the more intensive use of clear groundwater may leach the soils created by four centuries of silt deposition associated with gravity irrigation.

Though there currently is an overabundance of water in the Crau, there is little additional land available to be developed even if there were sediments for warping. The present agricultural system is still largely tied to the production of hay and its sale to horse racing teams and should retain its importance as long as hay sells for a high price.

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CHAPTER I

INTRODUCTION

Water availability conditions the possibility of human life in a given area. Agricultural, industrial and domestic activities are impossible without water. Because human activities often developed in periodically or permanently dry areas, water management is a necessity in many areas. The Crau Plain of southern France is such an area.

The Crau Plain is a nearly flat surface covered with stones and stony soils and the climate is Mediterranean with a dry summer and a moist winter. Yet today about half of the Crau is a rich agricultural region as a result of four centuries of irrigation and other improvements associated with irrigation development. Management of irrigation water has evolved from simple gravity flow to spray and drip irrigation that uses both surface and ground water. Accompanying these changes have been importation of silt and nutrients from the Durance River basin, soils modifications, rising water tables, and in places, water logging of land.

Statement of Problem

The purpose of this study is to describe the development of irrigation, land modification and agriculture in the Crau. This includes a review of the historical development of gravity water irrigation, the recent development of spray and drip irrigation techniques, and the control of the water supply in the Durance River Basin. The role of the public and private financing of irrigation and water management systems, the development of agriculture and the ecological consequences of irrigation are also investigated.

Study Area

The Crau is a plain adjacent to the lower Rhône Valley in the South of France (Figure I-1 & I-2). Its limits are the Alpilles Chain to the North, the Arles-Fos-sur-Mer Waterway to the West, the marshes and salty lakes located along the Mediterranean Sea to the South and the first slope of the Prealps west and north of the Lake of Berre to the East. It has a triangular shape and covers about 55,000 hectares. The Rhône River lies along the western edge of the Crau and the Durance River, which is north of the Alpilles Chain and at a higher elevation than the Crau Plain, is accessible through the Lamanon Pass (Plate I).

The topography of the Crau can be characterized as a nearly flat plain sloping gently from Lamanon Pass southwestward. From Lamanon to the Arles-Fos-sur-Mer Waterway the elevation drops from 107 to 2 meters over a distance of 30 kilometers. Geologic studies show that the Crau is an alluvial fan built by the Durance River during a time when it passed through the Lamanon Pass. The fan deposits cover Rhône River alluvium and other earlier deposits.

On the geologic map one can detect the evolution of the Durance River from the pre-Riss to Würm, prior to its present location (Figure I-3). These three geologic ages are represented in weakly developed or immature soils constituted as follows:

- A horizon - medium and large size gravels constitue 40 to 70 percent of the volume; clay and sand are the other textures, and the soils are poor in calcium and minerals.

- B horizon - a hardpan layer, usually 40 to 80 centimeters in thickness, but may be as much as 15 meters thick in

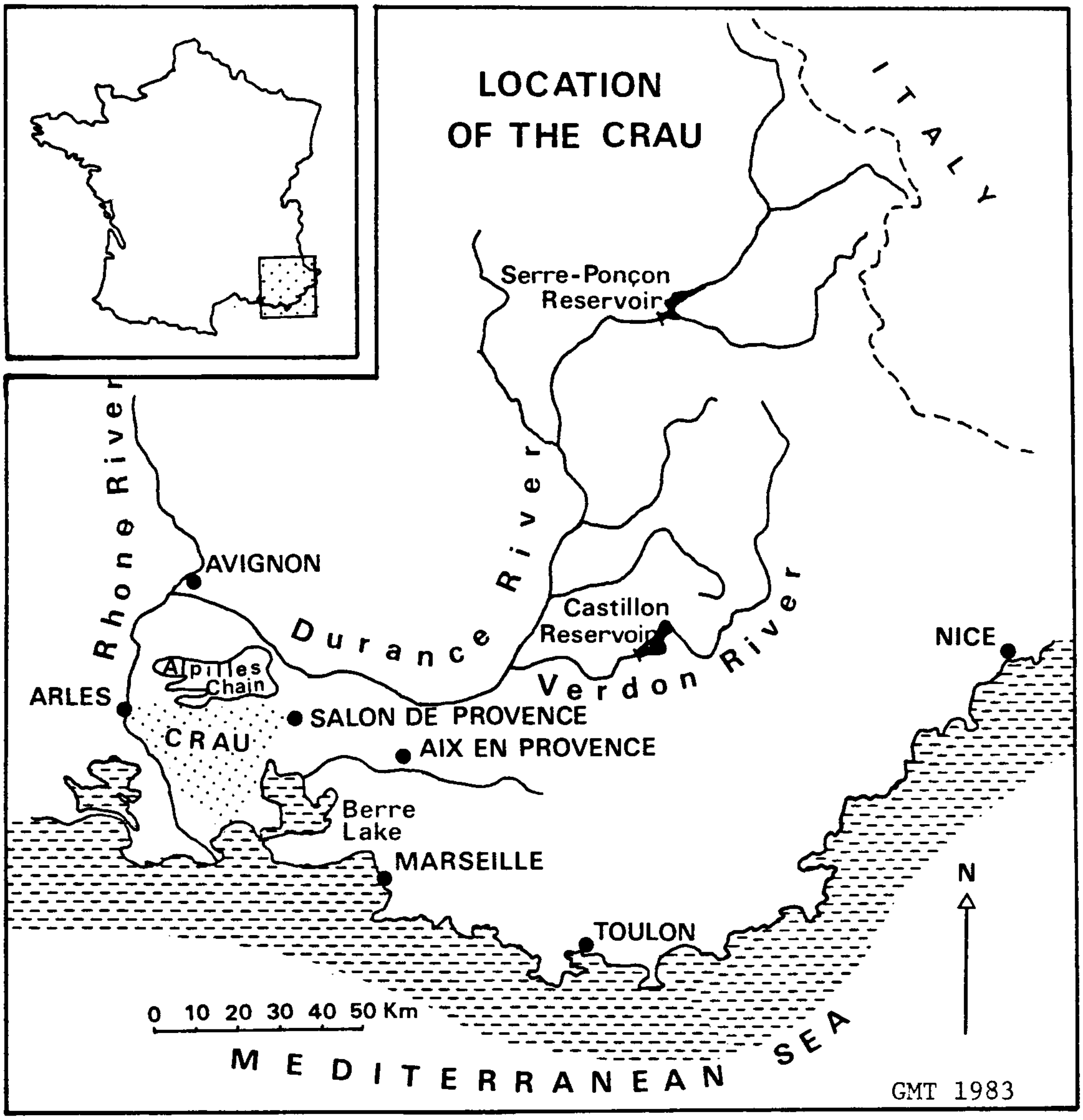


Figure I-1. Location of the Crau.

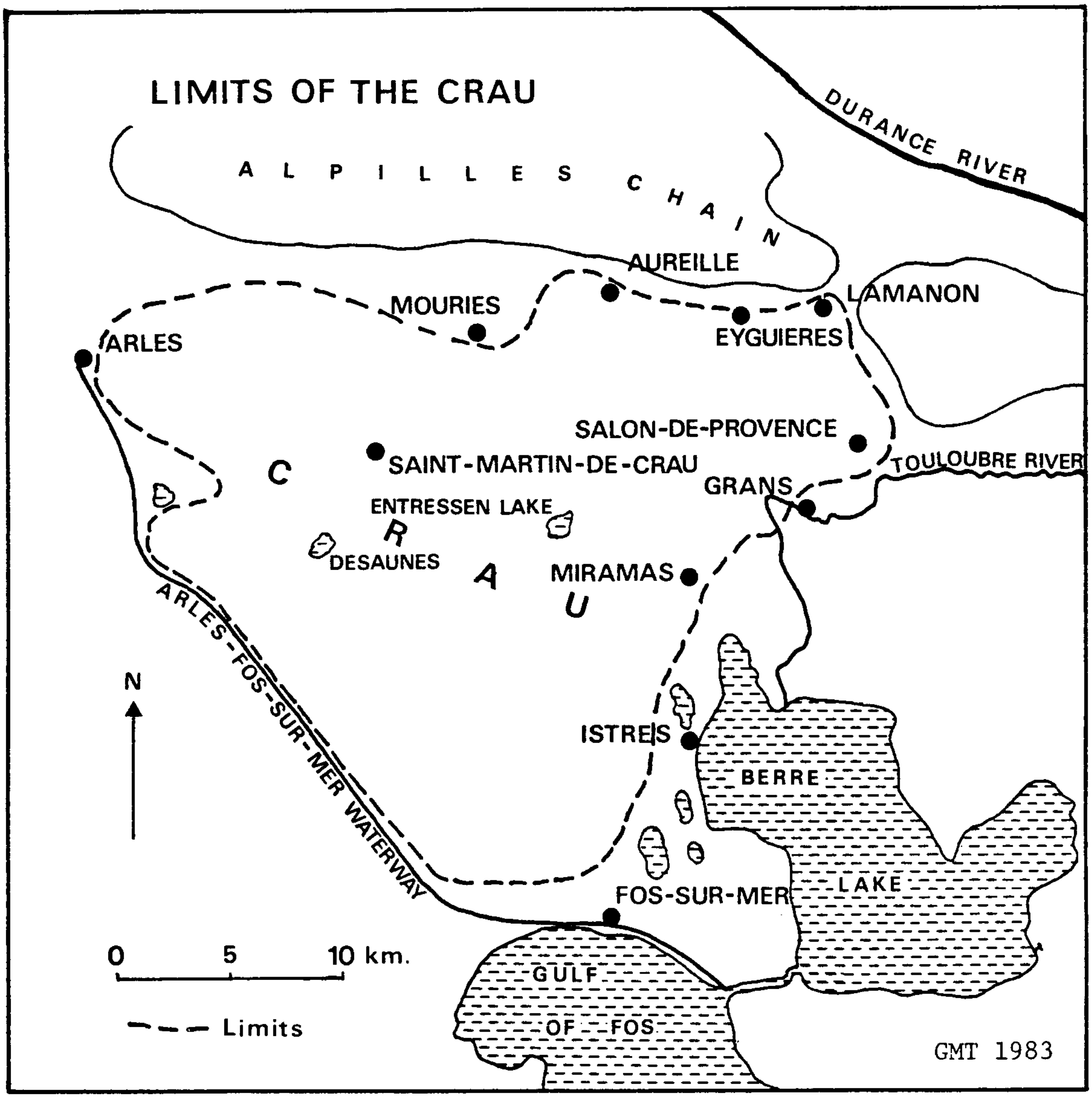
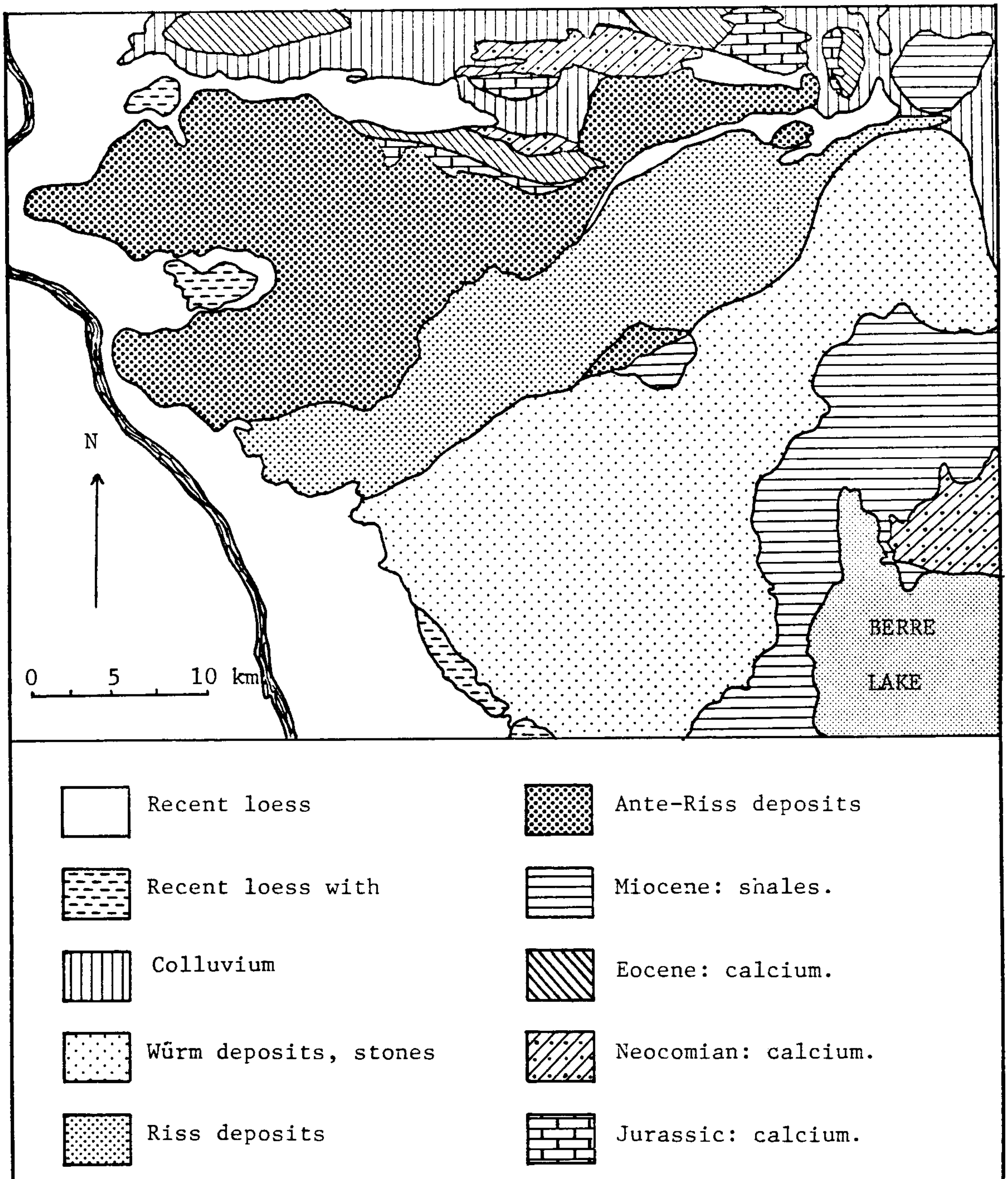


Figure I-2. Limits of the Crau.



Source: Carte Géologique de Marseille au 1/250,000 of the Bureau de Recherches Géologiques et Minières.

GMT 1983

Figure I-3. Geologic Map of the Crau.

places. Excepted when fractured this hardpan is quite impermeable.

- C horizon - Miocene deposits consisting mostly of gravels and some shales.

It is generally accepted that the hardpan was formed from precipitates of calcium and other minerals leached from the A horizon. When not fractured the hardpan blocks downward percolation and upward movement from the ground water.

The A horizon has a low water holding capacity, and infiltration water is mostly diverted laterally by the hardpan. Such flow may create water logged surface soils where the hardpan is close to the surface. The seepage that makes its way through the hardpan goes into the water-table laying in the C horizon, 10 to 40 meters deep.

Like much of the Mediterranean Coast of France, the Crau has a dry summer and a relatively mild winter. (Table I-1). From mid-June to October, the weather is dry and hot, and by the end of the summer all non-irrigated vegetation, except green oaks and olive trees, are dessicated by the sun and wind. A water budget analysis of climatic data for the nearby Marseille-Marignane-Airport shows a yearly water deficit of 34.5 centimeters concentrated from mid-June to early October (Figure I-4). Runoff is only generated during winter and spring, and soils moisture is depleted by mid-June. Summer rainfall is generated during thunderstorm and does not occur every year.

Located in the axis of the Rhône Valley, the Crau is in the path of Mistral winds. The Mistral usually blows from the North-North-West or

Table I-1. Climatic Table for Marseille-Marignane-Airport

Latitude 43°27′N, longitude 5°13′E, elevation 3 m

Month	Mean sta. press. (mbar)	Mean daily temp. (°C)	Mean daily temp. range(°C)	Temp. extremes(°C) highest	Temp. extremes(°C) lowest	Mean vapor press.[2] (mbar)	Mean precip. (mm)	Max. precip. 24 h[1] (mm)	Mean evapor.[2] (mm)
Jan.	1016.2	5.5	8.5	20.0	−10.7	7.0	43	48	
Feb.	1015.3	6.6	9.4	21.9	−16.8	7.1	32	81	
Mar.	1014.6	10.0	9.9	24.0	−10.0	8.7	43	80	
Apr.	1014.1	13.0	10.3	28.5	− 2.4	9.6	42	47	147
May	1013.8	16.8	10.7	33.0	− 0.0	12.3	46	45	176
June	1015.3	20.8	11.4	36.0	5.4	15.2	24	55	223
July	1015.1	23.3	11.8	39.0	7.8	16.6	11	26	276
Aug.	1014.8	22.8	11.3	36.6	8.6	17.0	34	46	241
Sept.	1016.3	19.9	10.4	34.3	1.0	15.6	60	68	175
Oct.	1016.0	15.0	9.4	30.2	− 2.2	12.3	76	86	125
Nov.	1015.5	10.2	8.7	22.8	− 5.4	9.6	69	44	
Dec.	1015.7	6.9	7.9	20.2	−12.8	8.3	66	46	
Annual	1015.2	14.2	10.0	39.0	−16.8	11.6	546	86	

Month	Number of days with precip. >0.1 mm	Number of days with thunder-storm[2]	Number of days with fog[2]	Number of days with gale[2]	Mean cloudi-ness[2] (oktas)	Mean sun-shine[1] (h)	Most freq. wind dir.[2]	Mean wind speed[2] (m/sec)
Jan.	8	0.6	2.0	6	4.6	134	NNW	4.0
Feb.	6	0.8	2.1	7	4.5	157	NW	4.3
Mar.	7	0.7	1.2	8	5.1	208	NW	4.6
Apr.	6	0.9	0.1	8	4.4	251	NNW	5.2
May	7	1.3	0.1	6	4.4	281	W	4.6
June	4	1.9	0.1	4	4.1	323	NW	4.8
July	2	1.5	0.3	5	2.5	368	W	5.0
Aug.	4	3.2	0.3	4	3.3	324	NW	4.4
Sept.	6	3.0	0.5	5	4.0	253	W	4.0
Oct.	8	2.5	0.9	6	4.8	191	NW	3.9
Nov.	8	0.6	1.9	6	4.9	151	NW	4.1
Dec.	10	1.3	2.5	8	5.1	123	E	4.2
Annual	76	18.3	12.0	73	4.3	2764	NW	4.4

[1] Period 1946–1960.
[2] Period 1951–1960.

Source: Lansberg, 1970, p.189.

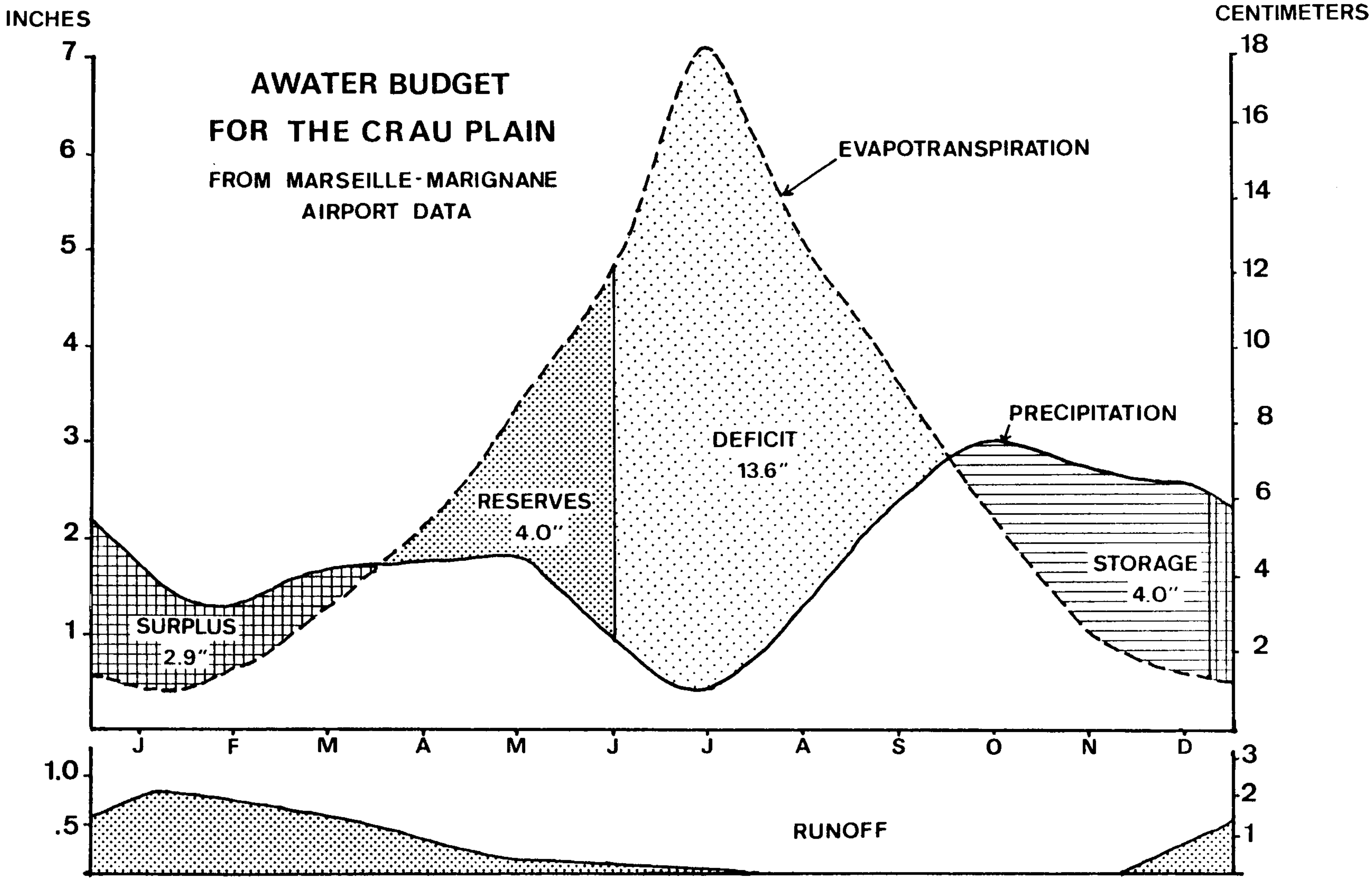


Figure I-4. A Water Budget for the Crau Plain.

North-West in strong gusts. Table I-1 shows a yearly average of 73 days of gale in Marseille-Marignane-Airport. The Mistral may blow year round and dessicates plants in a matter of days. It dries hay in 24 hours according to the farmers of the Crau.

An asset of the natural condition of the Crau is the 2764 hours of sunshine it receives every year, but the study of 2 Landsat image (E-2182-09451 generated on July 23, 1975) shows a different Crau than the one suggested by its natural environment (Figure I-5 and I-6). The bright areas on band 5 image (Figure I-5) are unmodified stony surfaces; the marshy areas of western Crau are dark grey, along with the forested areas; and cultivated areas are light or medium grey. Forested areas are dark grey on band 7 image (Figure I-6) while cultivated areas are light grey; stony areas are dark grey. Both band 5 and 7 images show large uniform areas which suggest that landuse in the Crau is less fragmented and diverse than in surrounding regions.

Human activities in the Crau have traditionally been agricultural and today about half of its area is irrigated, mostly in the northern Crau (Figure I-7). The southern half is mostly in Government ownership for such uses as Istres Air Force Testing Center, Miramas Army Depot, Vergière Explosive Stockpile and Dynamite National Explosive Factory. The southern tip of the Crau is being developed into an industrial zone.

For centuries, the population of the Crau was mainly a native one with very few newcomers, but the end of the Algerian war (1954-1962) brought a flow of "Pieds-Noirs" (Europeans born in Algeria) back to France and a significant number of them settled in the Crau. These newcomers from Algeria did not adhere to the traditional agricultural

Figure I-5. Enlargement of Landsat Image E-2182-09451 Band 5.

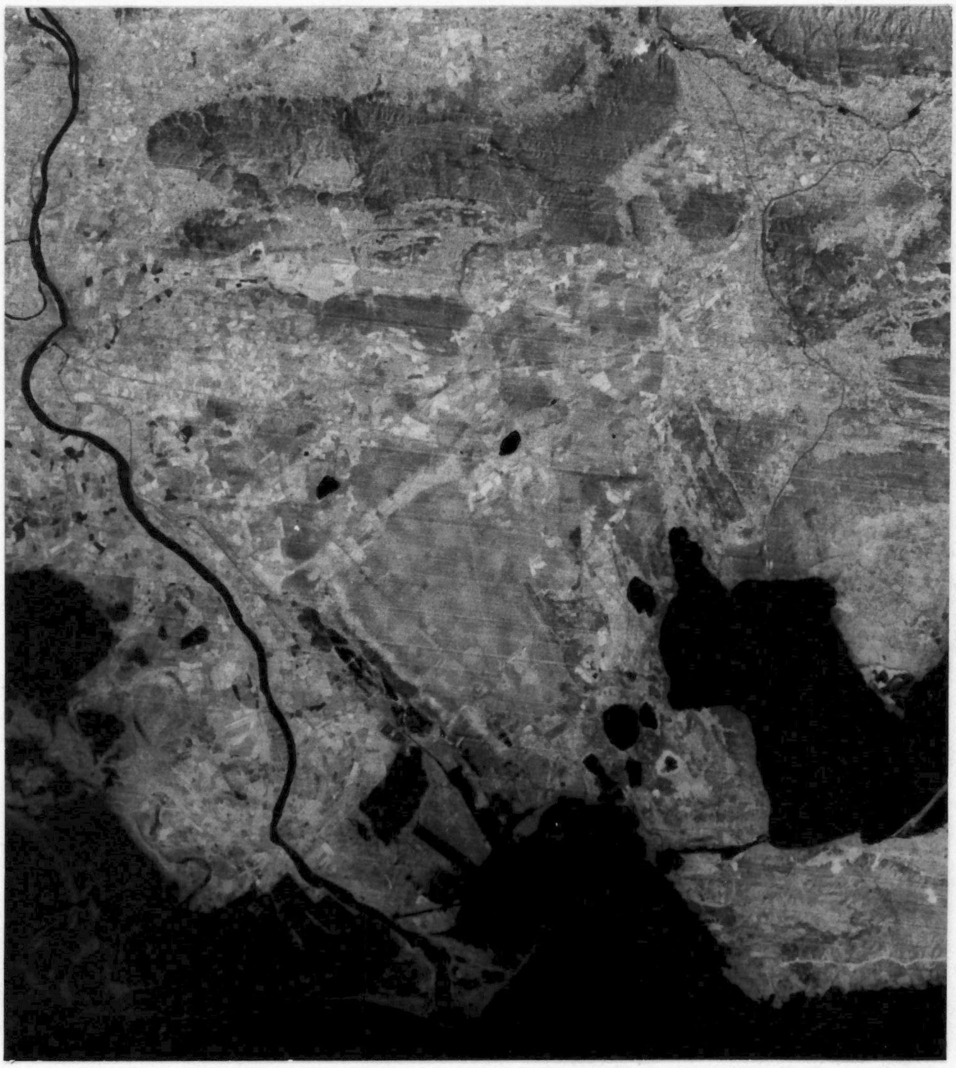


Figure I-6. Enlargement of Landsat Image E-2182-09451 Band 7.

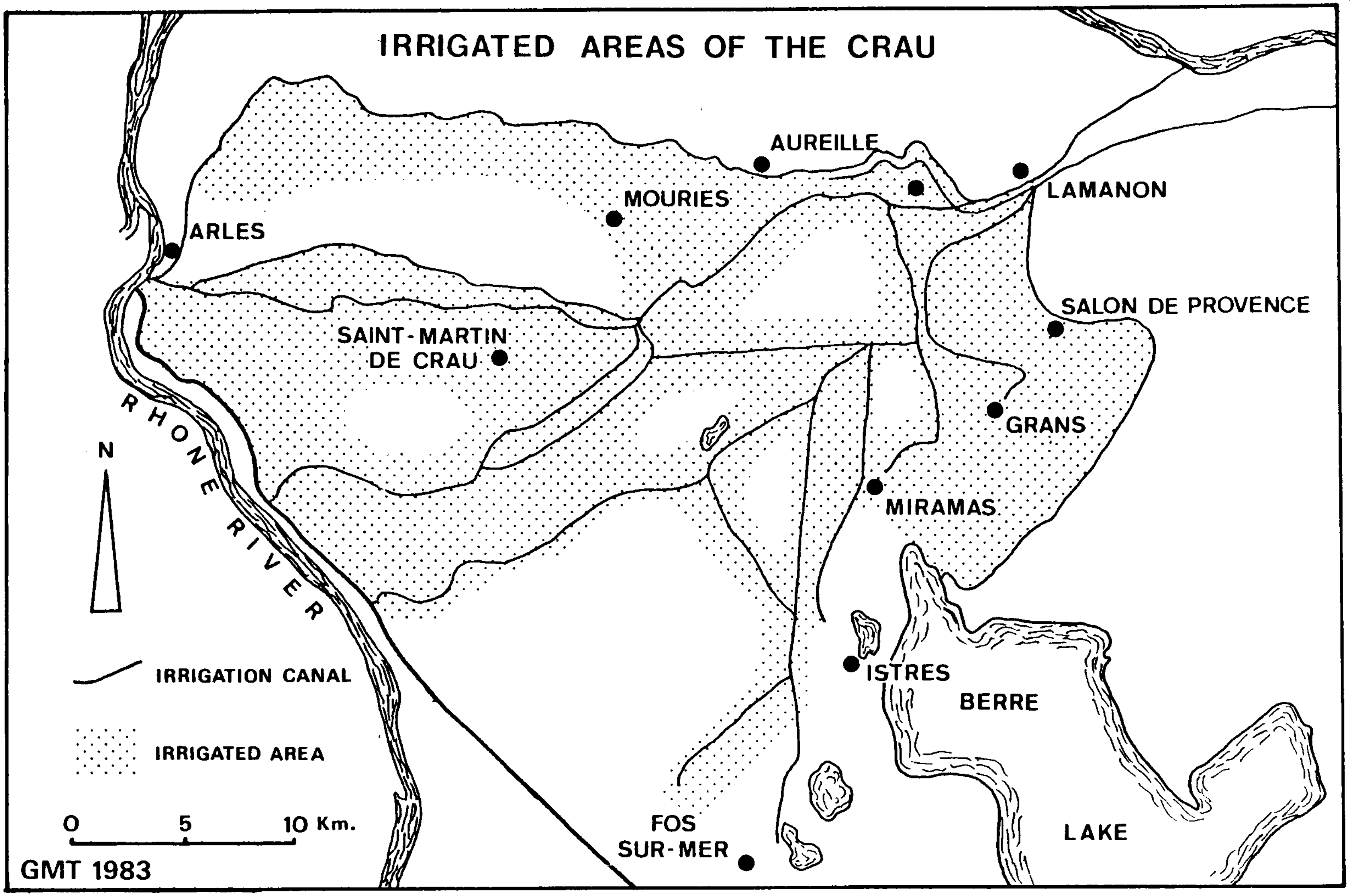


Figure I-7. Irrigated Areas of the Crau.

and irrigation practices of the area but developed new forms of irrigation and agriculture.

Traditional agriculture of the Crau relies on irrigation and the building of soil from silt sediment in water diverted from the Durance River. Warping is the technique by which soil is built. To warp a piece of land, a levee is built around it, water is let in and allowed to stand long enough so that its silt content is deposited and then let out. The operation may be repeated many times. To use such a process requires a nearly flat piece of land, a large supply of silt loaded water and time. In order to obtain sufficient soil in a shorter time, one can use decantation basins to collect the silt deposit and spread them on the land.

Literature Review

The Crau has not been the topic of a great deal of geographical studies in recent times. The only book published on the Crau is Adam de Craponne et son Canal (Alphéran, 1851). The area is mentioned in geography textbooks (Brunhes, 1952; Chabot, 1969; Pinchemel, 1969; Noin, 1976), in specialized books on agriculture (Livet, 1980), water management (Conac, 1978), economics (Meiller, 1974) and in atlases (Livet, 1974).

Academic theses constitute a larger source of information, although only one deals with the Crau specifically (Thomas, 1967). Groundwater in the northern Crau is the focus of one thesis (Cova, 1966). Most theses deal with one aspect of the Crau as part of a larger area study (George, 1935; Barthélémy, 1966; Houot, 1970; Béthemont, 1972). Béthemont's thesis is a major work on water uses in the Rhône Valley, but his focus was not on irrigation practice and water management.

Prior to 1950 several articles were published on the Crau (Rainaud, 1893; Peyre, 1926; Cholley, 1926; Bénévent, 1931; Molinier, 1949) whereas others are specialized (Brun, 1965; Livet, 1965; Garde, 1965; Carrière, 1966; Livet, 1970). A special issue of Méditerranée was devoted to water in the South-East of France (1980) and was a useful source of information.

The most important sources about the Crau are government publications. Specialized information on hydrology (Compagnie de Prospection Géophysique, 1962; Dellery, 1964; Annuaire Hydrologique de la France, 1965; Castany, 1978), in techniques of irrigation (Barral, 1876; Chambre d'Agriculture des Bouches-du-Rhône, 1980; agricultural activity (the 1980 Agricultural Census, 1982), and general information on the region (Niasset and Toni, 1976, 1982) were useful. La Crau (Borrey, 1964) is an extensive study describing agriculture in the region, but does not deal with water management. Few works deal with irrigation practices and water management in the Crau in a comprehensive and systematic manner.

Data Sources and Procedures

Data sources for this study fall into four categories: maps, public documents, published studies and interviews. Maps published by the Institut Géographique National (I.G.N.), Bureau de Recherche Géologique et Minières (B.R.G.M.) or found in diverse publications were used to assess physical factors. Public documents provided information from which to describe the irrigation system and its functioning as well as irrigation techniques. Published articles and theses were relied upon for historical and technological aspects of the study.

Interviews with government personel and farmers proved very helpful in assessing the recent trends in irrigation techniques and their possible risks. Mr. Toni of the Direction Départementale de l'Agriculture des Bouches-du-Rhône in Arles was an especially useful fource for agriculture and irrigation. Mr. Roman of the Service Régional d'Aménagement des Eaux (S.R.A.E.) in Aix-en-Provence provided information about the Durance River regulation. Mr. Lafage of the Direction Départementale de l'Agriculture des Bouches-du-Rhône in Marseille was very helpful in assessing the agriculture of the Crau.

Because of year round agriculture practice, few farmers were available for extensive interviews. However, Mr. Thomine-Desmazures of the Mas de Gouin in Saint-Martin-de-Crau spent several hours with me explaining his operation and showing me his irrigation system.

Most information was collected during field work in France which took place from November 20 to December 20, 1982.

CHAPTER II

GRAVITY WATER IRRIGATION: THE CRAU PRIOR TO WORLD WAR II

Prior the mid-sixteenth century the natural landscape of the Crau was practically untouched by man. Although rain water was stored in the Entressen, Des-Aunes and the Des-Baux Lakes during the wet season, no significant stream entered the Crau. The stony surface materials and windy conditions along with little or no summer rainfall made the area a near desert except in a few places where water was available in lakes that collected run-off during the winter (Figure II-1). An agriculture based on sheep, olives and cereals was successful in a limited scale. Several attempts to channel the waters of the Durance River were made as early as the Roman occupation and later in the Middle-Ages, however, the first significant and successful project was the Craponne Irrigation Network in 1559.

This chapter will examine the development of irrigation in the Crau from the Craponne project to the regulation of the Durance River in the 1950's. Water management will be discussed in terms of purpose, organization, financing and operation of the network and its impact on the natural environment.

Pioneer Phase

Adam de Craponne (1525-1576) was a distinguished engineer attached to the Court of King Henry II and was one of the best civil engineering specialists of this time. A native of Salon-de-Provence in the eastern Crau, he resolved to help his hometown by supplying it with much needed

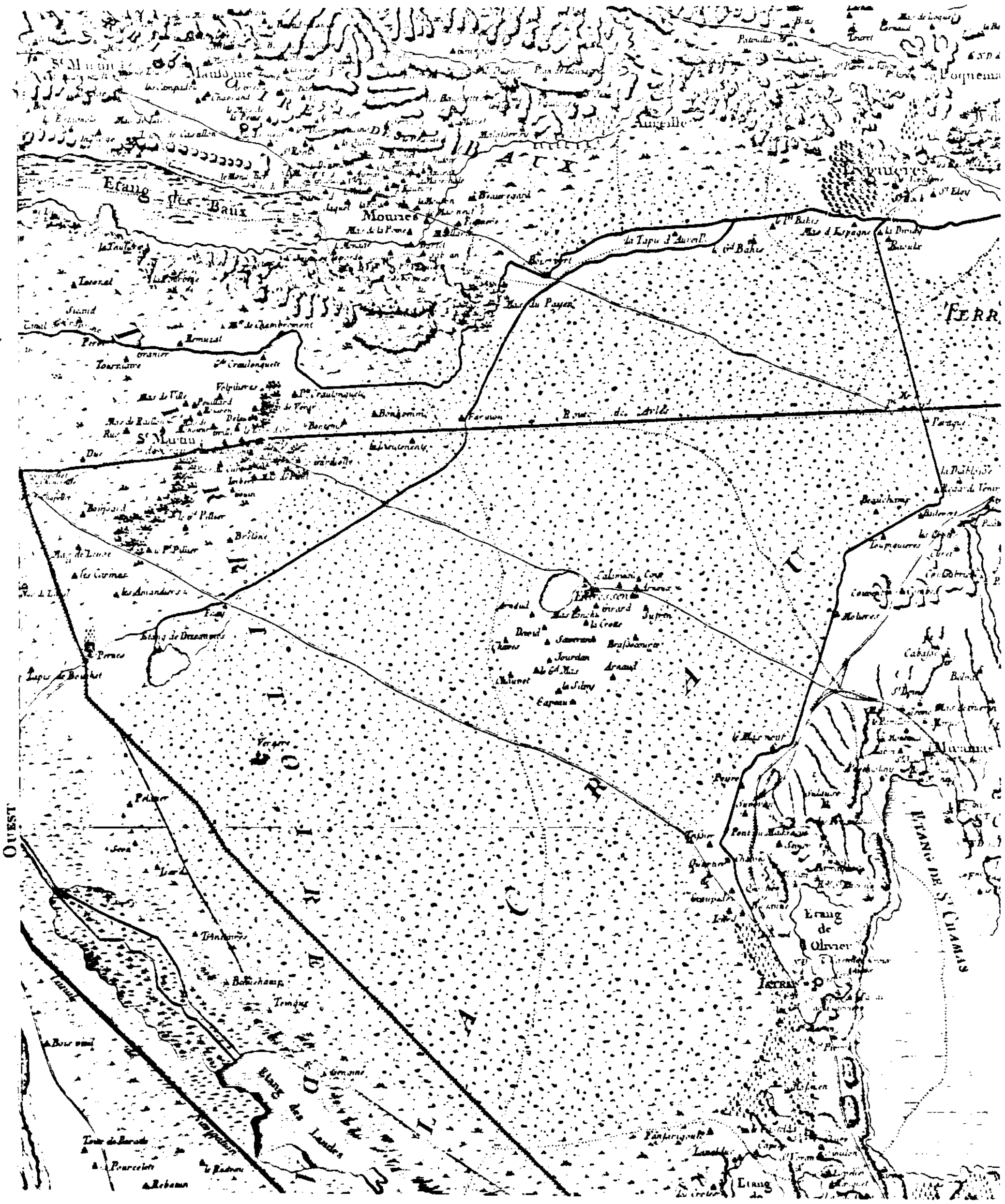


Figure II-1. The Crau During the Eighteenth Century.

Source: Sheet 123 of the Map of France by De Cassiny, Reduced by 50 percent; Approximative Scale: 2 and a Half Mile to the Inch.

water (Rigaud, 1934). During the sixteenth century water in the Crau meant power more than agricultural growth. Water provided the force to process flour and olive oil. A reliable supply of water for Salon-de-Provence meant economic growth for the whole region. Mills located on channels with permanent flows would replace those located on smaller and more irregular current like the Touloubre River. Windmills were also no match to a regular flow of water.

In the spring of 1554, the Chambre des Comptes de Provence, the regional parliament, approved his project to take the water out of the Durance River, to canalize and use it with the authorization to build mills and other machines using water (Alphéran, 1851). On August 17, 1554 King Henry II approved the project and granted authorization and licence to divert the waters of the Durance River for Craponne's profit and to enjoy, use and dispose of them wherever he pleases to Adam de Craponne (Rigaud, 1934).

Through the financing of de Craponne, the first branch of the project was realized with the water arriving in Salon de Provence on April 30, 1559 and mills began operation. On October 6, 1559 the same channel reached Istres. The water was also used for irrigation but on a limited scale. However, in that same year 1559, a severe drought occured which lasted seven months. Michel de Nostradamus, wrote that, "trees and plants irrigated by the water of Mr. de Craponne were the only vegetation left." The idea of irrigation thus became more popular.

Adam de Craponne irrigated his land and used the silt content of the Durance water to build soil. This technique is known as warping. A piece of land is surrounded by ditches and water is allowed in and left to drop its sediment content. The sediment-free water is then drained off the land. The operation is repeated many times and soils are slowly built. At that time, however, most of the water was not used for irrigation but simply flowed to the sea.

The financing, operation and maintenance costs of the channel proved too much for de Craponne and he soon went bankrupt. A court order of October 20, 1571 gave part of his rights to an association of users, on the grounds that the abandonment of the channel would be an invaluable loss for both parties as well as for the public welfare.

The project was completed with the addition of the Arles branch in 1581. As interest in warping increased with the passing of time, the area served by irrigation expanded to use the available supply of water.

The management of the Arles and Salon-de-Provence branches of the Craponne channel was consolidated under a new organization, Oeuvre Générale de Craponne (O.G.C.), in 1583. All interested parties, local associations, government, and farmers receiving water were members of its general assembly and voted proportionately to the amount of water they received. Operating and maintenance costs were supported by the user fees proportionately to their water allocation.

Second Phase

The first project specifically designed to warp and irrigate part of the Crau involved using the Alpine channel originally built to serve areas north of the Alpilles Chain but the water of which was left unused. This permitted doubling the quantity of water imported in the Crau. The project, started in 1782 and completed in 1787, was promoted by Archbishop de Boisgelin, head of the administration of Provence. It was financed and owned by the Etats de Provence, the regional parliament. The usefulness and benefits of warping and irrigation of the Crau had become so noticeable that public money was used in place of private funding, a tradition which continues today.

The Boisgelin project was shortly halted by a law suit in 1783. The Oeuvre Générale de Craponne claimed the right to retain exclusive use of the Durance River waters. However, the Courts overrulled their claim thus creating the legal basis for the future development of irrigation in the Durance Valley and forcing all future users of the Durance to cooperate.

The Alpine Irrigation Network was at first operated and maintained by the regional government, but its incompetence lead to reorganization in 1813. Copying the O.G.C., the new organization of the users of the Alpine Irrigation Network received the properties, rights and duties for the southern branch of the network and was named Oeuvre Générale des Alpines (O.G.A.).

By 1887 the irrigation networks of both O.G.C. and O.G.A. were able to supply water to half of the Crau. Warping was widely adopted by local farmers and an unique agriculture based on hay was well established.

Irrigation Techniques

The first step of warping land to be irrigated was to plow it throughly and clearing away the largest stones. Lines of trees were planted to reduce wind effects and irrigation ditches were constructed (Figure II-2). Fields were then flooded and seeded in alfalfa, often

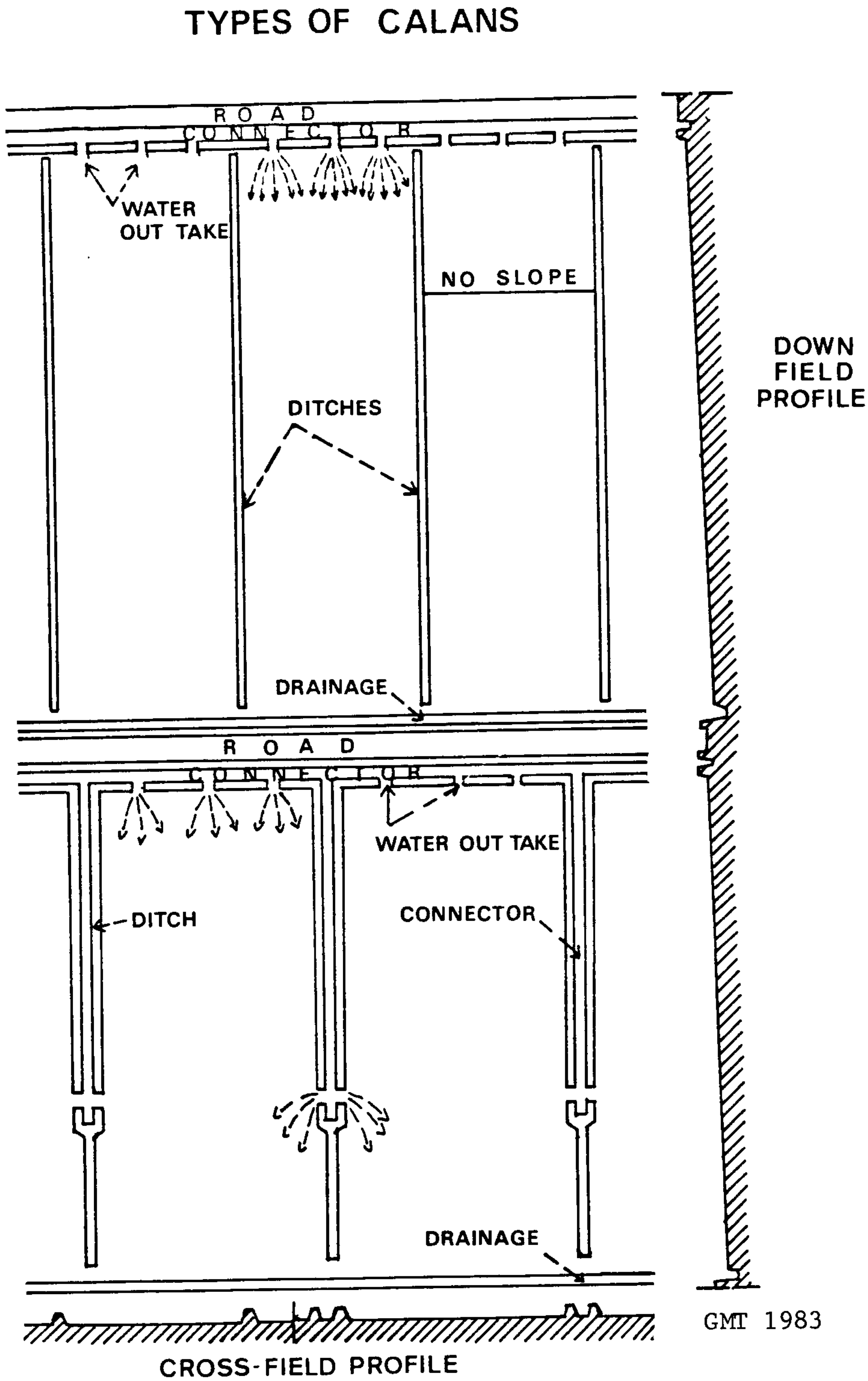


Figure II-2. Types of Calans.

in association with a less productive cereal crop, such as barley or rye. This system known as "calans" is still in use today. The silt in the irrigation water derived from the Durance River accumulated slowly but progressively created a silty surface soil. The irrigation water also brought seeds of alpine plants and often within ten or twelve years the original alfalfa had vanished and was replaced by a pasture crop similar to that of the alpage. Irrigation allowed three cuttings a year and hay was readily sold in this region when horses were the main draft animals and means of transportation.

Irrigation also brought about a mutually beneficial association of farmers and sheep herders. From June to September herds of sheep are taken to the Alps to graze on the rich alpages. In October these herds would return to the Crau to be maintained until May. The herders would rent the use of land from the farmers which normally included some pasture and some rocky ground known as "coussouls." One unit of pasture was considered equal to ten of "coussouls." The herders were required by contract to drive their herds over all the rental land in accordance with a preestablished pattern to distribute fertilizer and reduce over grazing. The association was a beneficial one because the herders got a place to stay during the winter and the sheep provided natural fertilizer for the land. Cost of the rent depended on the number of sheep in the herd.

Effects of Irrigation

Irrigation water from the Durance River brought not only the necessary moisture for agriculture, but it also brought minerals and built improved surface soils. The effects can be summarized as follows:

Pedogenetic - the heavy load of silt in the Durance River waters added deposition estimated to equal twenty tons per hectare irrigated per year on average or create between one half and one millimeter of soil per year.

Calcification - the waters of the Durance River also contained a large amount of calcium. Studies showed a calcium content between 34 and 48 percent of dissolved solids (Mangon, cited in Borrey, 1964, p. 18). This calcium helps stabilizing the soils by aggregating the clay and serves as an indispensable nutrient for plants.

Fertilization - the waters of the Durance River brought a variety of nutrients to the Crau soils in solution and the silt deposit also contained valuable quantities of nutrients in solid form (Table II-1). Between 100 and 125 kilograms of nitrates, phosphates and potassium are received on every hectare of land free of charge for the farmer. This alone would justify the cost of water.

Development of Irrigation

Warping became very important during the nineteenth century making large areas more valuable. The technique was improved by the use of Durance winter water, which were previously unused. The winter waters have a higher silt content than summer waters due to the more

Table II-1. Fertilizer Content of the Durance River Water.

	Average Content in Grams for		Quantity Brought per Hectare, in Kilogram		
	1 m^3 of Water	1 Kg. of Silt	in Water	in Silt	Total
Nitrates	0.323	0.80	4.85	8.0 to 12.0	13 to 17
Phosphates	0.150	1.05	2.25	10.5 to 15.7	13 to 18
Potassium	3.000	2.90	45.00	29.0 to 43.7	74 to 90
Total	3.473	4.75	52.10	38.5 to 71.2	100 to 135

Source: Gastine, cited in Borrey, 1964, p.18.

intensive erosive action at that time of the year. The silt was recovered in decantation basins called "nays", collected and then sprewn on the land. The high level of investment required by this technique ruled out financing by local farmers and this phase of technical development in the Crau was largely conducted by the regional bourgeoisie seeking profit. Samuel Abrams, a wealthy businessman from Marseille for example, warped 526 hectares (1260 acres) between 1836 and 1869, multiplying the income of his land by eight (Béthemont, 1972).

Interest in, and benefits from irrigation were then widely recognized. An irrigation contest was even organized in 1876 to compare the different irrigation techniques and their results. The results of the contest, the participants of which principally belonged to the bourgeoisie, are contained in a report by Mr. Barral. For example, he cited a case in which a piece of land could produce an alfalfa yield of 14 tons per hectare per year as opposed to 7 tons per hectare per year when not irrigated (Barral, 1876).

Water Distribution

The quantity of water to be delivered to the members of both O.G.C. and O.G.A. is governed by the same set of rules. These rules were the product of centuries of testing and experience and are still in use today. They were handed in a court order on March 20, 1884. During the maximum irrigation period, May through August, the quantity to be delivered to each member of the associations equals a permanent supply of 1.2 liter per second per hectare. Water is delivered every ten and half days for pastures and every five and one fourth days for crops.

This procedure allows for day and night irrigation in alternance with every hectare receiving about 18,000 cubic meters of water a year. Water is delivered to the main channel as close as possible to the user's land and then it becomes his responsibility to bring it where he wants to use it.

Operation and maintenance costs are supported by the users proportionately to their water allocations. Costs for building, operating and maintaining the ramifications necessary to bring the water out of the main channel are supported in common by the several users.

Drainage Problems

The combined efforts of the O.G.C. and O.G.A. delivered about 30 cubic meter of water per second to 22,000 hectares for several months a year near the end of the last century. Since water could not seep through the hardpan, which lies close to the surface, areas of stagnant water began to appear. As early as 1850, local authorities began to voice concern about wet areas where fevers were occuring. They were especially prevalent along the Rhône River and in the flatter regions of the central Crau. Drains were dug to evacuate the undesired water. Costs were supported by the government. It was decided that each new ramification of the irrigation network would be in conjunction with the construction of drainage system (Béthemont, 1972).

Water Shortage

The development and success of irrigation in the Crau convinced other regions of the lower Durance Valley to build their own irrigation networks (Figure II-3). The water allocations to irrigation channels was

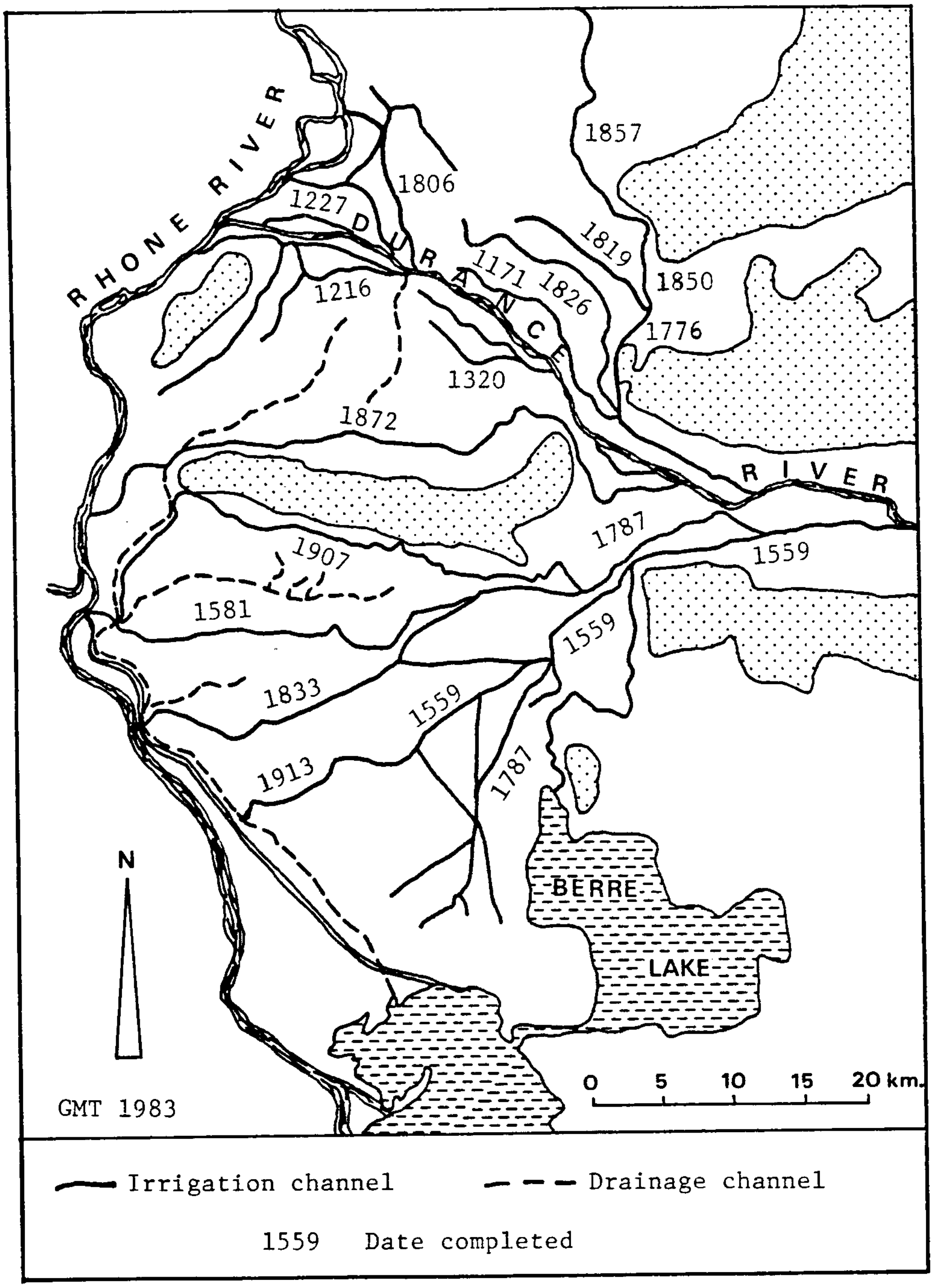


Figure II-3. Irrigation Network in the Lower Durance Basin in 1913.

85 cubic meters per second and grew to 114 cubic meters per second by 1947. Since the right of first user was not recognized by the courts, the pressure on the available water supply became so high that the Crau and other irrigated regions began to experience water shortages in the summer again. During the summer the average low flow of the Durance River was 80 cubic meters per second, but could go as low as 40 cubic meters per second. The Crau alone could use most of that supply (Figure II-4).

In 1907 the drought problem was already so acute that farmers were likely to receive only 50% of their water allocation during several weeks each summer. Several incidents of irrigation users trying to use the water to the detrement of others occured. On July 11, 1907 the Commission de Réglementation des Eaux de la Durance (Durance Waters Regulatory Commission) was created by the government. During droughts the commission had the authority to impose reduced water supply to users, and to close networks in order of seniority if necessary.

Because the water concession of the networks was the result of theoretical calculation often biased by user associations in their favor, an old network would sometimes receive more water than it could actually use, while others would have their supply reduced or cut off. This was an arbitrary solution that could not solve the problem of summer droughts but incidents did become more rare. Unfortunately this situation was to last as long as the flow of the Durance River was not regulated.

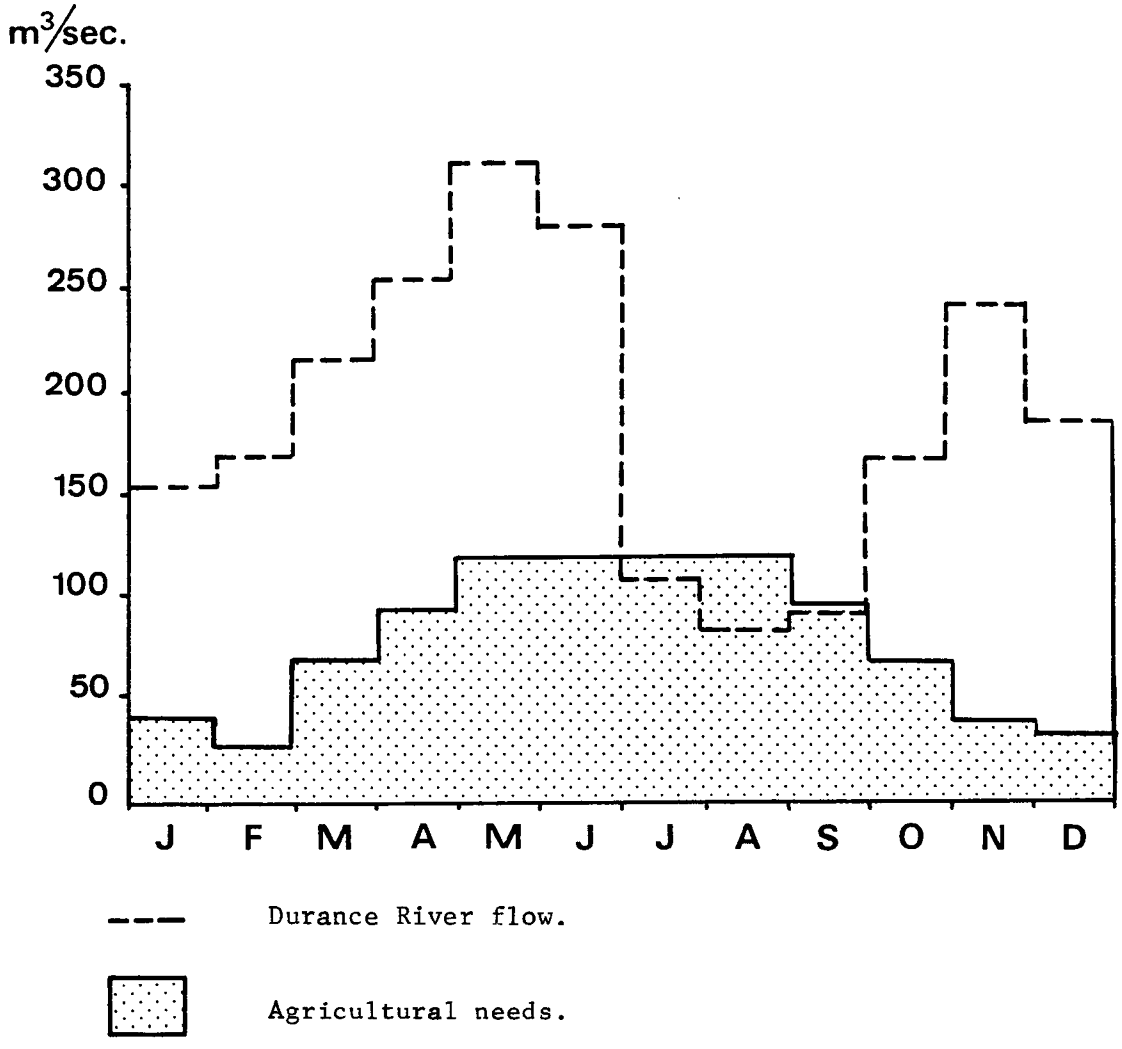


Figure II-4. Situation of the Water Supply Before 1950.

Source: E.D.F. and Annuaire Hydrologique de la France, 1965.

Summary

The use of silt sedimentation from Durance River water which was also used for irrigation has enriched the soil and agriculture of the Crau. Irrigation was first initiated by Adam de Craponne in 1559 but soon became a public concern. Adoption of irrigation was slow at first but its successes proved the value of the technique. During the nineteenth century, there were increases in warping and irrigation use. Unfortunately the water needs of all irrigated demand exceeded the low peak of the Durance River by 1900 and droughts reappeared.

CHAPTER III

GRAVITY WATER IRRIGATION SINCE WORLD WAR II: SECURITY

By the end of the ninteenth century the demand for irrigation water was greater than could be satisfied from the unregulated Durance River. Water shortages in the summer were nearly back to conditions prior to irrigation. The Crau still received silt from winter flow but summer agriculture was endangered. Large scale regulation of the Durance River was the only solution.

This chapter discusses the regulation works on the Durance River and will examine changes in water supply and irrigation practices since 1950. The regulation of the Durance River is assessed in terms of organization, financing, and operation of the regulatory system and the consequences of regulation on agriculture and the natural environment of the Crau.

The Durance River Potential

In 1947 the water needs for the Durance Basin were approximately equal to 130 cubic meter per second (m^3/sec.) in summer of which 114 m^3/sec. was for agricultural use and 15.2 m^3/sec. for Marseille domestic water. The average annual flow of the Durance River was 191 m^3/sec. with an average summer season low peak of 88 m^3/sec. (Annuaire Hydrologique de la France, 1965). Low flow in summer, however, sometimes went as low as 40 m^3/sec. the water deficit at such times was at least equal to 25 m^3/sec., considering the effective use of irrigation water, and had the potential to become a catastrophe.

Adequate volumes of water were available from the Durance River on a yearly basis. A study of table III-1 shows that about 6,000,000,000 m^3 each year flows past Cadarache, 10 miles upstream from the Craponne Channel intake. The flow of the Durance River is characteristic of a Mediterranean climatic regime with Alpine influence. It has its lowest flow in August. From October to June the flow is more uniform because of the rain and snowmelt. The normal high peak occurs in May. In 1947 the water needs for both agricultural and domestic use equalled 1,010,000,000 m^3 during the summer season while only 850,000,000 m^3 were available. In order to solve the water shortage, the Durance River would have to be regulated and part of the unused winter and spring flow stored in reservoirs in the upper Durance Valley for release during the summer.

The Regulation of the Durance River

The financial cost of regulating the Durance River and its main tributary, the Verdon River, far exceeded the financial capacity of the agricultural users. The Government stepped in and decided that Electricité de France (E.D.F.), the National Utility Company would be in charge of the project and created the Société du Canal de Provence (S.C.P.), Provence Channel Company, which would be in charge of maximizing the use of water in the region, other than hydroelectric, for agricultural, industrial, and domestic purposes.

Electricité de France built and supported the cost of construction of four reservoirs for the dual purpose of electrical generation and water regulation. Construction of the dams took place between 1946 and 1974. Castillon Reservoir on the Verdon River was operational in 1948, Serre-

Table III-1. Durance River Flow at Cadarache, from 1920 to 1960.

YEAR	WINTER (J.F.M.)		SPRING (A.M.J.)		SUMMER (J.A.S.)		FALL (O.N.D.)	
Mm^3	Mm^3	%	Mm^3	%	Mm^3	%	Mm^3	%
5,950	1,400	24	2,200	37	850	14	1,500	25

Mm^3 stands for million of cubic meters.

Source: Annuaire Hydrologique de la France, 1965.

Poncon Reservoir on the Durance River in 1959, and Sainte-Croix Reservoir on the Verdon River in 1974. Combined with Quinson Reservoir on the Verdon River, these four reservoirs have a storage capacity of 1,495, 000,000 cubic meters of water (Figure III-1). Castillon Reservoir alone improved the situation so much that a contract was signed in 1955 between E.D.F. and all irrigation network associations allocating water and guaranteeing the supply at 80% of the maximum allocation set by court order in 1884. Since 1959, a 200,000,000 m^3 emergency irrigation reserve has been kept at all times in Serre-Poncon Reservoir. This reserve has never been touched so far and even during the 1976 and 1982 droughts, water shortages were never a concern in the Durance Basin (Figure III-2).

Today the S.C.P. diverts and additional 40 m^3/sec. in the Durance River to bring it to the newly irrigated area of the Durance Basin and in Upper Provence, raising the water needs to 1,356,000,000 cubic meters for the summer season. (Figure III-1). This quantity is less than what is stored in the Serre-Poncon Reservoir plus the summer flow of the Durance River. Therefore it was decided that water could be diverted from the Castillon and Sainte-Croix reservoirs for use in the Riviera, Toulon, Marseille areas (Figure III-1).

The Agro-Industrial Channel

Serre-Poncon Reservoir is located about 220 kilometers upstream from the Rhône River at an elevation of 850 meters. In order to capitalize on the gradient of the River and maximize the use of water while reducing the losses by leaks, E.D.F. built a concrete channel lateral to the Durance River called the Agro-Industrial Channel. Ten hydroelectric plants

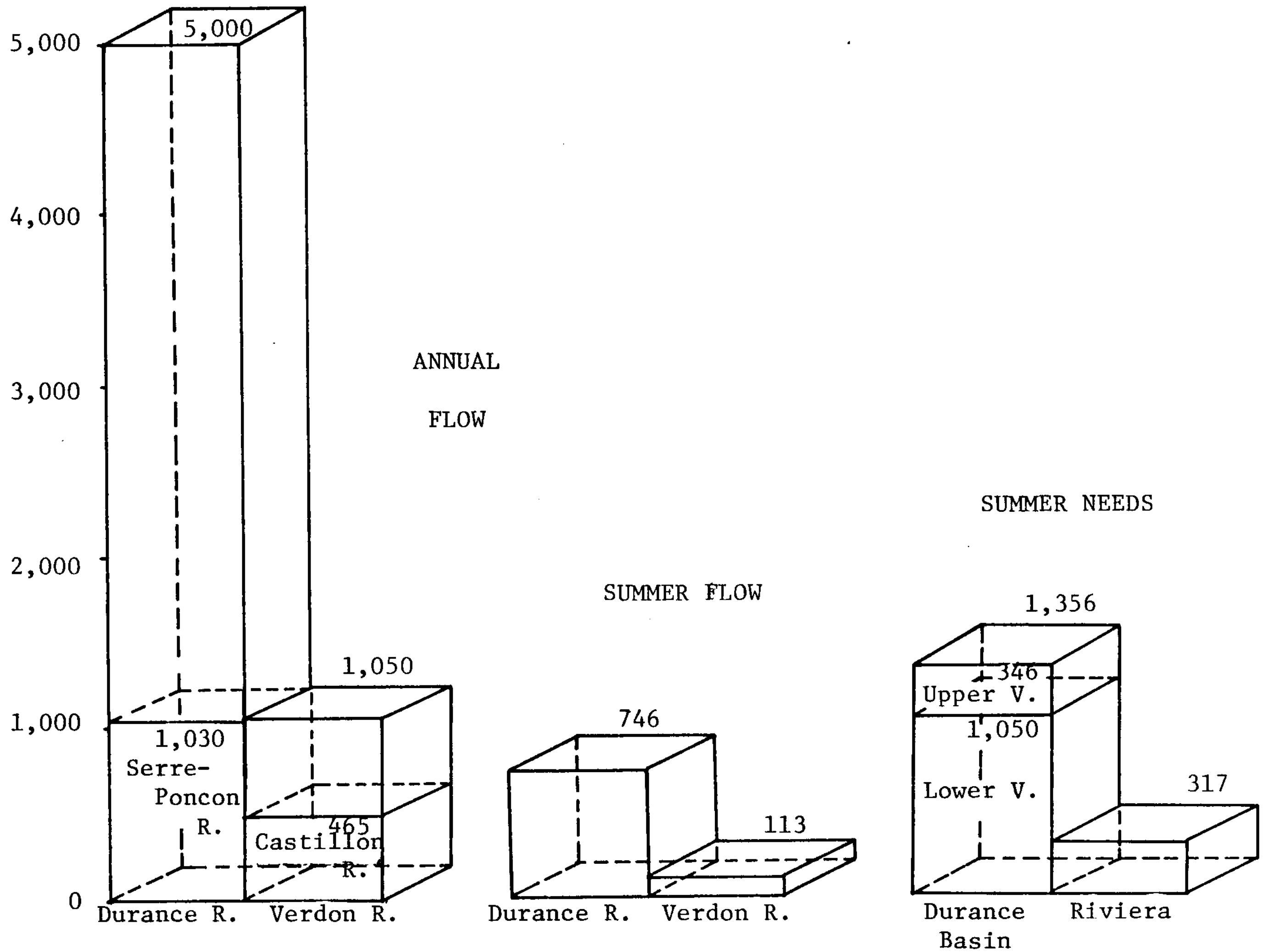


Figure III-1. Water Management Data in the Lower Durance Basin in 1978.

Source: Annuaire Hydrogéologique de la France, 1965 and S.R.A.E. Aix-en-Provence.

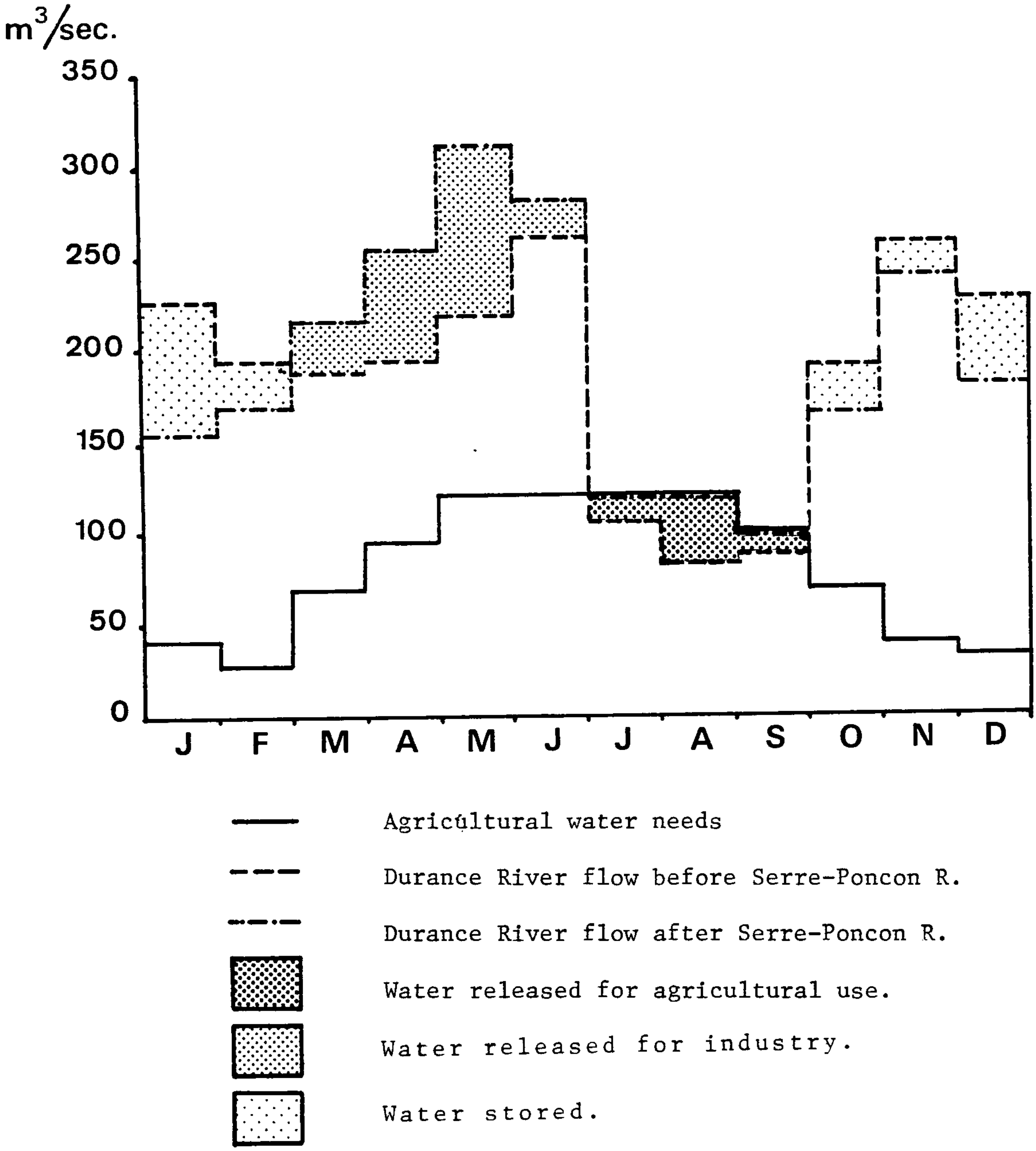


Figure III-2. Influence of Serre-Poncon Reservoir on the Durance River at Pont-Mirabeau.

Source: Annuaire Hydrologique de la France, 1965 and S.R.A.E. Aix-en-Provence.

were constructed along the channel which can generate 2.4 gigawatt per hour (the equivalent of two TVA's Brown's Ferry nuclear units) (Nuclear Stations Achievement, 1980). The Agro-Industrial Channel runs from Serre-Poncon Dam through the Lamanon Pass to the Berre Lake. Its maximum capacity is 234 m^3/sec., which is more than the average flow of the Durance River. For sanitary purposes, E.D.F. is required to let a 2 m^3/sec. flow in the natural channel of the Durance River. Any water that is in excess of the flow in the Agro-Industrial Channel when the reservoirs are full also flows in the bed of the Durance River. Several inter connections between the natural channel of the Durance River and the Agro-Industrial Channel permit exchanges between the two at intervals along their lengths (Figure III-3). This project was for the most part completed in 1970 with full completion in 1976.

The New Irrigation System

In order to avoid congestion in the Lamanon Pass it was also decided that all former irrigation channels would be regrouped. On January 21, 1968 the Union de Boisgelin-Craponne was created. The new association is managed by seven associations member of the Oeuvre Génerale de Craponne (O.G.C.) or the Oeuvre Génêrale des Alpines (O.G.A.).

The Boisgelin-Craponne Channel, named after the two pioneers of irrigation in the Crau, replaces all but on older irrigation channels with a 3.5 kilometers long concrete channel in the Lamanon Pass area. E.D.F. financed the project from the sale of electricity generated at a hydroelectric plant built in the new channel through Lamanon Pass. After the water passes through the new combined channel both O.G.C. and O.G.A. re-

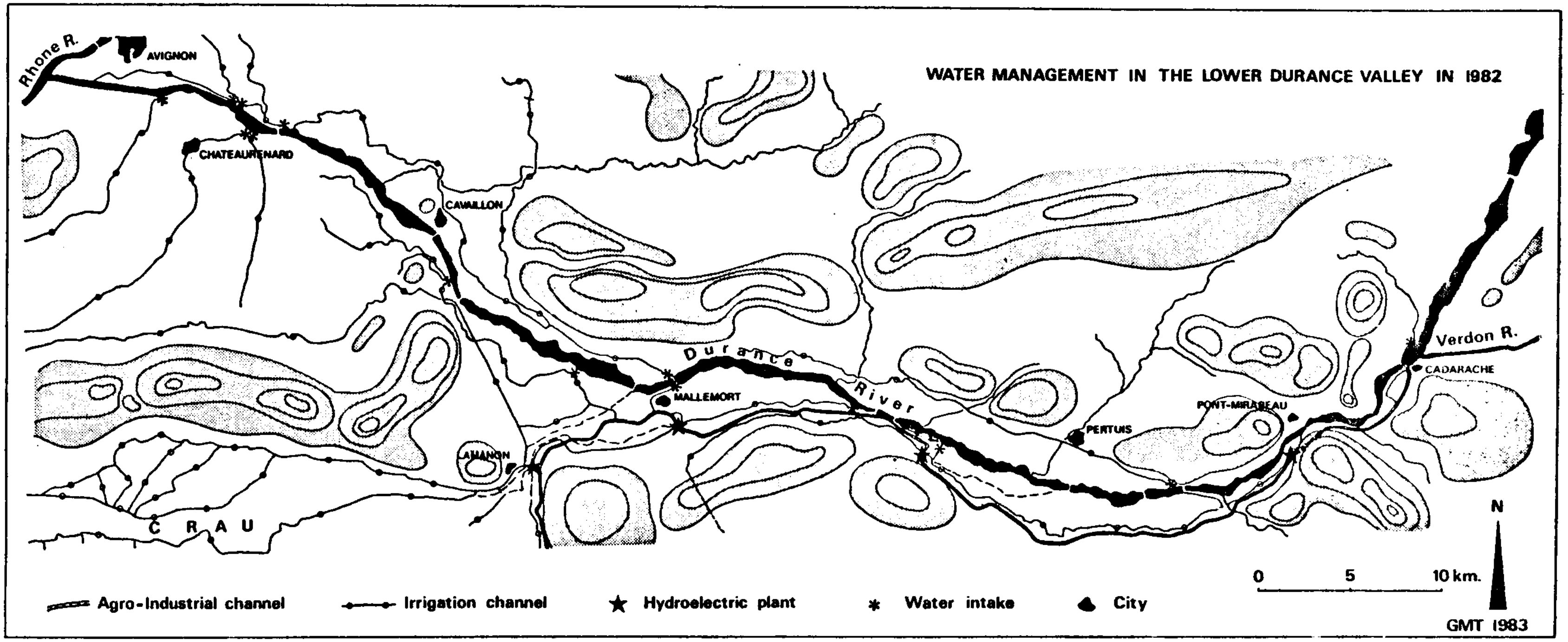


Figure III-3. Water Management in the Lower Durance Valley in 1982.

gain their autonomy and rights. The Boisgelin-Craponne Channel has a maximum capacity of 31.453 m^3/sec. The branches not involved with the new channel are Salon-de-Provence (3.820 m^3/sec.) and La-Roque-d'Anthéron (4.559 m^3/sec.) which receive their water allocation directly from the Agro-Industrial Channel.

Water allocations for both O.G.C. and O.G.A. were negotiated with E.D.F. in 1955 and modified in 1980 (Figure III-4). According to the resulting contract the 26,000 hectares of the Crau receive a maximum 39.848 m^3/sec. representing 35% of the total agricultural water used in the lower Durance region. In winter share going to the Crau goes as low as 22%. The total irrigation water allocation for the lower Durance Valley is 114.008 m^3/sec. for 75,000 hectares. With its 26,000 hectares the Crau represents 34.6% of the irrigated land which is consistent with its water allocation of 35%.

Both O.G.C. and O.G.A. irrigation networks have been improved and expanded in the recent years. The most important addition is the Haute-Crau Branch of the O.G.C. built in 1964 which brings water through an aqueduct to 2,600 hectares of land in an area where topography made it inaccessible to irrigation water by gravity flow. The construction cost was supported 80% by public money.

O.G.C. and O.G.A. irrigation networks are today interconnected to make a more efficient network but each keeps its identity. Farmers are grouped in associations depending on their location, and are often member of several organizations. These organizations represent them in the management of O.G.C. and O.G.A. or for other issues that interest them, such

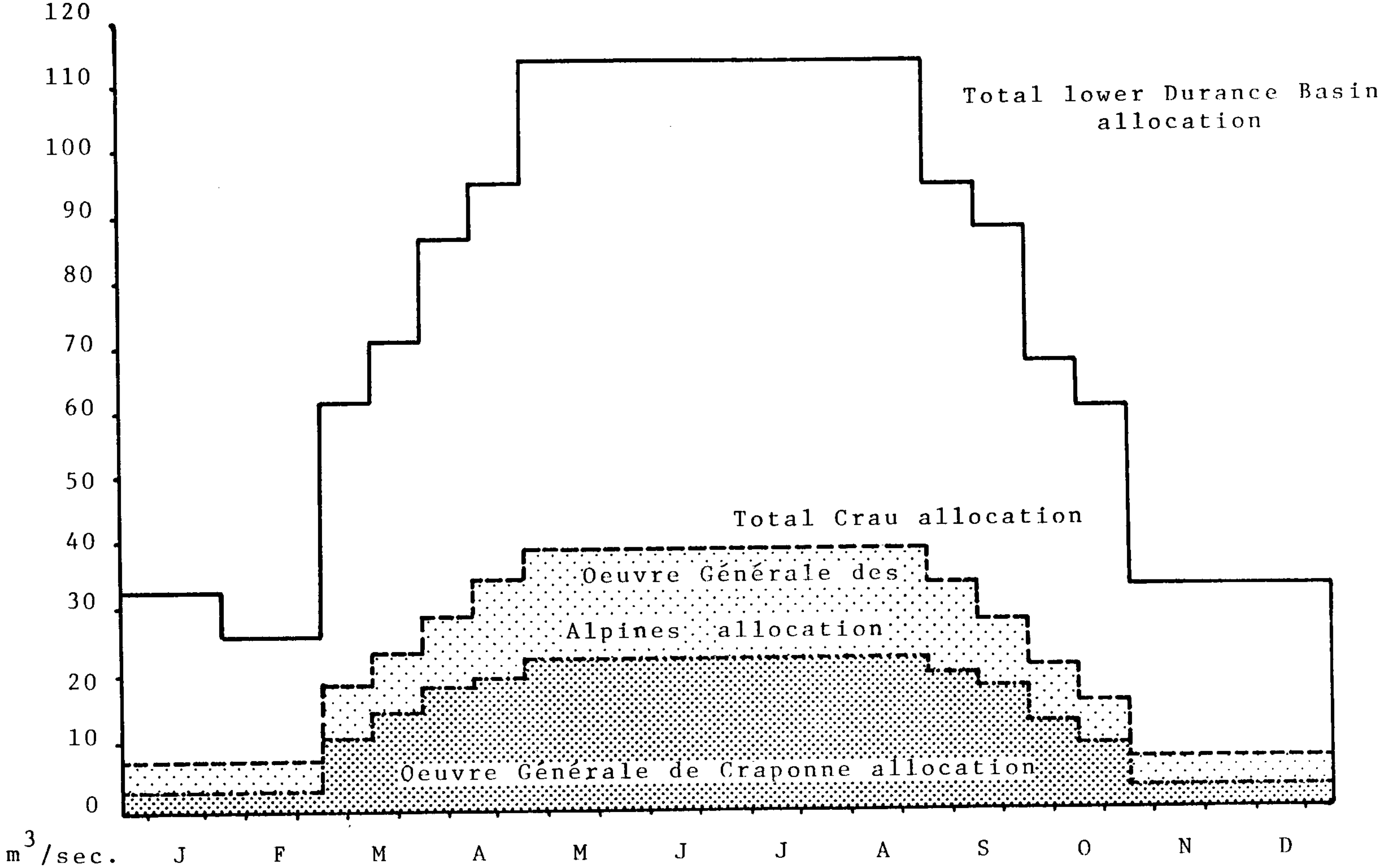


Figure III-4. Annual Modulation of the Water Allocation of the Irrigation Networks in the Lower Durance Basin.

Source: E.D.F. Contract of 1955, Modified in 1981 and S.R.A.E. Aix-en-Provence.

as lobbying the Department of Agriculture.

Water is still delivered according to the 1.2 liter/sec./ha. rule with a coefficient depending on the month of the year (Table III-2). All O.G.C. and O.G.A. channels are built so that their bottoms are one meter above the land. The delivery of water is made from the main channel through two valves (Figure III-5). The downstream valve is opened by the O.G.C. or O.G.A.'s employee according to the delivery schedule. If the farmer wants water he opens the upstream valve. To leave the valve closed or close it before taking his full allocation does not alter future rights. The measure of quantity is made in a gauging basin next to the valves. When the water is delivered to the users through a ramification, the ramification's users association uses the same procedure.

Operation and maintenance costs along with the private share of investment, usually 20% of the total investment cost, are supported by users. For example, the maintenance cost for the Arles Branch of O.G.C. amounted to 10 francs per meter of channel in 1982, and the fee to the user totalled 220 francs per hectare for those along the main channel. Delivery by connector ditches adds to the cost and may double it depending on the location.

Water Distribution

Irrigation canals, connector ditches, and field ditches were traditionally unlined and water losses were high. To deliver 1.2 liter per second hectare of water involved an estimated loss of an additional 10%, or .12 liter/sec., due to leakage just in the main channel. Thus the total needed was 1.2 + .12 liter/sec. or 1.32 liter/sec. per hectare.

Table III-2. Seasonal Variations of the Water Allocation of the O.G.C. and O.G.A. Irrigation Networks (in liters per second).

		O.G.C.		O.G.A.	
Month	Period	Total	Percent	Total	Percent
January	1-15	3,400	.14	4,050	.25
	16-31	3,400	.14	4,050	.25
February	1-14	3,400	.14	4,050	.25
	15-28	3,400	.14	4,050	.25
March	1-15	12,269	.52	6,000	.37
	16-31	15,119	.64	8,000	.49
April	1-15	19,887	.84	10,000	.61
	16-30	21,334	.90	13,000	.80
May	1-15	23,638	1	16,210	1
	16-31	23,638	1	16,210	1
June	1-15	23,638	1	16,210	1
	16-30	23,638	1	16,210	1
July	1-15	23,638	1	16,210	1
	16-31	23,638	1	16,210	1
August	1-15	23,638	1	16,210	1
	16-31	23,638	1	16,210	1
September	1-15	21,220	.90	13,000	.80
	16-30	18,646	.79	10,000	.61
October	1-15	13,776	.58	8,000	.49
	16-31	9,914	.42	6,000	.37
November	1-15	3,400	.14	4.050	.25
	16-30	3,400	.14	4,050	.25
December	1-15	3,400	.14	4,050	.25
	16-31	3,400	.14	4,050	.25

Source: E.D.F. Contract of 1955, modified 1981. S.R.A.E., Aix-en-Provence.

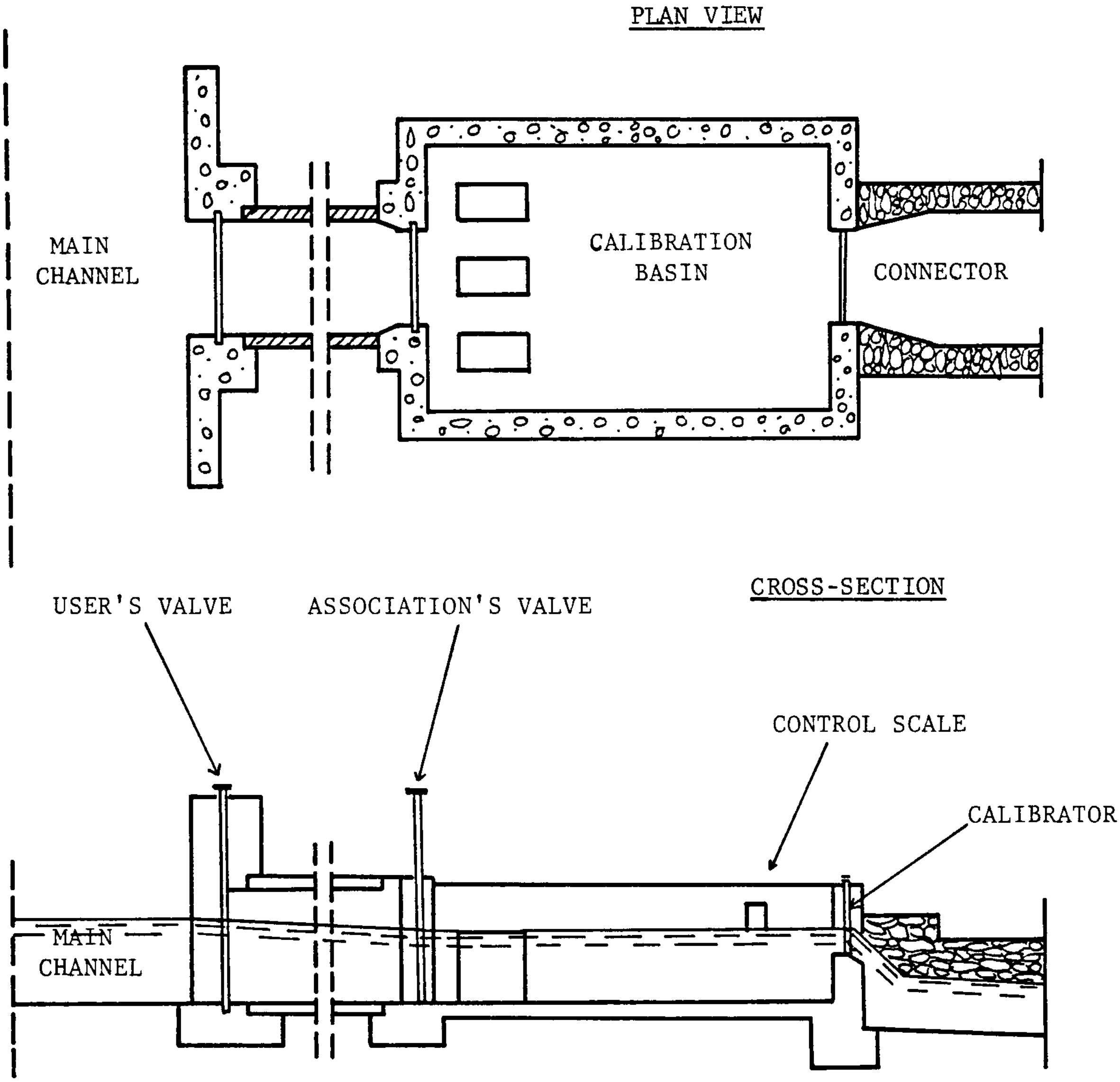


Figure III-5. Type of Water Intake.

Another problem is illustrated by pasture irrigation. From May to August it takes .5 liter/sec. to irrigate on hectare of land but about 12% or .15 liter/sec. is lost in transit; seepage in the pasture because of overflooding takes another .35 liter/sec., and .2 liter/sec. is collected by the drainage network at the end of the field. In this situation only 38% of the water taken out of the Durance River is used effectively with the remaining 62% being wasted. While it is impossible to avoid seepage in a field, it is possible to reduce losses in transportation. O.G.C., O.G.A and all other users are gradually lining canals with concrete. This could save up to 22% of the current water allocation for use elsewhere. To lower the operation costs users are encouraged to group land lots so that the water allocation of a lot would range from 35 liter/sec. to 144 liter/sec. and be delivered by only one valve on the main channel.

Agricultural Practices

Pasture in "calans" are still the major agricultural land use of the Crau today. These cover about 70% of the total irrigated area of the Crau, down from 90% in 1955. (Recenscement Général de l'Agriculture, 1980). Irrigation by "calans" requires the constant presence of a worker to stop the water input when four fifths of the length of the field is flooded so as to minimize the water losses by run-off and maximize the silt and nutrient deposition. This is equal to 80 millimeters of rainfall every ten and a half days. It is estimated that one fulltime worker is necessary to operate and maintain the irrigation system of 70 hectares.

Hay production is obtained in four to five cuttings a year with a total yield between 6 and 8 tons/ha. For years, the hay from the Crau was a trade mark controlled by the Department of Agriculture and was easily sold at a very high price. The trade mark disappeared in 1965, but due to its quality the horse racing teams remain loyal to the hay from the Crau. At the end of 1982, hay from the Crau was selling for 850 francs per ton ($120) compared to 500 francs per ton ($75) for alfalfa. (Produits et Marchés, 1982). The Crau produces 140,000 tons of hay a year representing a $16,800,000 business. As long as the horse racing teams remain profitable, hay will continue to sell for a good price.

Today more land is in crop usage and irrigated by furrows than ever before in the Crau. Orchards and market gardening have been developing in the Crau since the 1920's. The market economy after World War II made it more profitable to produce fruits and vegetables on a large scale for sale outside of the region, particularly in the North. Change in the Crau have been very slow and has come from new settlers, not local inhabitants. Hay is a good and safe product and local farmers do not work to abandon it. Besides, it requires little investments for those who were already in the system. Pioneers of the garden market cam from the Comtat-Venaissin or from the Marseille area because they could rent the land for a low price and get all the water they needed.

The main garden market product of the Crau is melons. They are grown on the "coussouls" after the biggest stones are removed and require abundant use of water and fertilizers. Stones remaining on the fields store heat from the sun and enhance growth in this case. At first melons were grown in open fields with lines of cannisses every 20 feet to reduce windiness. In order to harvest earlier and sell when the prices are higher, melons are cultivated under plastic today. Every year melon farmers move their melon fields to avoid disease, and the former melon field are used to grow other products such as cabbages, aubergins, leks, cucumbers and tomatoes to fully utilize their heavy infrastructure investment.

At first orchards were limited to the urban fringe of Salon-de-Provence, Istres and Arles where their product could be sold. Hay was traditionally exported to Algeria but the independence of Algeria caused a decline in sales and lead the Crau farmers to plant some of their pastures in orchards. Fruits ripen earlier in the Crau than in any other place in France, thus receiving the benefits of the best market prices.

Consequences of Durance River Regulation

Regulation of the flow of the Durance River had made gravity water available year round in the Crau. However other problems have been created. More water input in the Crau ecosystem means more drainage problems. With the flooding of new areas water started to reappear in places sometimes far from the irrigated areas. The opening of the Haute-Crau Branch of O.G.C. caused water to emerge all along the Arles-Marseille railroad. The response to high groundwater is to dig drainage channels and, as a consequence, the Crau today has a drainage network at least as important as its irrigation network (Figure III-6).

But the major problem of today's irrigation in the Crau is the water itself. Channelized and regulated by reservoirs the Durance waters do not carry as much silt as they used to. Silt deposition still occurs but in much smaller quantities. Much of the early development of the Crau was stimulated by using silt sedimentation to build surface soils.

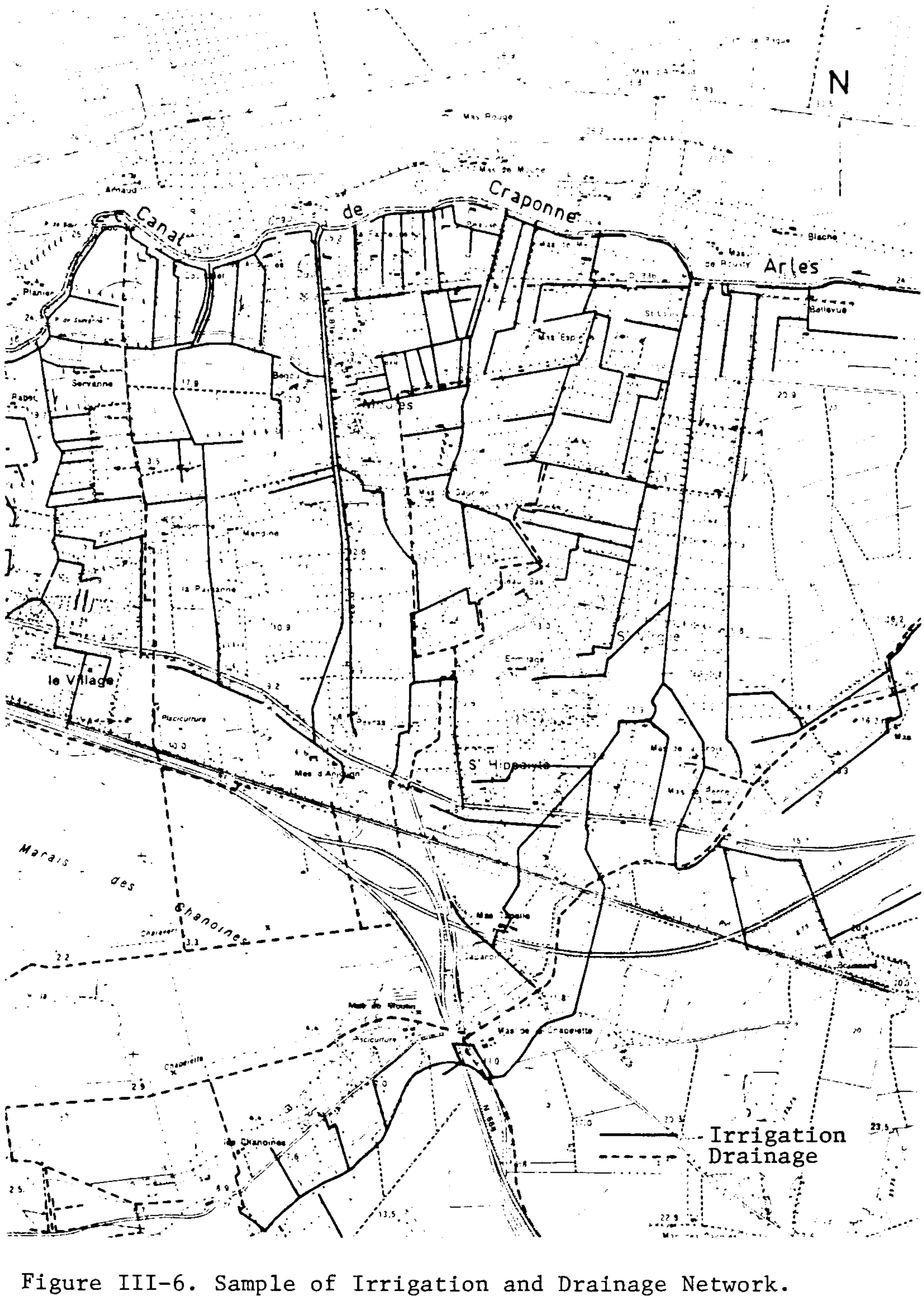


Figure III-6. Sample of Irrigation and Drainage Network.

Source: 1/25,000 I.G.N. Topographic Map of Saint-Martin-de-Crau.

If the silt content of irrigation water drops too low, it is possible that irrigation water will slowly leach the soils, taking away what it once brought. Farmers and Department of Agriculture have asked E.D.F. to maintain sufficient silt content to avoid leaching through irrigation. E.D.F. claims that the waters are agitated enough so that the silt content is maintained at a sufficient level. But the fact remains, there is less silt in irrigation water today. It will take a long time to monitor what is happening. It took more than one century to create these soils, their leaching may be equally slow.

Another problem is the climate modification. Since water is brought in the Crau to saturate the potential evapotranspiration, the Crau is no longer a place with dry air. Rather, humid air now dominates, making the Crau a place uncomfortable to live in during the summer.

Summary

Availability of gravity irrigation water in the Crau has been made quite certain by the regulation of the Durance River. Water is now stored in reservoirs and used for electricity generation while also being channelized downstream. Market garden farmers began using Crau land in part because of the low risk of drought. Local farmers tend to remain loyal to hay production. However, warping stopped due to the lower silt content of stored and channelized Durance River water.

CHAPTER IV

GROUNDWATER IRRIGATION IN THE CRAU

At the time when water management problems seem to be solved for the Crau another revolution in agricultural techniques is taking place. The change in the 1980's is the emergence of new forms of irrigation. People displaced to metropolitan France after the Algerian War ended in 1962 received resettlement money and some settled in the Crau. The newcomers have introduced spray and drip irrigation techniques, and the use of groundwater. Spray and drip irrigation cannot use the Durance River water because silt content clogs the equipment and thus the introduced system requires clear, groundwater.

This chapter will describe the new irrigation practices and their extent in the Crau. It includes a review of the causes of groundwater irrigation development, a description of the new techniques, an assessment of the groundwater supply, and a review of the modifications of the agricultural system caused by the new techniques and their influence on the ecology of the Crau.

The factors that caused the appearance of new irrigation techniques in the Crau include the consequences of the Algerian War (1954-1962) and the modification of the national market for agricultural products.

After horse traction was abandoned in France, Algeria became the largest market for hay from the Crau. The end of the war discontinued this trade and the price of hay dropped.

The end of the war also caused a flow of refugees to come back to France. Called "Pieds-Noirs", they received indemnification money from the Government for what they had lost in North-Africa. Many of them were farmers and sought agricultural land where they could settle down. Numbering close to one million, their appearance in the metropolitan agricultural system caused the prices of land to rise steeply, especially in the South of France. The higher prices these newcomers paid for their land forced them to use more productive forms of agriculture to make operations profitable. Those who come to the Crau found traditional agriculture of the Crau unattractive because they could not get sufficient return on their investment and could only afford small tracts, especially in areas of good quality soil.

In the early 1960's a modern infrastructure for agricultural trade materialized through the National Market Centers of Chateaurenard and Cavaillon and modified the business behavior of the farmers of the South. Cavaillon and Chateaurenard are among the major agricultural products supply centers for Paris and the North of France and provide the market garden farmers with a large market for their products. Many market gardeners from the Marseille area or from the Comtat-Venaissin, 30 kilometers north of the Crau, moved their operation in the Crau. The land was available as opposed to the Marseille area and the rent was cheaper.

Both categories of newcomers were free from the Crau tradition and were guided by their professional needs. They did not adhere to traditional agricultural practices because they believed that a modern drip and spray irrigation system was better suited to a high intensity use of small acreages.

Spray Irrigation

The first new irrigation technique introduced in the Crau was spray irrigation. Spray irrigation consists of the discharge of a fine jet of water from a pipe where the water is kept under pressure, through a sprayer. Lines of sprayers are distributed over the fields so that it receives an artificial rain. This technique requires a high water pressure in the pipe in order to work satisfactorily.

The newcomers first invested in spray irrigation using the available irrigation water from the Durance River but this water soon proved to be unworkable. Its silt content quickly clogging the irrigation pipes and sprayers. Wells were then dug and pumps installed to use groundwater. Groundwater was cost free as opposed to the Durance River water. It also did not involve water delivery schedules and the initial investment was entirely supported by the farmers. They also benefited from low rate and long term loans from the "Crédit Agricole". Studies on the effectiveness of different techniques were provided by the National Institute for Agricultural Research (I.N.R.A.) but public support did not extend to any direct investment.

Spray irrigation is very labor intensive. Several workers are needed to move the pipes and sprayers over the land when it is used in open fields and orchards. Spray irrigation also has a high consumption of energy. The pressure necessary to force water into the whole system and activate the sprayers is high. With the rising costs of energy and labor in the 1970's it appeared that new techniques requiring less energy and less labor would be more profitable, even if the investment was higher than spraying irrigation.

Drip Irrigation

Drip irrigation was introduced in the Crau to solve the deteriorating financial situation of farmers because of higher cost of energy and manpower. It involves the discharge drop by drop of water from pipes where the water is kept under pressure, just like in spray irrigation. However, drip irrigation does not produce an artificial rainfall over the whole field; rather water is delivered right ot the plant through a dripper at a rate computed to meet the plant's needs. This system does not require a high water pressure, thus reducing the energy costs.

Drip irrigation is usually conceived as a permanent system, controlled by automatic devices such as hygrometers, thermometers, or even a computer, thus minimizing human intervention. The investment cost of such a system is high when compared to the investment cost of spray irrigation, but operation and maintenance costs are much less. Water quality is very important; most drippers require that no particle be bigger than 100 microns. Groundwater of the Crau proved to have the required qualities and be plentiful, thus insuring a safe water supply.

Groundwater Supply

The soils of the Crau do not have a high water holding capacity. Water seeps rapidly through the A horizon and is stopped by the hardpan. The hardpan causes a secondary watertable that flows horizontally under ground level. About 60% of the water reaching the hardpan seeps through its cracks to reach the main watertable in the C horizon.

The main watertable is replenished by water coming from two origins: precipitation and irrigation. Annual precipitation on the Crau watershed brings about 590 millimeters of water on 61,500 hectares representing 362,664,000 m^3 or 11.5 m^3/sec. About 60% of this water, or 6.6 m^3/sec. is estimated to reach the watertable. It is also estimated that 17.5 m^3/sec. of gravity flow irrigation water is lost by seepage with 60% or 10.5 m^3/sec. reaching the watertable during the maximum irrigation period.

The water from both precipitation and irrigation water is seasonal but at different times. This dual influence of water contribution to groundwater supply is shown in figure IV-1. Wells in non-irrigated areas have a winter maximum while wells in irrigated areas have a summer maximum (Congrès de l'Eau en Crau, 1928). The timing of the recharge of the watertable is also shown in figure IV-2. Using the water level in wells in March and August, the same phenomenon appears: The watertable elevation increases in irrigated areas from spring to summer while it decreases in non-irrigated areas. It was also found that the wells located far from irrigated areas have a very high maximum water level in humid years (1955, 1956, 1960). Their regime closely followed the precipitation fluctuations whereas wells in irrigated areas show little variation from one year to another (Compagnie de Prospection Géophysique, 1962).

Two zones of groundwater availability can be delineated in the Crau. In the areas with gravity flow irrigation, the groundwater supply is at its maximum in summer because maximum diversion of the Durance River is from May through August. The rest of the year the groundwater supply is the result of recharge from precipitation, which is heaviest in fall and winter. Groundwater supply in non-irrigated areas will be lowest in late summer and will not be recharged until the rains of fall. Therefore,

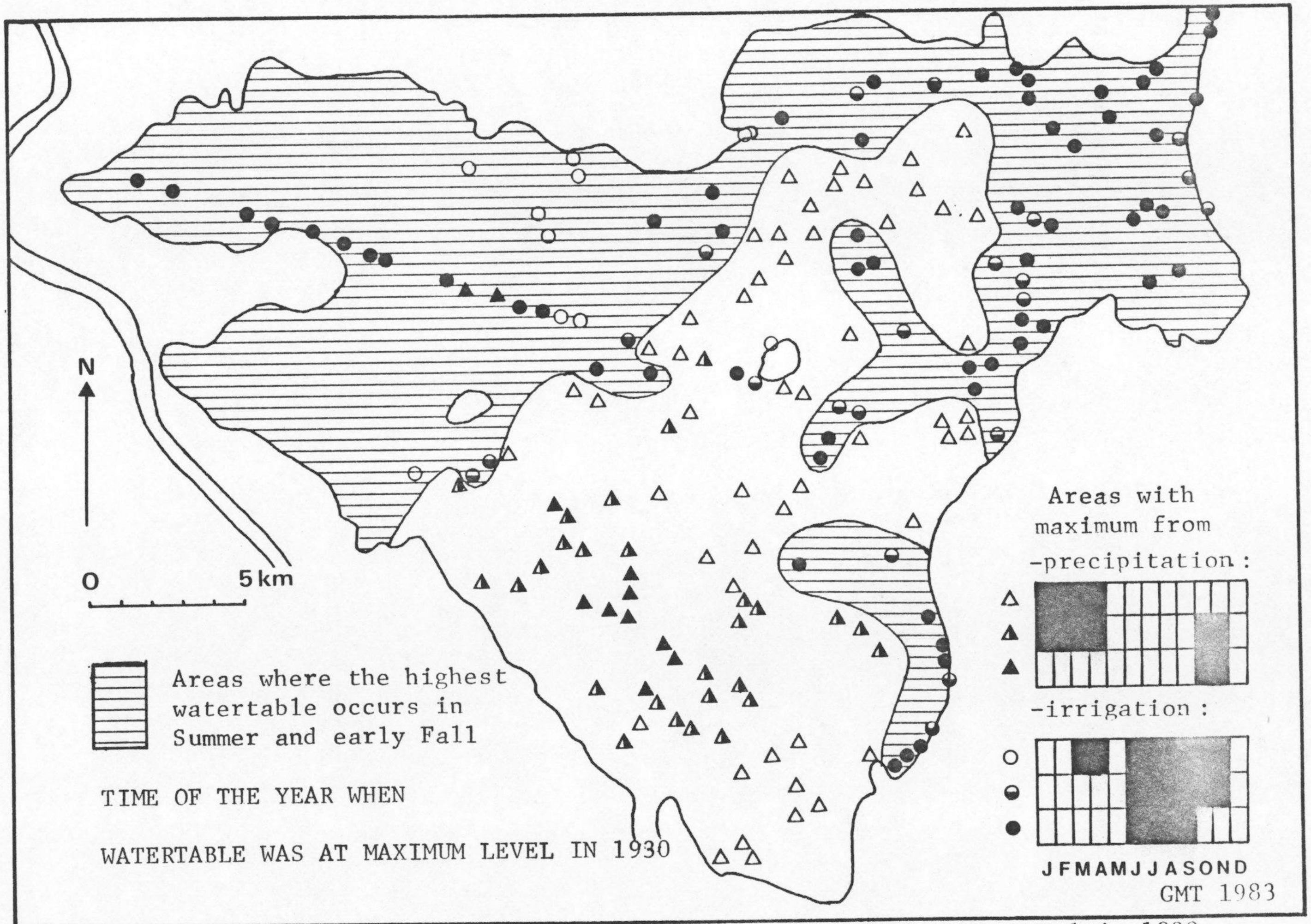


Figure IV-1. Time of the Year When the Watertable Was at Maximum Level in 1930.

Source: Congrès de l'Eau en Crau, 1930.

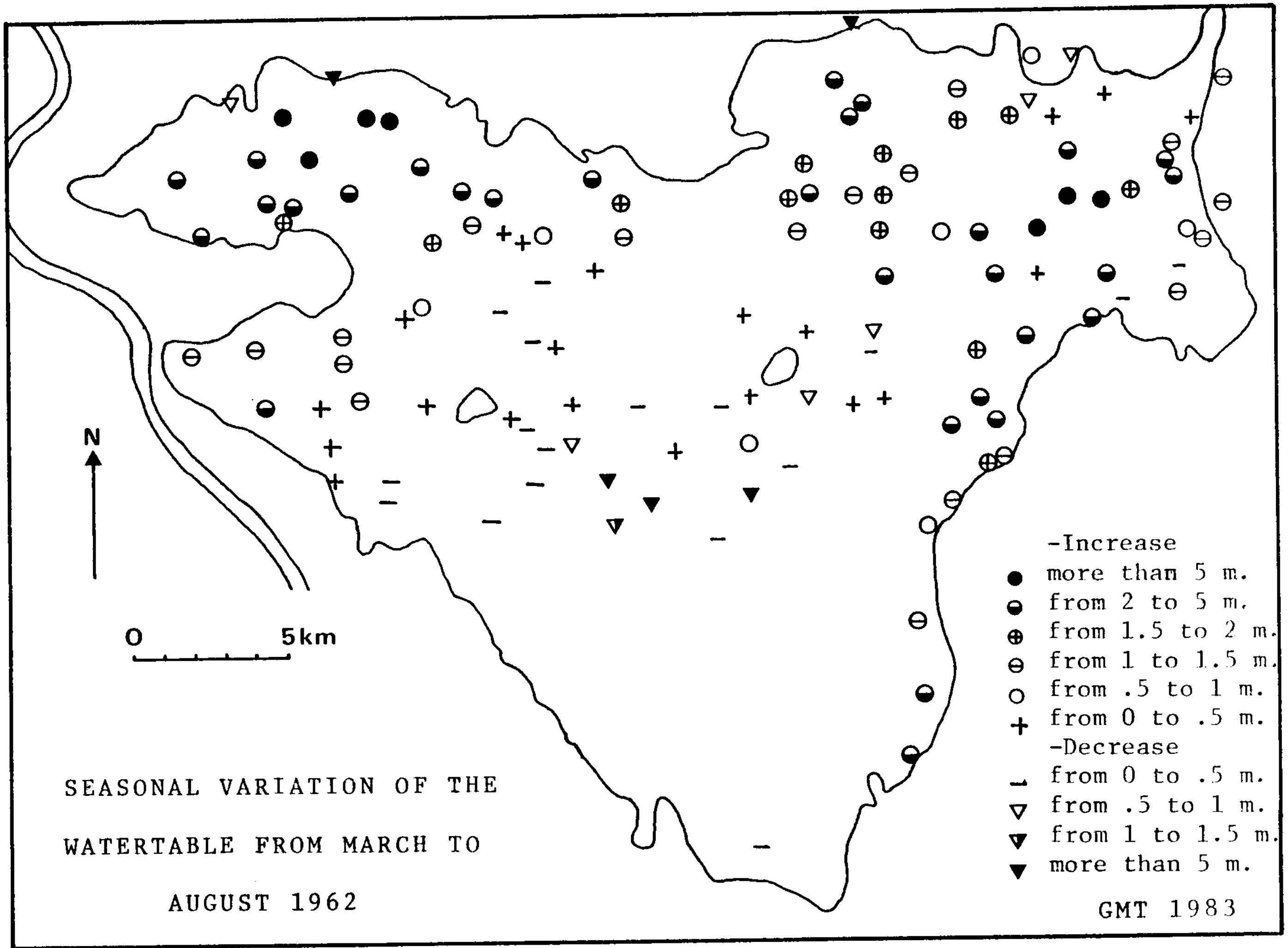


Figure IV-2. Variation of the Watertable from March to August 1962.

Source: Compagnie de Prospection Géophysique. 1962.

the use of groundwater for agriculture is more secure in already irrigated areas.

In some areas of the Crau, the watertable is very close to the surface making it easy to pump to the surface (Figure IV-3). If the watertable comes too close to the surface because of excessive water recharge there is the adverse effect of water logging of the root zone and plants suffer from poor aeration.

The general configuration of the watertable is shown in figure IV-4. Its surface follows the same general pattern as surface topography but is more varied. The highest point of the watertable is the Lamanon Pass and drops towards the South-West where it coincides with sea level. Due to the relief, groundwater literally flows in two major streams; from Lamanon to Istres and Fos-sur-Mer, and from Lamanon to Le-Mas-d'Icart through the central Crau with several branches. The quantity of water flowing in these streams was estimated to average 10 m^3/sec. in 1930 (Figure IV-5). Congrès de l'Eau en Crau, 1930).

First Uses of Groundwater

Several attempts to use groundwater were made during the 1920's and 1930's, but failed because the water was used according to traditional Crau methods. Because groundwater is pure and cold, the irrigated soils were leached quickly and the low temperature of water hampered plant growth. It was only in the late 1950's that groundwater irrigation became significant and successful in the Crau using techniques such as spray and drip that were developed elsewhere, particularly in Israel.

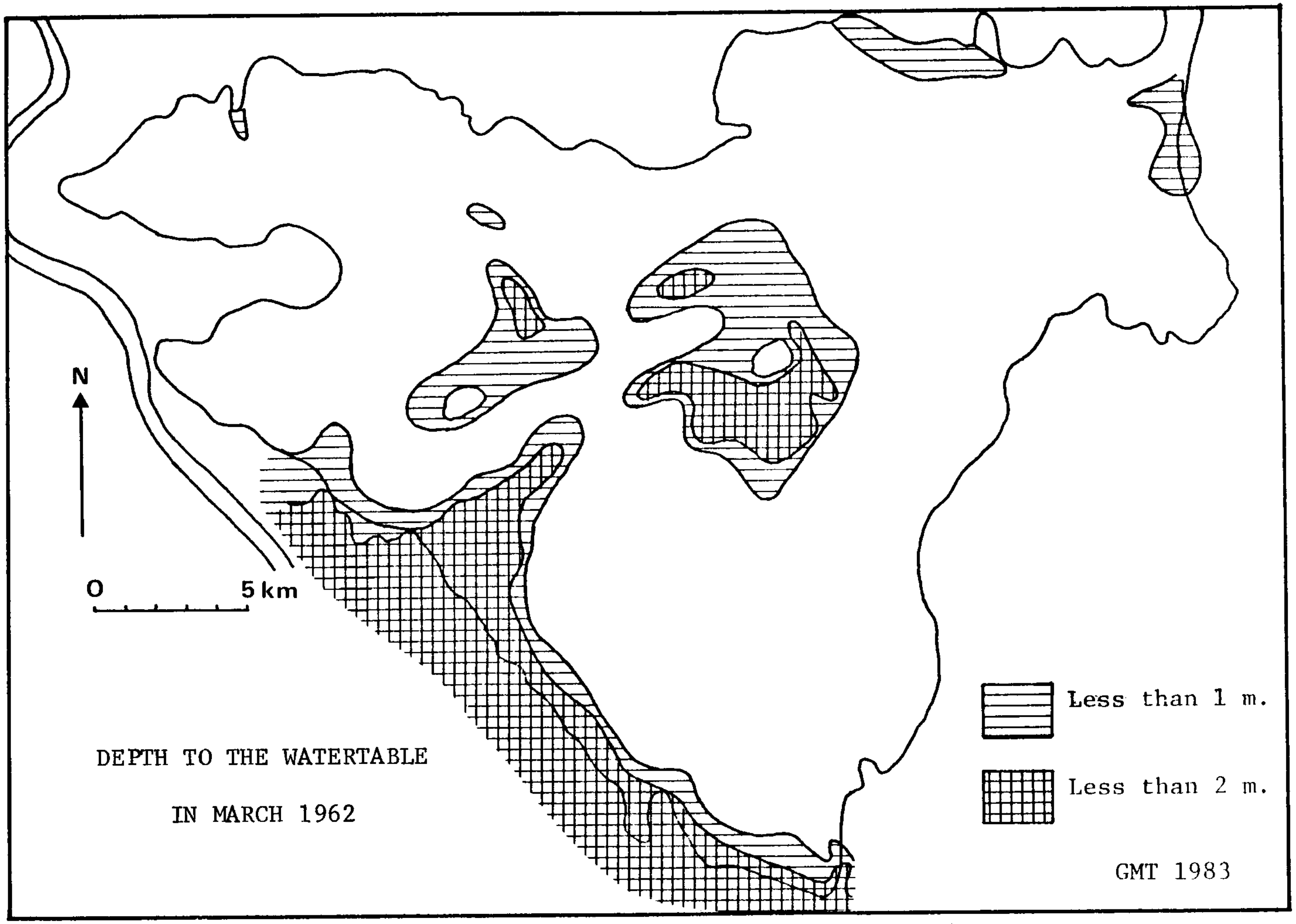


Figure IV-3. Depth to the Watertable in March 1962.

Source: Compagnie de Prospection Géophysique, 1962.

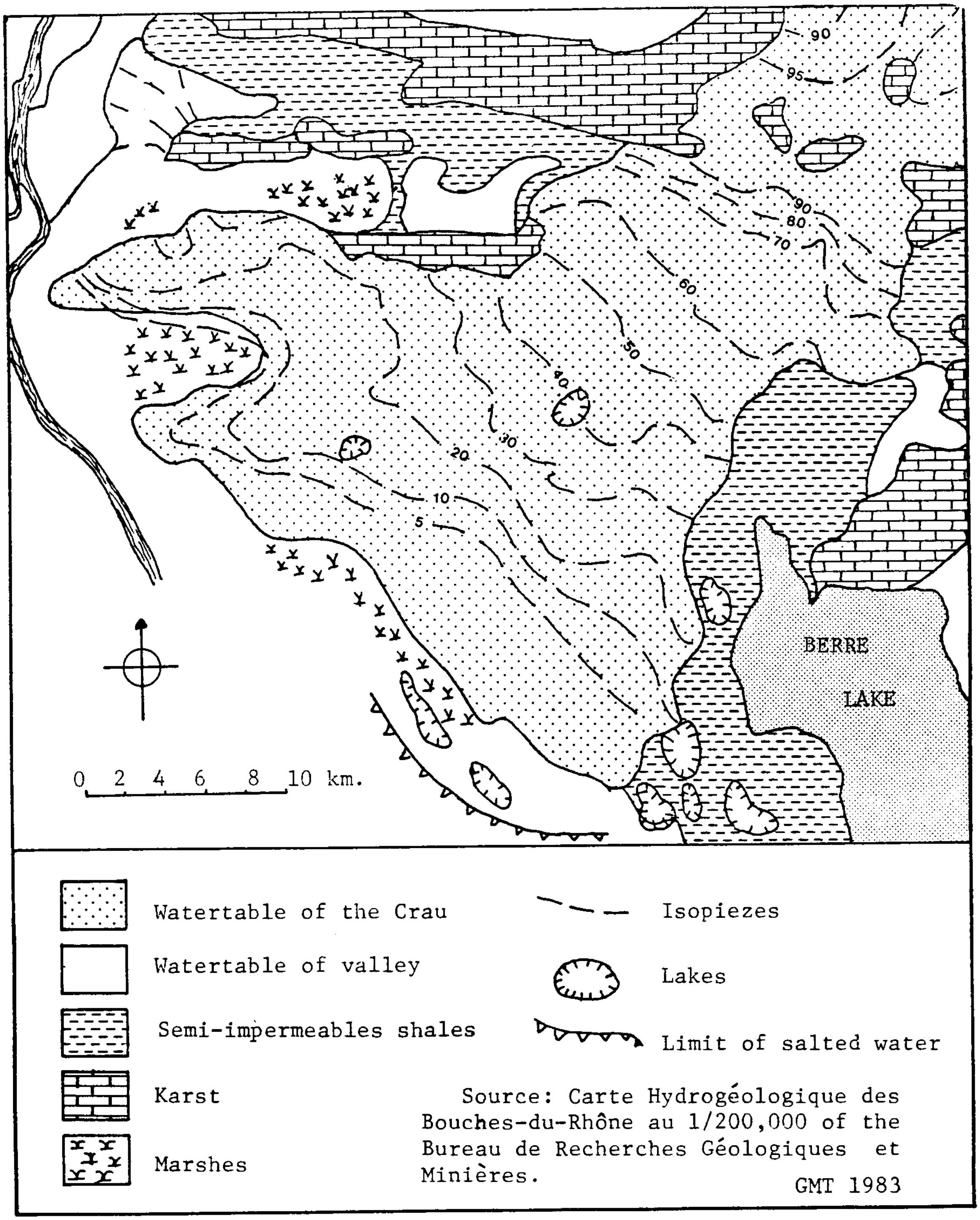


Figure IV-4. Groundwater in the Crau.

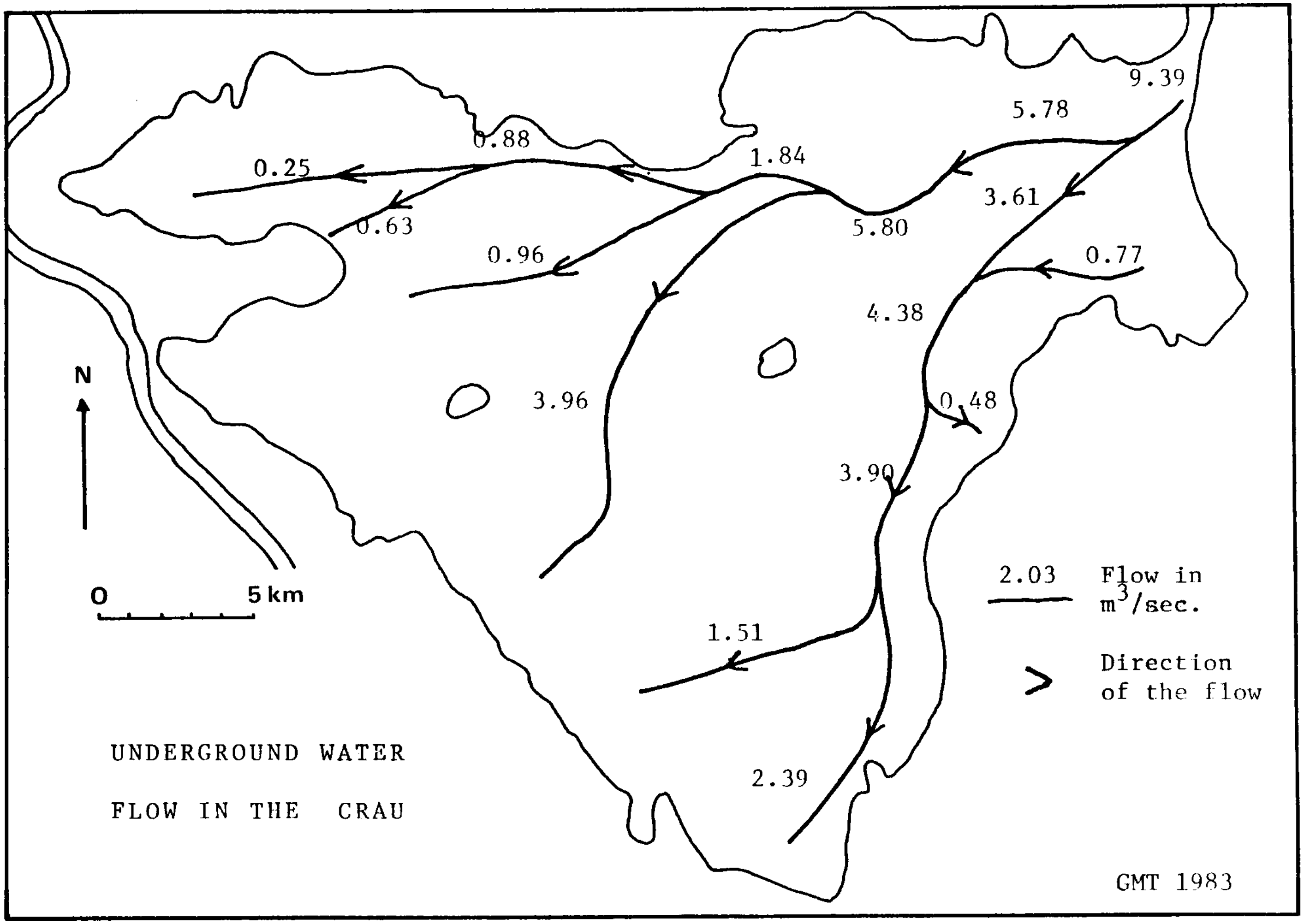


Figure IV-5. Underground Water Flow in the Crau.
Source: Congrès de l'Eau en Crau, 1930.

Groundwater is also pumped by industries located in the Crau. The National Explosive Factory located in La-Dynamite was one of the first users. Many industries cannot use surface water from the Durance River without purifying treatment to remove the sediment. It was cheaper and easier to pump groundwater that is available in large quantity. The costs of digging the shallow wells and putting on pumps were relatively low. Electric power and maintenance were the only permanent expenses.

Groundwater Irrigation

The appearance of groundwater irrigation marked the beginning of industrial farming in the Crau. Farmers select their product according to the market's prospective and adapt their production to the market conditions as quickly as possible.

Groundwater is used in open fields and greenhouses to produce vegetables and fruits in large quantity with priority given to high profit productions. The large, unrestricted and inexpensive water supply and the long growing season allowed farmers in the Crau to have a long season of production and the benefits of higher market prices with both early and late crops.

An Example

An interview with Mr. Thomine-Desmazures, a farmer in Saint-Martin-de-Crau, gives an overview of drip irrigation. He came to the Crau from Algeria. From 1960 to 1981, his 55 hectare farm was irrigated by sprayers using water from the upper watertable drawing from a four meter deep trench. The crops produced were tomatoes, cucumber and some cereals and fruits. But spray irrigation required high pressure and a three-man crew during the maximum irrigation period so he decided to shift to drip irrigation. Peach trees planted in 1975 were irrigated by sprayers at first, but 15 hectares have been converted to drip irrigation in early 1982. A well 20 meters deep was dug in order to get sediment-free groundwater. An Israeli-made Maral 2000 computer was purchased to regulate the system of hydraulic valves to control irrigation over the farm. Optimum dripper water flow in this area of the crau was determined by I.N.R.A. as being 4 liters/hour. Drippers are set on line so that each peach tree is surrounded by two drippers. The irrigation system is divided into section consuming the same amount of water so as to make it easier to control the system (Figure IV-6). Real evapotranspiration data are received daily from the nearby Istres Air Force Base and entered in the computer so that the necessary amount of water can be computed. The computer then controls the necessary flow of water for each section of the irrigation system according to the age of the trees. The summer of 1982 was used as a tune-up of the system. The remaining 40 hectares were equipped during the Winter of 1983 and today the only production of the farm is peaches irrigated by the drip system.

All costs were supported by Mr. Thomine-Desmazures. He estimates the total cost of equipping one hectare at 14,000 francs ($2,000). Savings from the manpower and energy costs are expected to pay for the system in five years. Mr. Thomine-Desmazures considers the risk of monoculture not as high as in most cases because his peaches will be ripe before others. Located on the main Craponne channel, he owns irrigation water rights that he sells to his neighbors thus adding to his income. He claims that drip irrigation insures better control over the

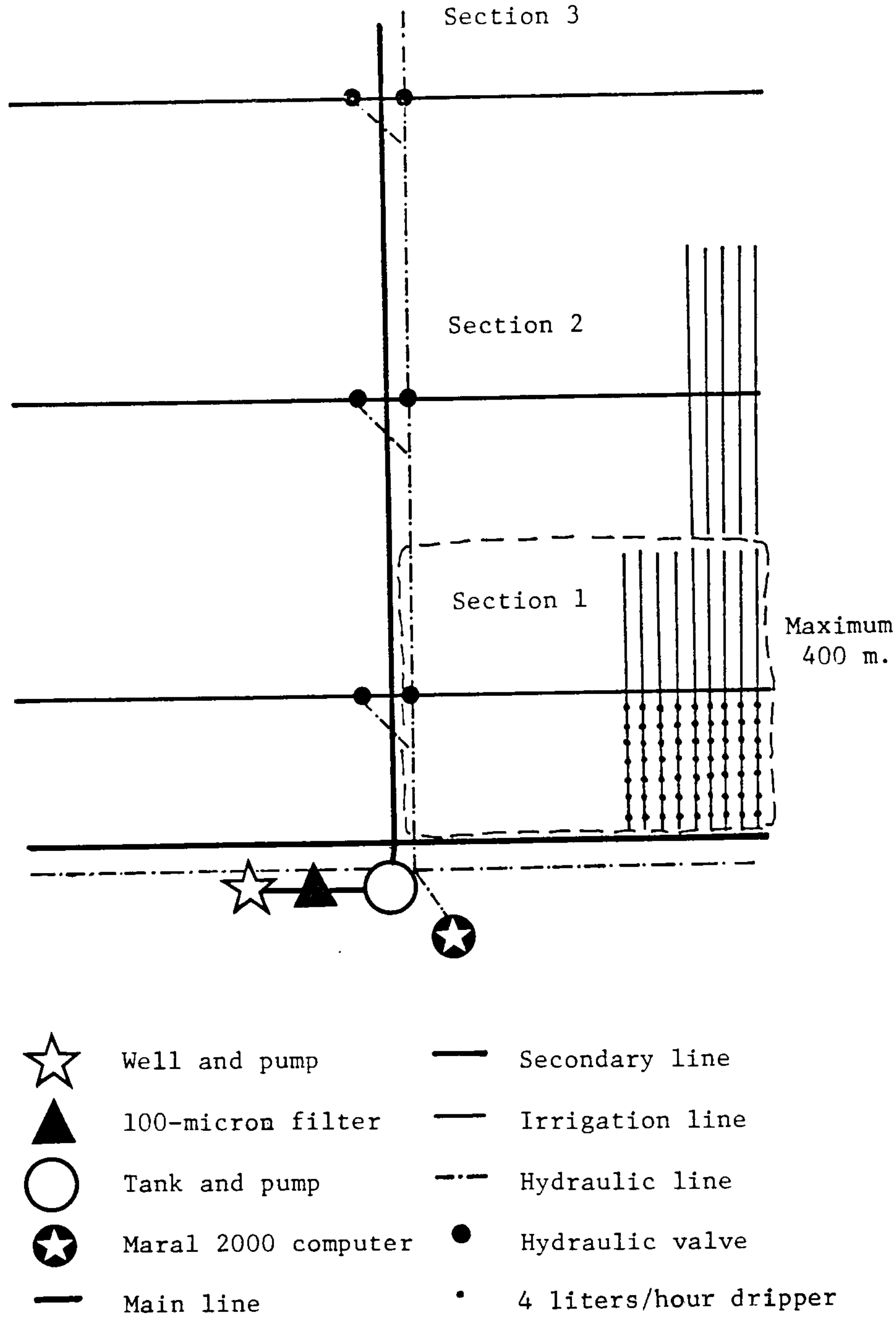


Figure IV-6. Example of the Irrigation Scheme of Mr. Thomine-Desmazures.

timing of production as well as regulating the fruit size for better marketing. Mr. Thomine-Desmazures does not use a calibrator anymore having sold it during Fall 1982. He believes that drip irrigation is the future in the Crau.

Situation in 1983

Although spray and drip irrigation practice have modified the Crau landscape, most of the Crau is still cultivated according to the traditional methods in 1983. The study of the 1979-1980 Agricultural Census (Recensement Général de l'Agriculture, 1982) shows that:

- Hay production still covers about 70% of the agricultural land and haying is practiced by 62% of the farmers. The average hay farm of the Crau covers 30 hectares. Hay farms are mostly located in the West and North of the Crau where they are as large as 300 hectares.

- Cereals, mostly rye, cover 9% of the land. Cereals are cultivated in the Western and Northern Crau where they are associated with hay production (16% of the farms).

- Orchards cover 3.7% of the agricultural land and are mostly located in the North and East of the Crau. Peach trees represent 43% of all the orchards planted, apple trees 20%, and apricot trees 19.5%. Orchards are found on 26% of the farms of the Crau and average 10 hectares.

- Vegetable production in open field covers .7% of the agricultural land and is practiced by 6% of the Crau farmers; it can be found everywhere there is irrigation. The average area devoted to vegetables is 3 hectares.

- Garden market production covers only 1.7% of the agricultural land, but is practiced by 30% of the Crau farmers. Garden market farms average 1.4 hectares and are mostly located in the East of the Crau from Istres to Salon-de-Provence and in the extreme West near Arles. 11% of the garden market farms use drip irrigation.

Hay farmers often devote small tracts of their land to cereal, vegetable or fruit production. They also rent land to garden market farmers. Hay and cereal producers use gravity flow irrigation, while most of the producers of orchards and garden market use groundwater irrigation in the form of spray. Drip irrigation is used on 11% of the garden market farms and on a part of the orchards; in any case drip irrigation is not widely used, yet. Vegetable production in open fields uses both spray and gravity flow irrigation.

The traditional association of the hay farmer and of the sheep herder still continues today. About 100,000 sheep are pastured in the Crau annually and the transhumance continues with trucks being used to move the animals to and from pasture.

Assessment of Groundwater Irrigation

The use of groundwater for irrigation has several advantages for garden market and fruit production. Once the wells are dug and the irrigation system installed, the water is virtually free and available at any time as opposed to gravity water from the Durance River which is delivered according to a schedule that may not fit the plants needs.

Groundwater of the Crau is clear and available in large supply, allowing the farmers to use spray and drip irrigation without clogging their water distribution pipes or running out of water.

The use of groundwater, however, brings some problems. The supply of sediment for warping land and natural supply of nutrients in Durance River water is missing from groundwater. Groundwater, in fact, may cause excessive leaching of soils if it is used in quantities that exceed soil moisture storage capacities. Since soils of the Crau are sandy, leaching can readily occur. The drip norm of 4 liters/hour is considered acceptable for most soils of the Crau. However, no real long term experiment has been conducted and it is uncertain what the effect of groundwater irrigation will have on soils of the Crau in the long run.

Summary

Groundwater irrigation was introduced by both garden market farmers and refugees from Algeria using spray irrigation at first, and later drip irrigation. It is used for intensive production of garden and fruit crops. As a result of long growing season the Crau offers a competitive advantage for such agriculture within the market of France. The effects of groundwater irrigation as practical result is more efficient use of water but may lead to leaching of soils.

CHAPTER V

CONCLUSION

Over four centuries of irrigation has transformed a large part of the Crau from a poor stony area into a productive agricultural region with good soils. This transformation is the result of the practice of both traditional and modern irrigation techniques supported by both private and public initiatives and funds.

From the mid-sixteenth century to World War II, the Crau slowly became an agricultural area. Private initiative at first, but quickly backed by public action, developed a gravity flow irrigation system based on the diversion of water from the Durance River through Lamanon Pass. This Durance River water with its sediments was used to create soils by a technique called warping. Warping and irrigation improved the original land conditions and the practices were widely accepted by the beginning of the nineteenth century. Farmers of the other regions of the lower Durance Valley then started practicing irrigation, thus increasing the pressure on the water supply. By the end of the nineteenth century the Durance River could not supply enough water to cover the summer needs and deficits reappeared.

This period is characterized by an agricultural system that was essentially stable, practicing year-round warping and seasonal irrigation. Hay combined with some cereals and transhumant sheep herding typifyed agriculture of the Crau.

After World War II the Government decided to regulate the Durance

River in order to fully use its potential to alleviate recurring droughts or periods of deficit. Electricite de France built reservoirs, channels and hydroelectric plants to reach its assigned goal. Since 1955, irrigation water has been available in sufficient quantity to cover all gravity flow irrigation water needs in the Durance Basin. The water supply is guaranteed today, thus making the practice of gravity irrigation secure in the Crau. However, the storage and channelization of the Durance River water caused its silt sediment to drop behind the reservoirs so that today it is impossible to use the irrigation water to warp non-developed tracts of land. In fact, there is some concern that these non-silt laden waters will leach out some of the sediments added in earlier years and the area will lose some of its man-made soils.

The situation was modified in another way with the end of the Algerian War that closed part of the market of hay, and brought refugees back to France, some of whom settled in the Crau. The consequent decline in hay price and increase in cost of land as well as a changing national agricultural market for specialty crops led to new agricultural practices in the Crau. Spray irrigation at first, and then drip irrigation began to appear in the Crau to support market-oriented production.

The market of hay of the Crau improved in the early 1960's with the opening up of horse racing and approval of betting on horse races. This provided the hay producers with a new market which revitalized traditional hay production practices. Thus, today both traditional flood irrigation and more recent spray and drip irrigation coexist in the Crau.

The Crau receives 39.848 m^3/sec. or 103,286,020 m^3 of water per month for gravity flow irrigation and an estimated 22 m^3/sec. or 57,024,000 m^3 from groundwater per month. The total water supply is then equal to 160,310,020 m^3 per month. Industry uses about 14 m^3/sec. or 36,288,000 m^3 per month, leaving the water available for agricultural use at 124,0220,020 m^3 per month. One hectare generally receives up to 3,154 m^3 of water per month if irrigated by gravity flow but only up to 1,840 m^3 per month if irrigated by spray and between 1,000 m^3 and 300 m^3 of water per month if irrigated by drip techniques.

The water supply available for agricultural purposes in the Crau exceeds the quantity of water that can be actually used. The water supply could theoretically irrigate 39,322 hectares using gravity flow irrigation but only 26,000 hectares are currently irrigated in the Crau. Such a supply would be enough for 67,000 hectares under spray irrigation and over 100,000 hectares using drip irrigation.

It is obvious then that the Crau is in a situation of water overabundance. This situation is likely to last because the gravity water supply is guaranteed by contract with E.D.F. and will be delivered no matter what happens as long as the contract remains in effect.

It should be also noted that not all non-irrigated land is available for agriculture (Figure V-1): large areas are owned and used by the Government: Istres Air Force Testing Center (A), Miramas Army Depot (B), Vergière Explosive Stockpile (C): other unavailable areas are Salon-Eyguières Airport (D) and Fos-sur-Mer Industrial Zone (E). The remaining area covers about 15,000 hectares and includes mainly a large area covered with big stones in the southern Crau, which would require an intense warping program to develop. This is unlikely to happen due to the drop

Figure V-1. Areas Not Available for Agricultural Development in the Crau.

Base: Enlargement of Landsat Image E-2182-09451 Band 5.

in silt content of the Durance River waters. Some development of irrigation is possible in the northern Crau, but these could not use all the available water supply.

Gravity irrigation is complementary to groundwater supply in the Crau. It provides water to groundwater supply while groundwater irrigation removes part of the excess water in the ground. It is desirable that both systems continue to be used in the Crau.

It does not seem that the Crau will experience major agricultural changes in the near future. The shift to groundwater is not likely to occur on a large scale and should be limited to orchards and market garden. As long as hay production remains profitable it will retard the shift to agriculture based on groundwater irrigation. The traditionalism of a large part of the Crau farmers will also slow down the shift to groundwater irrigation which is not suitable for large scale operation.

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