

No. 1,551.—“Irrigation in the South of France: Department of the “Bouches-du-Rhône.” By GEORGE WILSON, M. Inst. C.E.

THE department of the Bouches-du-Rhône is situated in the south of France, on the shores of the Mediterranean Sea. Marseilles is the chief town. The soil is mostly of a dry calcareous nature and the geographical position is such that generally but a small quantity of rain falls during the spring and summer months. Under the rays of a hot sun and a dry atmosphere, most of the crops become parched for want of moisture, and their production is consequently small in amount. But when the land is irrigated, under such a fine productive climate, crops of all kinds are both luxurious and abundant, consisting of wheat, rye, oats, barley, maize, grass meadows and pastures, luzerne, clover, potatoes, tobacco, madder, beetroot, hemp, vines, olives, mulberries, almonds, &c. Vegetables of all kinds. Fruits of great variety, such as peaches, pears, apples, apricots, plums, cherries, figs, quinces, medlars, pomegranates, jujubes, strawberries, melons, marjorams, mint, &c. The necessity for, and the great benefits to be derived from, irrigating the land have been known, appreciated, and practised by the inhabitants since the time that the Romans quitted the country, of whom there was an important colony in the Bouches-du-Rhône, the town of Arles was the centre of the colony.

The climate of the Bouches-du-Rhône, notwithstanding the mistral which blows occasionally, is considered one of the finest and most productive in France. There is comparatively little rain during some of the spring and summer months, and the temperature is high. The annual amount of rainfall varies considerably in different districts, and also yearly for each district, of the department. The following table (see next page) shows the average rainfall at Marseilles from 1860–1871.

This table shows that there is a mean rainfall of 11·2 inches for the seven months, March–September. The mean temperatures in the district of Marseilles, from observations continued during more than fifty years, are for the whole year, in degrees Fahrenheit 57°·9; summer, 70°·9 (the maximum being 92°·3 for nine years); and winter, 45°·5. In the district of Arles the mean temperatures for the whole year are 58°·8; summer, 74°·7 (the maximum being 99°·5), winter, 43°·5.

Seasons and Months.		Rainfall per Month.	Number of Rainy Days per Month.	Rainfall each Season.	Number of Rainy Days each Season.
		Inches.		Inches.	
Winter	{ December . . .	1.5	5.2	4.9	15.4
	{ January . . .	1.7	5.2		
	{ February . . .	1.7	5.0		
Spring	{ March . . .	2.1	6.6	5.2	15.1
	{ April . . .	0.9	3.0		
	{ May . . .	2.2	5.5		
Summer	{ June . . .	1.1	3.5	3.2	8.8
	{ July . . .	0.5	3.1		
	{ August . . .	1.6	2.2		
Autumn	{ September . . .	2.8	5.1	8.8	16.9
	{ October . . .	3.3	6.1		
	{ November . . .	2.7	5.7		
		22.1	56.2	22.1	56.2

For comparison with the above-mentioned rainfalls and temperatures in the Bouches-du-Rhône, the following are particulars of the same for Spain, Italy, and Algiers. For Spain, the mean temperatures at Madrid for summer, April–September, are $67^{\circ}\cdot 8$; winter, October–March, $48^{\circ}\cdot 6$; at Seville, summer, 81° Fahr., winter, 64° ; at Valencia, summer, $75^{\circ}\cdot 5$; winter, $57^{\circ}\cdot 6$; at Alicante, summer, $71^{\circ}\cdot 9$, winter, $58^{\circ}\cdot 8$.

TABLE SHOWING ANNUAL RAINFALL IN ITALY, ALGIERS, and SPAIN.¹

		Inches.
Italy	{ Lombardy	38.0
	{ Piedmont	37.0
Algiers	{ Algiers	27.0
	{ Bona	25.0
	{ Oran	14.5
Spain	{ Granada	33.42
	{ Seville	22.51
	{ Valladolid	20.86
	{ Zaragoza	17.03
	{ Valencia	15.88
	{ Alicante	13.58
	{ Madrid	11.98

¹ "Irrigation in Spain," by George Higgin, M. Inst. C.E. Minutes of Proceedings Inst. C.E., vol. xxvii., p. 483.

TABLE SHOWING COMPARATIVE MEAN and MAXIMUM TEMPERATURE and MEAN RAINFALL of ITALY and SPAIN DURING the SEVEN IRRIGATING MONTHS from MARCH to SEPTEMBER.

—		Mean Rainfall.	Mean Temperature.	Maximum Temperature.
		Inches.	Fahr.	Fahr.
Piedmont	General average . .	29·00	63·2	85·3
Lombardy	{ Milan	22·00	63·2	85·9
	{ Pavia	22·00	66·1	88·0
	{ Brescia	22·00	65·3	86·4
Spain	{ Madrid	5·31	64·7	98·0
	{ Alicante	7·66	69·4	94·0
	{ Valladolid	8·98	62·5	90·0
	{ Seville	5·45	78·0	111·0

The system of irrigation has been for centuries gradually extended in the department of the Bouches-du-Rhône, necessitating the execution of important canals and works, some of which are not surpassed in an engineering sense by any others for a similar purpose, resulting in enormously improving and enriching the country. The geographical position of a large extent of the department is admirably situated for the purpose of irrigation by means of the water of the river Durance, which flows along the north side of the department at a considerable altitude.

In Plate 5 is shown a map of a portion of the department with the main irrigating canals, &c., the particulars of which are stated in the reference on the map.

Before describing the mode and results of irrigation in the Bouches-du-Rhône, a brief description will be given of the river Durance, from which the irrigation canals mostly derive their waters, and also a few details of four of the main irrigating canals.

THE DURANCE.

The source of this river is in the Alps, separating France from Italy, and the river flows into the Rhône near Avignon. Its mountainous basin is about 5,200 square miles superficial area, and its main tributaries are the rivers Verdon, Asse, Bléone, Ubaye, and the Guil, all of which are generally torrential. The inclination of the bed of the Durance is considerable; it increases

continually in steepness in following its course from its conflux with the river Rhône up to its mountainous basin in the Alps. From the river Rhône to Mallemort the inclination is about 1 in 500, from that point to Pertuis 1 in 400, then 1 in 330 to the junction of the river Verdon, and 1 in 250 to the junction of the river Bléone, after which the inclination becomes excessive up to the source of the river. The quantity of water in the Durance, at extreme low water and at the greatest floods, varies from about 1,400 to 210,000 cubic feet per second. At ordinary low water there is a flow of about 2,540 cubic feet per second. A large quantity of sediment is carried in the water of the Durance, estimated at about 17,000,000 tons per annum. This sediment being a rich alluvial soil, containing more than 40 per cent. of carbonate of lime, flows into the river Rhône, and is deposited by that river, near its mouth, in the Mediterranean Sea. The immense Camargue plain, near the mouths of the river Rhône, embracing an area of more than 220,000 acres, has been gradually formed, in the course of time, by means of the alluvial deposits of that river, and the process is still going on, gradually extending the plain further into the sea. At a remote chronological period the town of Arles was close to the sea; whereas, at the present time, the sea is 24 miles distance from that town. A more recent estimation of the extent of this alluvial deposit is afforded by the fact that the tower of St. Louis was built in 1737, near one of the mouths of the river Rhône, and that at the present time the sea is about $3\frac{3}{4}$ miles distant from that tower.

In addition to the sediment mechanically suspended, the Durance waters hold much valuable agricultural matter in solution, which is considered the main cause of the waters of that river being so valuable for irrigating purposes. The quantity of sediment mechanically suspended increases with the flow of the river. The ordinary maximum is about 30 grammes of sediment to 1 litre of water, equal to a proportion of $\frac{1}{33}$ by weight. In exceptional cases, as in August 1858, the proportion was as high as 100 grammes per litre of water, or $\frac{1}{10}$ by weight. In extreme low water the proportion by weight is about $\frac{1}{1000}$. The average proportion for the nine years 1867-75 was about $\frac{1}{550}$. For irrigating purposes the water, when containing much sediment in suspension, is injurious if caused to flow over certain crops, excepting in such cases where it can be applied only to the roots. The following analysis by M. Paul de Gasparin, of the Central Society of Agriculture of France, shows an average composition of the matter held in solution in the water of the Durance after being filtered.

The proportion of solid matter being about $\frac{1}{1600}$ the weight of the water.

	Per cent.
Silicic acid	1·23
Phosphoric acid	0·04
Sulphuric acid	12·67
Chlorhydric acid	4·35
Carbonic acid	41·70
Lime.	31·56
Magnesia	2·74
Soda	3·84
Potash	1·82
	<hr/> 100·00

For comparison with the above, the following is an analysis, by Dr. Voelcker, of the proportion of the solid matter held in solution in the clear filtered water taken from the river Nile at the beginning of the rise. The proportion of solid matter, when dried, held in solution being about $\frac{1}{4000}$ of the weight of the water :—

	Per cent.
Oxides of iron and alumina with traces of phosphoric acid	0·38
Silicate of lime	10·00
Carbonate of lime	23·54
Carbonate of magnesia	15·15
Carbonate of potash	3·56
Carbonate of soda	17·56
Chloride of sodium	12·40
Sulphate of potash	5·02
Nitrate of potash	0·97
Organic matter	11·42
	<hr/> 100·00

A quantity of the sediment, mechanically suspended, taken from the river Durance, was submitted to Dr. Voelcker for analysis, and gave the following result :—

	Per cent.
Organic matter and water of combination ¹	2·770
Oxide of iron	4·348
Alumina	1·550
Phosphoric acid	0·102
Carbonate of lime	42·625
Sulphate of lime.	1·197
Magnesia.	1·250
Potash	0·434
Soda	0·222
Nitric acid	0·001
Insoluble siliceous matter	45·501
	<hr/> 100·000

¹ Containing nitrogen. 0·063 per cent.
Equal to ammonia 0·076 „

For a distance of about 60 miles, between the points of conflux of the rivers Verdon and Rhône, the Durance flows at an altitude of several hundred feet above the level of the sea. There is thus ample fall for its waters to flow along the numerous canals on to the land by gravitation.

THE CRAPPONNE CANAL.

The authority to construct this canal was conceded to Adam de Craponne, an eminent engineer, in the year 1554. It takes its water, through sluices, from the river Durance, near to St. Estève-Janson, at an altitude of 492 feet above sea level. There the river varies from 600 to 6,500 feet in width, and the bed consists of a succession of sand and gravel banks, and alluvial deposits, intersected by numerous branches, which shift at every flood. Such a state of things cannot be considered as constituting the bed of a river, in the ordinary acceptation of the term, and to have constructed a permanent and fixed barrage across the river, to lead the water through the sluices, would have been not only a costly work at that remote time, but also one of considerable difficulty. Craponne constructed, therefore, what are termed *barrages volants* across the river. These are formed, where the depth of water is about 2 feet, by stakes, with fascines, and filled in with stones. In the deeper parts of the river, which may be sometimes 12 to 15 feet, *chevalets* in place of stakes are driven, consisting generally of trunks of trees cut near the point of the bifurcation of the principal branches, and which are placed closer together in proportion to the depth. The *chevalets* are bound by cross-pieces and supported by fascines. These *barrages volants* are always placed obliquely to the current of the river, for the purpose of causing the fascines to press against the stones or the *chevalets*. Such *barrages volants* need continual repair, but their cost is comparatively trifling. It is mostly a question of labour, as the material employed is cheap. The average cost of maintenance of the barrage for the Craponne canal is about £500 per annum. This system, adopted by Craponne more than three hundred years ago, has never been changed, and has been found by experience to answer its purpose of diverting the Durance waters through the sluices into the canal in all seasons; and the same system is adopted for some other irrigation canals. The Craponne canal, being the main canal from the river Durance, to Lamanon, is $14\frac{1}{4}$ miles in length. At Lamanon the canal has two main branches, one flowing south towards Salon and St. Chamas, and the other to the west towards Arles. The total length of the

canal, with its branches, is about 77 miles, not comprising the whole development of the branch to Arles, which is a special property independent of the original canal. The quantity of water supplied by the canal is as follows:—The main canal is 26 feet wide, and 6·5 feet deep; the mean velocity is 5 feet per second. The branch to Salon is 10 feet wide, and 6·5 feet deep; the mean velocity is 6·5 feet per second. The branch to Arles is 16·5 feet wide and 3·28 feet deep; the mean velocity is 5·3 feet per second. The branch to Istres is 6·6 feet wide, and 3·3 feet deep; the mean velocity is 6·6 feet per second.

Crapponne ruined himself in carrying out the works, and in order to raise funds and satisfy his creditors, he was compelled to grant concessions for the use of the water at very low prices. These concessions have given cause to continual law-suits and troubles in the administration of the canal, and have been a hindrance to the proper development of the canals. The volume of water employed is from 350 to 500 cubic feet per second for irrigating purposes, and for moving thirty-three mills situated on the course of the canal. But the canals are of sufficient capacity for a volume of 850 cubic feet of water per second, and it is estimated that the area of the land upon which the waters of the Crapponne canal could be caused to flow for irrigation is more than 100,000 acres. The surface actually irrigated by the canals, including the branch to Arles, is about 24,000 acres.

THE ALPINES CANAL.

This, which was commenced in 1773, takes its water, for the main channel, from the Durance at Mallemort, and for the west branches near Châteaurenard. The main canal is considered one of the best in Europe as regards its utility. The system consists of more than 194 miles of canal, disposing of 770 cubic feet of water per second, which with the west branches of the canal, irrigates more than 20,000 acres. The branches to Tarascon and Barbentane have generally an inclination of 1 in 2,000. In some portions of the former branch the inclination is 1 in 4,500; in other portions 1 in 1,250; while over some of the aqueducts it is as much as 1 in 154. The widths at the bottom of the west branch canal vary from 7·8 to 9·2 feet, and for the branch to Barbentane between 5·2 and 6·2 feet. The inclination of the slopes varies from 1 to 1 to $1\frac{1}{2}$ to 1 in ordinary cuttings and embankments. The west branches of the canal have passed through considerable financial difficulties, and are now managed by an independent company.

In order to develop irrigation, numerous syndicates have been formed, as some of the land was held in small parcels by proprietors and farmers who had neither the funds nor the power, in opposition to intervening landowners, to obtain branches to conduct the water from the main irrigating canal to their properties. The price charged for the water is regulated by the price of corn, on the basis of 1.66 bushel per acre irrigated. The quantity of water given at the above rate is fixed at about 0.57 gallon per acre per second, supposed to flow continuously during the irrigation season, commencing on the 1st of April, and terminating on the 1st of October of each year, which is equal to covering the ground for the total number of irrigations to a depth of $66\frac{1}{2}$ inches, and with 22,130 cubic yards of water. In 1874 the cost of irrigation was equivalent to about 11s. 6d. per acre, being the price of 1.66 bushel of corn. The price has recently been reduced to about 8s. per acre, for three irrigations required during the season for such crops as corn and olive orchards. The same reduced price per acre is also charged for inundating vineyards during the autumn, as a preventive to the phylloxera.

THE MARSEILLES CANAL.

This canal, one of the most important engineering works in France, commenced in 1837 and completed in 1848, is constructed for the double purpose of supplying the town of Marseilles with water and for irrigation. The canal takes its water from the Durance, near the suspension bridge at Pertuis, at an altitude of 614 feet above sea level. The greater portion of the main canal is constructed through a hilly country. It is $51\frac{1}{2}$ miles in length to the boundary of the Marseilles territory, 10 miles of which is through tunnels. Three of the principal tunnels are each about 2.18 miles long. The canal, on arriving in the territory of Marseilles, continues for a distance of $26\frac{1}{4}$ miles to Montredon. There are, in addition, five branches of a total length of $21\frac{1}{4}$ miles. The main canal is 9.84 feet wide at the bottom, 30.8 feet wide at the top, and 7.87 feet deep. The inclination of the canal is 1 in 3,333. Its maximum capacity 424 cubic feet of water per second. One of the numerous important works of art on this canal is the Roquefavour aqueduct,¹ 1,253 feet in length, 271 feet in height above the river Arc, and constructed with three tiers of arches.

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 190.

The following are the principal dimensions of this aqueduct :—

	Feet.
Length	1,253
Total height above low water of the river Arc	271
Width of the piers at the base	44½
" " " top	14¾
Number of arches in first tier, 12.	
" " second tier, 15.	
" " third tier, 53.	
Span of arches in first tier.	49½
" " second tier	52½
" " third tier	16½
Width of the water-way of the aqueduct.	7¼
Depth " " "	7½
Inclination of the water-way, 1 in 250.	

Other important works consist of the dam across, and inlet sluices at, the river Durance; and settling basins, to rid the water of the sediment mechanically suspended, in order to render the water fit for domestic purposes. Four such basins have already been silted up with the sediment deposited in them, and the fifth, the Réaltort basin, 173 acres in superficial area, and having a capacity of about 159,000,000 cubic feet, is also fast filling up. In consequence of the continual silting up of the settling basins, another basin, with the necessary works for flushing it out, estimated to cost £65,000, is being executed in the valley of St. Christophe, situated near the Durance, 9¼ miles below the sluice through which the canal takes its water from the river. It is formed by constructing a masonry dam across the valley, 218 yards in length, 72 feet in height, and 55¾ feet in width at the base. The superficial area of the basin will be 57 acres, and its capacity equal to 81,000,000 cubic feet. At the end of each year, when a depth of about 5 feet of sediment has accumulated at the bottom, it will be flushed out into the river Durance at a lower level. The total cost of the canal to 1876 has been £1,792,800, which includes land, works, settling basins, and laying the pipes for supplying the town of Marseilles with water. To cover the above cost, and for payment of interest, the town of Marseilles has borrowed from time to time £2,279,000, which sum is to be redeemed partly by the revenues derivable from the canal, and partly by specified taxes; particularly by an additional tax on flour, which produced a sum of £41,160 in the year 1875. More than two thousand occupiers of land subscribe for the water for irrigation, and the total area under irrigation is more than 8,000 acres. The owners of one hundred and seven mills use the fall of the water in the canal for motive-power, developing 1,592 HP.

The revenue derived from the Marseilles canal for 1876 has been :—

	£.
Town subscription	13,400
Country "	25,000
Subscription for motive power	16,320
Payments by new subscribers for connecting works	4,600
Total	<u>59,320</u>

The annual cost of maintenance of the canal is important.

The Marseilles canal, belonging exclusively to the town, has not been subjected to financial difficulties. Some of the other irrigation canals, however, in the Bouches-du-Rhône have had to make from time to time disastrous concessions to raise funds; thus causing not only obstacles in developing the resources of the water to the best advantage, but also a reduction in the anticipated revenue, so much so as to give no encouragement to the shareholders.

The tariff arrangements and regulations of the Marseilles canal for the distribution of the water, as determined by the municipal council and fixed by the Prefect of the Bouches-du-Rhône, for irrigation and water-power, are as follows; subscriptions for the water being limited to a duration of fifty years.

Water supplied periodically, or for irrigation, including the expense of the connecting conduits and annual payment—

Quantity of Water supplied per Second for a period of Six Months.		Amounts to be Paid for making connecting Conduits.	Annual Subscriptions.
In Litres.	In Cubic Feet.		
1·00	0·0353	£. 16	£. s. d. 3 4 0
0·50	0·0176	8	1 16 9

Not less than half a litre (0·44 quart) per second can be subscribed for.

Water supplied continuously in the district—

Quantity of Water.			Amounts to be Paid for making connecting Conduits.	Annual Subscription.
In Modules.	In Litres per Twenty-four Hours.	In Cubic Feet per Twenty-four Hours.		
2·00	17,280	610·17	£. s. 20 0	£. s. d. 7 12 0
1·00	8,640	305·08	10 0	4 12 0
0·50	4,320	152·54	5 0	2 17 7
0·20	1,728	61·02	2 12	1 15 2
0·10	864	30·51	1 8	1 1 7

The water measuring $\frac{1}{8}$ module is only supplied in the country for lands less than 20 ares area (0.494 acre), and $\frac{1}{10}$ module when the area is 10 ares and under.

The tariff for the use of the water for motive-power at the numerous falls along the canal is £11 per horse-power per annum, but it must be subscribed for a period not less than six years. A horse-power is fixed at 100 litres of water falling 1 mètre per second, equal to 43,296 lbs. falling through 1 foot per minute. The water, after being used for motive-power, must be returned to the company's canal at a lower level, and not appropriated for any other purpose except by special arrangement with the town. When the water is not used by subscribers for irrigation, it can be employed temporarily for motive-power at the rate of £1 per HP. per month. In addition to the above charges, the subscribers have to pay for the cocks, or sluices and overflows for the purpose of obtaining and regulating the quantity of water subscribed for. The town undertakes to execute these works, payable in advance, for a fixed amount of 12s. per conduit for water taken periodically, and £1 4s. for water taken continuously, comprising the regulator, &c. It delivers the water by a conduit, whether open or covered, up to the boundary of each property, maintains the conduits, and does the service for regulation. The above are the general charges for water; but in some special cases, where additional canals have been made and the ground is more difficult, the prices to subscribers are increased both for the first outlay and for the annual cost of the water. The season for irrigation is fixed for a period of six months, commencing on the 1st of April, and terminating on the 1st of October. The quantity of water, subscribed for by each proprietor, means that the subscriber is entitled to receive the quantity agreed upon per second supposed to flow continuously for six months, the season for irrigation. For example, suppose a proprietor subscribes for 1 litre per second, he would be entitled to receive, at fixed periods, as many litres of water as there are seconds in six months. The town sends to each subscriber, before the 1st of April of each year, a table showing the dates and hours at each date that the water will be supplied to him during the season. It is found from experience that 1 litre of water per second is a good average quantity to irrigate 1 hectare, or 2.47 acres, of land. One litre of water per second (supposed to flow continuously) for six months, say one hundred and eighty-three days, is equal to 15,811,200 litres, which is sufficient to cover a hectare of ground with water to a depth of 62 $\frac{1}{4}$ inches. That volume of water may be used during the season by forty-three irrigations, each of three hours duration,

with a flow of 34 litres per second. The ground, in such a case, would be covered at each irrigation with water to a depth equal to a fraction less than $1\frac{1}{2}$ inch.

The water of the Marseilles canal, to the end of 1876, was disposed of as follows:—

	Litres.	Cubic Feet.
	Per second.	Per second.
For irrigation, already subscribed for	3,530	124·61
Continuous water, subscribed for in the territory	512	18·07
For Canal d'Aubagne	1,000	35·30
For watering roads.	250	8·83
For fountains	100	3·53
For the streams des Ayglades, Jarret, &c.	560	19·77
For public service, supply of the town of Marseilles } and purifying the port }	2,400	84·72
Losses by percolation, evaporation, and at the } settling basins }	1,648	58·17
	10,000	353·00

The maximum quantity of water which the concession determines may be drawn from the river Durance is 9,000 litres, or 318 cubic feet per second, comprising 1,000 litres for the Canal d'Aubagne. The available water is therefore fully used. To irrigate an increased area of land the town of Marseilles can only supply the water by taking measures to decrease the losses by percolation and at the settling basins, estimated, including losses by evaporation, at 1,648 litres or 58 cubic feet per second; and in purchasing some of the smaller independent canals to which water is conceded from the Durance and only partly used for irrigating or other purposes.

THE VERDON CANAL.

This canal was commenced in 1863, and opened at the end of 1875, for supplying water to the town of Aix, for irrigating purposes, and for motive-power. It takes water, at Quinson, from the river Verdon, a tributary of the river Durance. An important overflow barrage had to be constructed across the river Verdon, 36 feet 1 inch high and 138 feet long, to raise the water to the sluices. The cost of the barrage and intake at the river was £35,770. The main canal is $51\frac{1}{4}$ miles in length. The inclination is at the rate of 1 in 4,000 to 1 in 5,000, except through the tunnels, where it is 1 in 909. The canal has a sectional area of 113 square feet. Through the tunnels the sectional area is

52½ square feet. The number of tunnels is seventy-nine of a total length of 12½ miles, the three most important of which are respectively about 3¼, 2⅝, and 1⅞ miles long. There are numerous aqueducts, bridges, and culverts, and the difficulty of the ground has necessitated constructing the canal by retaining walls for a length of nearly 4 miles. There are, in addition, several syphons; four of which are across deep valleys. The most important is that at St. Paul, 890 feet long, constructed of two parallel wrought-iron tubes, each 5 feet 9 inches in internal diameter, with a maximum pressure equal to 116½ feet head of water. The horizontal portion of the syphon, laid at the bottom of the valley, is 321·64 feet in length. The remainder of the length of the syphon, consisting of the two inclines, is laid at a slope of about 2½ to 1. The pipes are of wrought iron, and respectively 0·353 inch and 0·315 inch thick for the horizontal and inclined portions. They are supported on, and fixed in, masonry at the junctions of the horizontal and inclined portions. The remainder of the lengths bear on cast-iron rollers resting on stone blocks, placed about 31 feet apart. The arrangements for expansion and contraction consist in constructing a short length of the tubes, in each of the horizontal and inclined portions, of a gradually increasing diameter from, and then decreasing back to, the normal diameter of the tube. The metal of the tubes at these swellings is reduced to about ¼ inch in thickness, in order to obtain greater elasticity, and it is contended that the bulging in and drawing out of the tube, at these swellings, will respectively allow for expansion and contraction of the metal.

The following is the cost of the canal:—

	£.
Land	27,972
Earthworks	81,182
Tunnels	169,024
Aqueducts and syphons	39,223
Dam and sluice	35,770
Retaining walls, pitching, revetments, puddling, &c.	49,506
Irrigating canals	15,900
Ordinary works	23,894
Plant, pumping, &c.	9,009
Staff expenses, &c.	39,152
Administration, printing, &c.	5,738
Interest at 6 per cent. on loans and sundries	155,322
	<hr/> £651,692 <hr/>

In addition to this cost, more than £200,000 will have to be
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expended, mainly for branches of the canal, to complete the work.

At the commencement the long syphons on this canal, including that of St. Paul above described, were constructed through the natural rock, and lined with masonry to prevent leakage, at a depth of 50 to 82 feet below the bottom of the valleys. The rock being intended to resist the hydraulic pressure. After completion, not one of these tunnel syphons acted satisfactorily when the water was let into them. Repairs were then commenced, experimenting at first with those under the least, and ending with those under the greatest head of pressure. After much trouble and expense all were at length caused to act satisfactorily, with the exception of that of St. Paul, which had to be abandoned.

The canal has eight branches, of a total length of about 47 miles, which, similar to the main canal, have necessitated the construction of numerous works of art, comprising an aqueduct 3,625 feet long, and 27 feet in maximum height; a syphon 443 feet long, under a head of pressure equal to $71\frac{1}{2}$ feet, and a tunnel 1,033 feet long.

The capacity of the main canal is equal to the supplying of 212 cubic feet of water per second, the quantity conceded; and there exists, at the numerous falls along the canal, water-power to the extent of 2,000 HP., which is fixed to be let at £8 per HP. per annum. The extent of land which can be irrigated by the canal, is about 40,000 acres; but, after deducting the water required for domestic and other purposes, the capacity of the canal is only sufficient to irrigate a portion of that area. The price charged for the water for irrigation is at the rate of 22s. 9d. per acre per annum for the commune of Aix, and 20s. for other communes. In the former case the company pay the cost of the conduit to the land; while in the latter such cost is paid by the irrigator. The quantity of water supplied at those prices is fixed, as is customary in that part of the country, at 1 litre per second, supposed to flow continuously from the 1st of April to the 30th of September, sufficient to irrigate 2.47 acres of average land. Soil of a light porous nature also for certain crops requiring more, and heavy soil and other crops less, than that quantity.

In addition to the four principal canals above described, there are numerous others in the department of the Bouches-du-Rhône. The total length of the whole of the canals exceeds 600 miles, with a capacity of about 2,000 cubic feet of water per second. The following is an approximate statement of the whole of the irri-

gating canals, and the area of land irrigated in the Bouches-du-Rhône.

Name of the Irrigation Canals.	Surface Irrigated.
	Acres.
Crapponne, general	16,920
" branch to Arles	6,357
Alpines	16,333
" West branches (French company)	4,337
Marseilles	8,644
Aubagne	1,038
Peyrolles	1,112
Peyrolles Mill	618
Puy-Sainte Réparate	618
Châteaurenard	6,422
Réal de Châteaurenard and Eyragues	1,482
Derivation of the Huveaune	1,514
Geménos and other minor canals in the arrondissement of Marseilles	413
Canals in valley of the Arc	1,245
Canals of the Touloubre	218
Other minor canals in the arrondissement of Aix	727
Other canals in the arrondissement of Arles, in addition to those above designated	5,587
Irrigation with water taken from the river Rhône	13,030
	86,675
These irrigations are effected with water derived as follows :—	
Irrigations from the river Durance	66,394
" from the rivers Huveaune, the Arc, the Touloubre, and minor streams	7,191
" from the river Rhône	13,030
	86,675

The other departments of France, where irrigation is the most extended, are the Vosges, where the amount is 140,000 acres; the Arriège, 93,000 acres; the Haute-Saône, 45,000 acres, and the Hautes-Alpes 35,000 acres.

SYSTEM OF IRRIGATION.

The water flows through a sluice from the main irrigating canal along a small canal or conduit to the limit of the property to be irrigated. The land is divided into compartments, the dimensions of which are regulated according to the nature of the soil, whether light or heavy, flat or hilly land, and also the crops to be grown. The circulating canals are generally 2 feet wide at the bottom, 2 feet 2 inches deep, with slopes from 1 to 1, to 1½ to 1. They are laid out so that the water is about 1 foot above the land

to be irrigated, and can be caused to flow freely into each compartment of the land under irrigation. When the circulating canals do not form one entire compartment to be irrigated, as may be the case when the land is flat, small banks or mounds are made for inclosure, which are generally 1 foot to 1 foot 6 inches high, and 1 foot 6 inches wide at the top. On flat land, which is not too porous, and for certain crops, the water sometimes flows over the land for a distance of 240 yards; but this may be considered the maximum distance under the most favourable circumstances. In most cases the distance is much less. On sidelong ground, if the inclination be considerable, the compartments are narrow; and generally the inclination is lessened by transporting a portion of the soil from the higher to the lower side of a compartment. But ground having a considerable slope, as much as 2 to 1 in very exceptional cases, is irrigated where water is abundant. The ground is reduced to an inclination of about 1 in 500 where possible, and the expense not too great.

The small sluices, built in the circulating canals in order to turn the water into the compartments, are simple and cheap. The arrangement comprise, for the most part, two blocks of stone forming the sides resting on another block of stone for a cill laid across the bottom of the canal. The sluice consists of a thin plate of wrought-iron, having a handle at the top, which is lifted in and out of two grooves cut in the side blocks of stone as may be required to open or close the sluice. These small sluices have openings, for the main circulating canals, from 14 to 18 inches, and those for minor canals 8 to 10 inches wide. The overflow dams are constructed in a similar manner to the sluices, with stone blocks for the side, resting on a stone cill. The most approved plans of the circulating canals, mounds for dividing the ground into compartments, small sluices, and overflow dams, is shown in Plate 6.

Plate 6 also shows an example of a property, consisting of meadows, the ground being hilly, as actually laid out for irrigation, the particulars of which are given in the reference. The cost of the large sluices is about 30*s.*, of the smaller, 12*s.*, and of the overflow dams 7*s.* each. The cost of laying out the land complete for irrigation, which necessarily varies greatly according to the nature of the soil, the crops to be grown, and the contour of the ground, is from £8 to £30 per acre. The time for irrigation commences on the 1st of April, and terminates on the 30th of September. The standard quantity of water adopted in the country is 1 litre of water, supposed to flow continuously for six months, per hectare.

This quantity of water would cover the ground to a depth of about $62\frac{1}{4}$ inches; consequently gives fourteen irrigations, each of about $4\frac{1}{2}$ inches; twenty irrigations of about 3 inches, or forty-three irrigations of about $1\frac{1}{2}$ inch depth of water.

The quantity of water used during the season for irrigation in Lombardy is about 1 litre per second per hectare, the same as in the Bouches-du-Rhône; while in Spain and India, countries where a greater quantity might be considered necessary, it is estimated that the amount used is only about $\frac{1}{2}$ litre per second during the season, and that quantity is thought an ample dotation. These great differences are doubtless owing partly to the nature of the crops irrigated, and partly to the degree of perfection of cultivation in the respective countries.

There is no fixed rule in the Bouches-du-Rhône as to the number of irrigations for such crops which require periodically irrigating during the whole season, as this must necessarily depend to a great extent upon the nature of the land, whether light or heavy, whether flat or sloping. In most cases the water is given by the companies once a week, which would be equal to twenty-six irrigations during the season. The Marseilles canal gives the water forty-three times during the season. Grass lands and gardens are usually irrigated at intervals of eight days; also madder-root, potatoes, and beans; but these latter do not require irrigating periodically during the whole extent of the season. Lucerne is generally irrigated at intervals of twelve days to a depth of about $2\frac{1}{2}$ inches of water; wheat, oats, and barley are irrigated once, twice, or thrice, each season according to the dryness of the weather, in April or the beginning of May. The depth of water is about $2\frac{1}{2}$ inches for each irrigation. Olive orchards are irrigated twice a year, in June and August, to a depth of about 2 inches each irrigation. Vines are not systematically irrigated, but sometimes, when the season is very dry, one or two irrigations are given where facilities exist for the operations. Grass, lucerne, beans, and most vegetables are cultivated on the natural flat ground, provided the water is sufficiently clear, which does not injure such crops by wetting them just above the ground. But if the water be muddy it is very injurious to all the crops. The mud in the water if deposited at and around the roots of the plants, hinders their growth, and sometimes destroys them. To lessen the effects of muddy water, on some properties, settling reservoirs are made for the water to flow into before entering the irrigating channels. In case of muddy water, suitable trenches are ploughed or dug out in the ground; in these the irrigating water is caused to flow and per-

colate through the soil to the roots of the crops. Some crops cannot be irrigated without injury, except the roots; such, for example, as potatoes.

The benefits derived from irrigation in the Bouches-du-Rhône, although not so great as in some parts of Spain in comparison with non-irrigated lands, are nevertheless considerable. In Spain there is less rain, and in most districts a hotter climate, consequently the effects of irrigation are more marked. But in the Bouches-du-Rhône there is, nevertheless, comparatively a small quantity of rain during the spring and summer months, the climate is fine and hot, and the soil is mostly of a calcareous nature. Grass meadows, when irrigated, are cropped three to four times each season; the produce is from $3\frac{1}{2}$ to $5\frac{1}{4}$ tons of hay per acre. Potatoes, when irrigated, produce from 14 to 25 tons per acre. Wheat and oats, when irrigated, yield an increased produce of about 30 to 50 per cent. in comparison with crops not irrigated. Lucerne when irrigated is cut six times, the produce being from $3\frac{1}{2}$ to $6\frac{1}{2}$ tons of hay per acre.

The following example shows the average produce and cost of cultivating an acre of lucerne on good land:—

<i>Crop.</i>				<i>£. s. d.</i>	<i>£. s. d.</i>
1st cut	735 lbs. of hay per acre	.	.	.	.
2nd "	1,548 " "	.	.	.	.
3rd "	2,627 " "	.	.	.	.
4th "	2,517 " "	.	.	.	.
5th "	1,848 " "	.	.	.	.
6th "	580 " "	.	.	.	.
9,855 = 4·4 tons at £4 . . . . .				..	17 12 0
Grazing land during winter . . . . .				..	0 8 0
<i>Cost per Acre.</i>					18 0 0
Irrigation				0 17 6	
Mowing, &c.				0 16 3	
Transporting, &c.				0 4 9	
268 lbs of guano (or other manure)				1 16 0	
Spreading "				0 1 0	
					3 16 0
Profit per acre, not including rental . . . . .				..	£14 4 0

An example of the produce of irrigated grass meadows on good land is similar in the result to that of the lucerne just mentioned. The hay was sold for £17 16s., and £1 realised for winter sheep-grazing per acre. The expenses, including the cost of manure, amounted to £4 16s., thus showing a net profit of £14 per acre. Meadows under irrigation are soon exhausted unless annually well manured. This is done at the rate of 8 tons per acre per

annum on good land ; in some cases guano is used in alternate years in place of ordinary manure. The net revenue of good land under irrigation, all expenses paid, varies from £3 to £14 and more per acre according to the situation of the land and the nature of the crops grown. This is from 30 to 50 per cent. for cereals, increasing to 400 per cent. and more for other crops, a greater net revenue than is obtained from cultivating the same land not irrigated. The net profits realised in irrigating cereals being less marked than for some other produce, the outlay for preparing cereal ground for irrigation has hitherto been sparingly given, but now the irrigation of cereals is increasing.

In numerous cases of farms under irrigation, the proprietor, instead of a fixed rent, takes one-third or half the gross annual revenue. The farmer supplies the manure, and pays all expenses excepting the annual rate for irrigation water, which is generally paid by the proprietor. The net annual profit to the proprietor under this arrangement, on good meadow land, is £6 10s. per acre. The above figures mainly refer to good land under irrigation, but the results of irrigation on poor land are comparatively even more important. The Crau plain consists of land upon which scarcely anything grows ; the surface is clay soil, about 9 inches in thickness, covered with small boulders and stones. Under the surface soil is a hard compact layer resembling *béton*, termed in the country "*Poudingue*." The plain has a uniform inclination of about 1 in 300. In spring and summer the comparatively small quantity of rain which falls on the plain flows down it, and is rapidly evaporated by a hot sun, there not being sufficient time for the clay soil to absorb the rain. The result is that the surface of the plain is sometimes almost as hard as baked brick. The value of this barren plain, in its present condition, is about £2 per acre ; but those portions of it now under irrigation are enormously increased in value thereby. The following example shows the results of irrigating the barren land :—

COST PER ACRE IN PUTTING THE LAND UNDER IRRIGATION AND ESTABLISHING MEADOWS.

	£. s.
Gathering stones off the surface	1 13
Ploughings, harrowings, &c.	1 17
Levelling, and irrigation drains	2 10
Lucerne seed	1 6
Manure (about 16 tons the first year)	8 0
Spreading manure and sowing	1 2
Purchase of land	2 0

£18 8

The annual produce per acre is $3\frac{1}{4}$ tons of hay, which at £4 per ton produces £13, in addition to 15s. for grazing during the autumn and winter. Supposing the total annual expenses to be £6, including cost of a sufficient quantity of manure and irrigation water-rate, the net profit would be £7 15s. per acre on this formerly barren land. To maintain the crops at their annual maximum, about 50 per cent. more manure is required for land of inferior quality. It is customary in the Bouches-du-Rhône to sow lucerne in the first instance. In the course of time, after regularly irrigating, the herbs gradually change, and ordinary grass meadows are established.

The price of good land for general cultivation is doubled in value by irrigation. For meadows and some other crops it is increased threefold. In Spain it is estimated that the value of good land in the valleys is enhanced tenfold by irrigation. The cultivation of vines in the Bouches-du-Rhône has been of considerable importance and is the most profitable of all productions. Unfortunately phylloxera has caused enormous losses since the year 1866, and has destroyed thousands of acres of vineyards. The area of vines under cultivation in the year 1866 was about 125,000 acres, while in 1872 the area was reduced to 70,000 acres through the destruction of this pest.

Among the various experiments carried out to cure the phylloxera, the system of M. Faucon has, after eight years trial, proved the most efficacious. It consists simply in submerging the ground of the vineyard with water to a depth from 4 to 6 inches for a period of thirty days successively during autumn, or forty-five days in winter. The main precaution consists in being careful that the entire surface of the ground is kept covered with water during the whole period of the thirty or forty-five days. The submersion is supposed to drown the insects at the roots of the vines. But if the surface of the ground, for even a short time, during the period of submersion should not be covered with water, the air penetrates the soil and revives some of the insects, which subsequently propagate and spread rapidly. This discovery of M. Faucon has hitherto been successful in nearly all cases when the system has been properly carried out, not only in absolutely preventing the phylloxera, but also in reviving vines which are attacked, providing they are not too much injured. A few cases occurred in the summer of 1876 when the phylloxera was discovered in vineyards, treated on M. Faucon's system, adjoining other vineyards not so treated full of phylloxera. It may be remarked that in the spring of that year some very severe frosts greatly injured most of the vines in the Bouches-du-Rhône, resulting in a

yield of wine considerably below the average quantity. An opinion is entertained, by some agricultural authorities in France, that the vines, growing for several years, become exhausted and enfeebled, and the land impoverished, until they are in a state which attracts the insects to prey upon them. However feeble at the commencement the phylloxera propagates and spreads rapidly. In support of this opinion it is contended that it is not so much in submerging the ground with water to drown the insects at the roots, which does not destroy all the insects in the stalks of the vines, as the beneficial effects to the vines from the deposit of the valuable sediment and action of the chemical matters held in solution of the water mostly drawn from the river Durance, which acts as a manure and stimulant. Although there are no satisfactory experiments to show how much of the beneficial effects of irrigation can be attributed merely to the water supplying moisture to the land and crops, or to the matter in solution¹ and mechanically suspended in it, yet it is well known that the waters of the Durance produce more satisfactory results than the waters of some other rivers, as, for example, the Sorgues. The clear water of that river can be had by the proprietors almost gratis, nevertheless they prefer to form associations, and, at a considerable expense, to obtain water from the river Durance. If this opinion, as to the virtue of the matter in the water being a preventative of the phylloxera, should be borne out by facts, the vineyards, after existing a limited number of years, will probably, notwithstanding the cost and time, namely, three years, required to establish a vineyard, be ploughed up and other crops cultivated on the land for a time; thus new vineyards would be planted at shorter intervals than is now the custom. In some districts, where vines were cultivated, the ground was either so hilly or of such a porous sandy nature that submerging the ground was not practicable. In other districts no available means for obtaining water existed to submerge the ground. In most such cases the vines have either perished or are greatly deteriorated, and are only maintained by means of costly chemical manures applied to their roots.²

¹ Some important researches in France on the application of water for irrigation, is by M. Hervé Magnon, entitled "*Expériences sur l'emploi des eaux dans les irrigations.*" 2^e édition. Paris, Dunod, 1869.

² The injurious effects of the phylloxera to the prosperity, and doubtless to the traffic of the country, have caused the Paris, Lyons, and Mediterranean Railway Company to supply chemical manures—and to publish instructions for their use—for the purpose of curing the vines attacked with the pest.

The benefits derived from irrigation in the department of the Bouches-du-Rhône are very important and extensive, nevertheless, the system is not carried out to the extent necessary fully to develop the resources of the water available for that purpose. The cost of irrigation, by the numerous canals, varies considerably; the extremes being from 6*d.* to more than 26*s.* per acre per annum. But the low prices result, in most cases, from exceptional causes and the advantages obtained formerly by concessions when the canals were under financial difficulties. Moreover, the supply of water is limited—it cannot always be regularly obtained. For a legitimate and proper supply the prices charged by the two modern canals, Marseilles and Verdon, respectively, about 26*s.* and 22*s.* per acre, may be considered the standard prices. The quantity of water given at these prices is equivalent to a flow of 1 litre per second per hectare during the irrigating season of one hundred and eighty-three days, sufficient to cover the ground to a total depth of $62\frac{1}{4}$ inches, with 20,681 cubic yards of water. The charge for the water on the Henares and Eslla canals in Spain, in comparison for the same quantity of water, would, respectively, be at the rate of 55*s.* and 40*s.* per acre per annum. But those canals only give water for twelve irrigations, each respectively 916 and 850 cubic yards, equivalent to a total quantity of 10,987 and 10,203 cubic yards of water per annum. The annual cost of irrigation is therefore reduced proportionately, viz., to the rate of 29*s.* and 23*s.* per acre. The total area irrigated in the Bouches-du-Rhône is about 87,000 acres, of which 13,000 acres are irrigated directly by water taken from the river Rhône, leaving 74,000 acres irrigated by the canals. The quantity of water conceded to the existing canals is about 71.9 cubic yards per second, which is sufficient to irrigate 137,500 acres. There is therefore sufficient water conceded to the existing canals to irrigate about 63,000 acres of additional land. The reasons why the system is not more fully developed are various. The old canals, such for example as the Crapponne, cannot be administered in a manner fully to develop their resources in consequence of the conflicting interests of the various owners or persons interested in them by virtue of the onerous concessions of former days. The water, in some instances, has to be supplied to land whose owners formerly bought the right for allowing the canals to be executed through their property, and to others who bought the right to use the water at a very low price. The result is that the annual revenue is barely sufficient to maintain the canals and works. The maintenance of the canals, taking their water from the Durance is

another reason. This river, which supplies about 80 per cent. of the water of the canals, is sometimes very muddy, thus causing the canals to silt up, and necessitating considerable annual expenses to clean them out. A difficulty is also encountered by proprietors, possessing land, sometimes of small area at a distance from the main canal, in obtaining a right to construct a connecting canal through the properties of others, and in disposing of the waste water. There is likewise the question of the necessary outlay in establishing the system of irrigation; sometimes the proprietor is not disposed to lay out the money, and the tenant is neither able nor willing to improve a property which does not belong to him. In many cases the holdings are of small extent, and it would not pay to make a long connecting canal to the land, even if there were no hindrances from intervening landowners. The difficulties inherent to the old canals would seem to point out the advisability of constructing new ones. This cannot be done for irrigation purposes, inasmuch as the whole of the water which the Durance is capable of supplying throughout the irrigating season is already more than conceded. The quantity of water flowing down the river, at the ordinary lowest summer level, is estimated at 2,540 cubic feet per second. The quantity already conceded in the departments of Bouches-du-Rhône and Vaucluse is 2,900 cubic feet per second. Excepting a limited area the ordinary level of the water of the river Rhône is too low to be of use for irrigating by gravity regularly throughout the season, even the lower portions of land situated in its course through the department of the Bouches-du-Rhône. In the case of the Marseilles canal some of these difficulties do not exist. That canal is well managed, and there are ample funds to execute the connecting canals and works to the limit of the properties to be irrigated. The result is that a charge for the water at the rate of 26s. per acre per annum is easily obtained, which is considerably higher than the charges of most of the other canals, and the whole available water of the canal for irrigation is nearly subscribed for. To meet some of the difficulties for extending the use of the water of the old canals for irrigation, numerous syndicates and independent companies have been formed from time to time, which have greatly helped to increase the area under irrigation as it now exists. The Government has also been liberal in granting subventions for the improvement of the Durance and its dykes, and for the construction of some of the canals.

In 1874 the Government decided to invite competition for a period of five years, open to all, and to reward those whose

system of irrigation was considered by a jury,¹ the best in the department of the Bouches-du-Rhône. It is anticipated that this will evoke a spirit of emulation in the department and country generally, as is the case in granting prizes in England for agricultural implements, machines, stock, and produce.

The following is the *arrêté* of the Government:—In order to encourage efforts tending to improve agriculture, principally in developing cultivation by irrigation, considering the losses caused by the phylloxera and necessity of transforming or of increasing the production of irrigated land, rewards will be accorded in the department of the Bouches-du-Rhône in 1875, 1876, 1877, 1878, and 1879, to agriculturists, proprietors, or farmers, who shall have utilised in the most intelligent manner the water of the different irrigating canals. The rewards will be given as follows:—

FIRST CATEGORY.

To properties consisting of more than 10 acres of irrigated land—

1st prize, a gold medal and	£.
2nd „ a silver medal, large size, and	40
3rd „ a silver medal and	28
	24

SECOND CATEGORY.

To properties consisting of 10 acres and under—

1st prize, a gold medal and	£.
2nd „ a silver medal and	24
3rd „ a bronze medal and	20
	12

An object of art can be awarded to the winner of the first prize of one of the above categories, acknowledged to be superior, or judged to be specially noted for the economical management of the water in practical irrigation. In the case of an object of art being awarded the gold medal destined for the first prize will not be given.

This communication is accompanied by a series of maps and drawings from which Plates 5 and 6 have been compiled.

¹ The map and plan annexed to this Paper, also some of the details, were obtained from the report of the jury for 1875. Sur le concours ouvert en 1875, pour la meilleur emploi des eaux d'irrigation, par J. A. Barral, secrétaire perpétuel de la société centrale des agriculteurs de France.

IRRIGATION IN THE SOUTH OF FRANCE. MAP OF CANALS IN THE DEPARTMENT DES BOUCHES DU-RHÔNE

PLATE 5.



IRRIGATION IN THE SOUTH OF FRANCE.

TYPES OF SMALL SLUICES &c. FOR IRRIGATION CHANNELS.

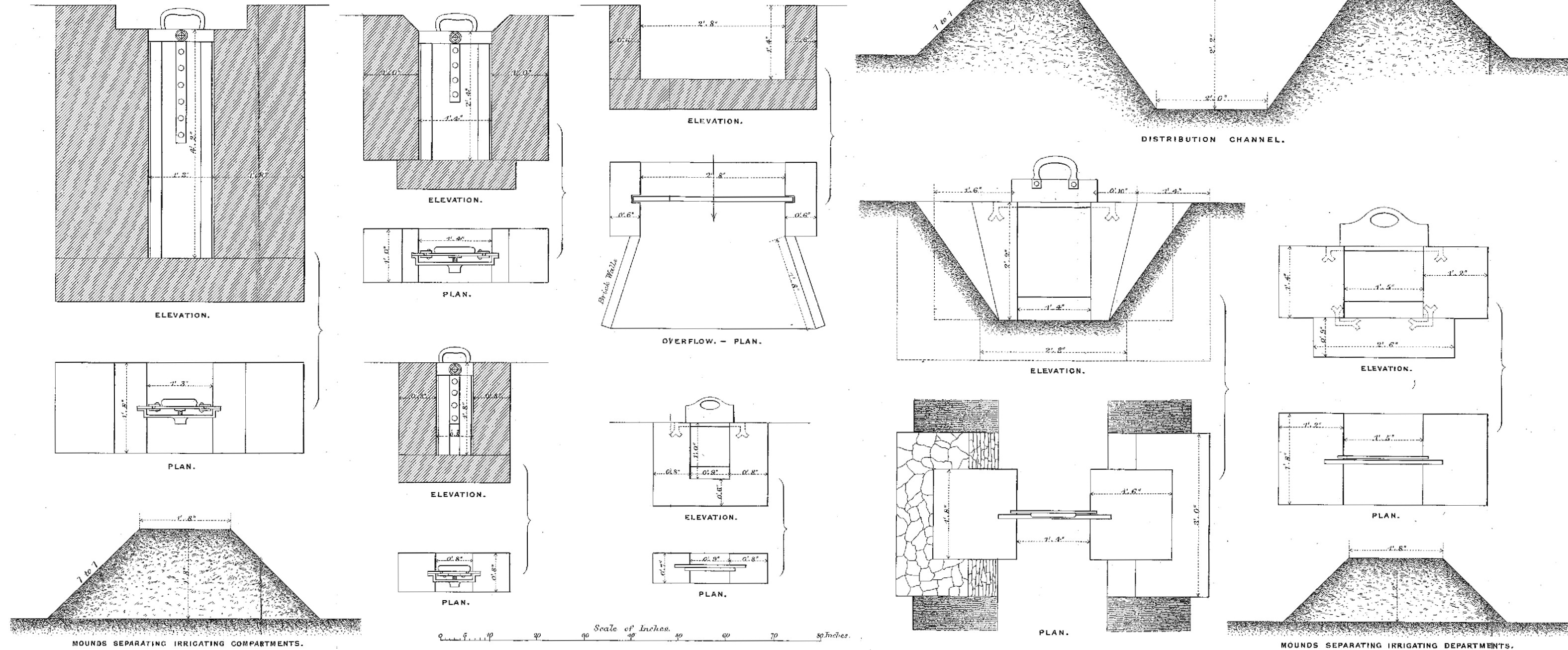
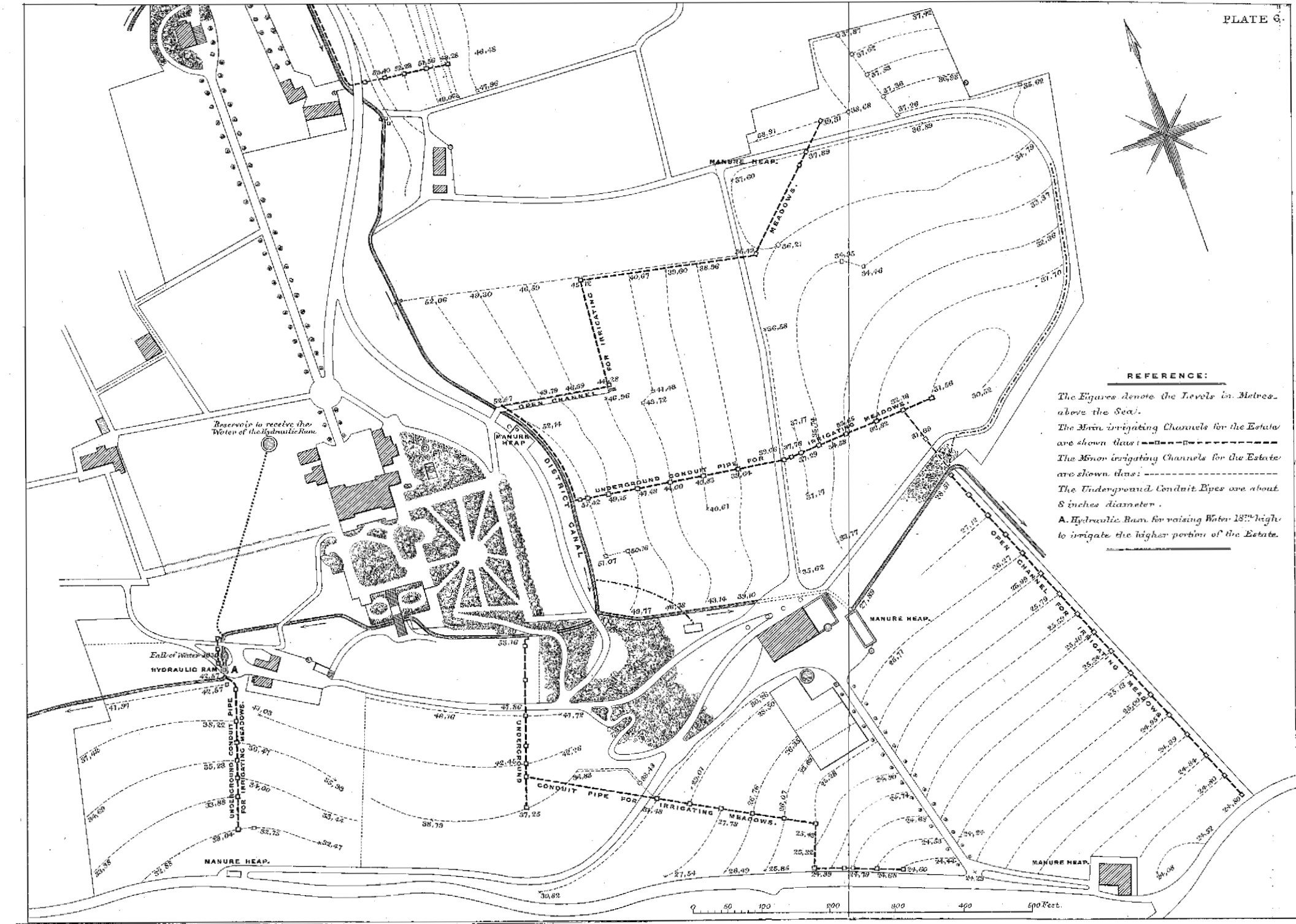


PLATE G.



REFERENCE:

The Figures denote the Levels in Metres above the Sea.

The Main irrigating Channels for the Estate are shown thus: ————

The Minor irrigating Channels for the Estate are shown thus: - - - - -

The Underground Conduit Pipes are about 8 inches diameter.

A Hydraulic Ram for raising Water 18' high to irrigate the higher portion of the Estate.