SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 2055.*)

“Constantinople Water-Works.”

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THE city of Constantinople is divided into two parts by the Golden Horn, its eastern shores being bounded by the Bosphorus and the Sea of Marmora. Galata and Pera, the European quarter of the city, stand on the northern side of the Golden Horn, the former on the sea-shore, and the latter on high ground above it; and Stamboul, the ancient and native portion, is on the southern shore; communication is established between them by two iron bridges, which open for the accommodation of shipping, sufficient headway not being obtainable owing to the extreme flatness of the banks. The villages on the European shores of the Bosphorus, namely Ortakeui, Kourouchesme, Arnautkeui, Bebek, Therapia and Bu-yukdere, have of late years become the summer resort of the wealthier classes of the city, and in estimating the population it is necessary to include these villages.

The existing sewers, or, more correctly speaking, longitudinal cesspools, are square in section, put together in the roughest manner, and consequently rarely water-tight; they are laid invariably with insufficient fall, the solid matters thus remaining in them until they become choked, when portions are opened and cleansed, poisoning the air for hours afterwards. The contents of these channels are finally discharged close to the most densely populated districts of the Golden Horn.

The supply of water has always been limited, and, with such disadvantages, it might well be imagined that the city would be rarely free from epidemics. This happily has not been the case, the most alarming outbreak having been one of cholera in the year 1865, when upwards of two thousand persons perished daily.

A marked improvement has taken place in one portion of the town during the last two years, especially since the tramway lines have been laid down. Part of the Grande Rue de Pera and the Rue Tépé Bachi are now decently paved, and a spacious club, and

new opera house have been erected, together with several private residences.

The population of Galata and Pera, together with the villages on the European shores of the Bosphorus, is about three hundred and sixty thousand. The highest part of Pera is Chichly, which is 370 feet above sea-level. Stamboul, the ancient city, has a population of about four hundred and twenty thousand persons, and its highest ground is about 260 feet above sea-level. To the above estimate must be added about five thousand for the floating population of the city, making up a total population of about seven hundred and eighty-five thousand persons.

The city is at present supplied from the reservoirs, or "bends" (this being the local term), situated at Chioy, Belgrade, Pergos, &c., the water being conveyed thence by aqueduct to service-reservoirs in different parts of the city. These "bends" are situated on the slopes of a range of hills, which are a south-eastern prolongation of the Balkan mountains. The works were carried out under the later Roman emperors, and both in design and in construction they compare favourably with any work of recent date.

It is only in the details of the distribution that the constructors appear to have shown any ignorance. The pipes which convey the water from the small reservoirs to the public fountains and to some of the houses are of lead, and vary in diameter from 25 millimetres (0·98 inch) to 60 millimetres (2·36 inches); lines of these pipes are laid through the streets and are easily damaged, their thickness being little more than that of a sheet of paper. In many houses large marble cisterns occupy the whole area of the basement, in which rain-water is collected.

The annual rainfall, from observations extending over a series of years, amounts to 71 centimetres (28 inches); but in a dry year, after deducting loss by evaporation and absorption, not more than about 5 inches can be reckoned upon for collection, which (considering the limited watershed available) is a quantity wholly inadequate for such a population as that of Constantinople.

In 1882 a company was formed under the auspices of La Compagnie des Eaux de Paris, with a capital of 20,000,000 francs (£800,000), to procure a supply of water for the city from Lake Derkos, near the Black Sea.

Lake Derkos is a freshwater lake having a depth varying from about 12 to 20 feet, and an area that may be roughly computed at about 10,000 acres. It is cut off from the Black Sea on its north side by sandhills or dunes; the channel between them, a comparatively narrow passage, has now been blocked by dams, so that the

sea is prevented from entering the lake, and the level of the latter has been raised. The water for the present is taken in at Kizildere, at the Western extremity of the lake, where the principal feeders flow in. The intake-tunnel commences at this point, and follows the northern contour of the lake through the sandhills until it reaches the well at the pumping-station at Derkos.

The upper portion of the tunnel is laid with open joints, and the water falling upon this large area of sand, to a great extent percolates into the tunnel and thus greatly augments the supply. A main is also laid, with branches and screw-cocks parallel with the tunnel, to draw from the lake itself when desirable.

The pumping-station is situated near the village of Derkos, which is about 29 miles from Constantinople, and $4\frac{1}{3}$ miles from the port of Karabournou on the Black Sea. The level of the floor of the engine-house is 1 metre (3 feet 3 inches) above the highest level of the water of the lake, or 2.5 metres (8 feet 2 inches) above that of the sea.

The engine- and boiler-houses have been designed of sufficient dimensions for six pairs of engines and twelve boilers, to furnish a daily supply of 40,000 cubic metres (8,800,000 gallons), but as the company only contemplates supplying 13,333 cubic metres (2,933,260 gallons) for the present, only three pairs of engines and six boilers have been laid down. These collectively are capable of pumping 20,000 cubic metres (4,400,000 gallons) to a maximum height of 125 metres (410 feet) in eighteen hours.

The engines are high-pressure and horizontal, of the direct-acting type, of 600 HP. (French) collectively, driving double-acting piston pumps. Each pair is coupled, but each engine can be worked independently. Their normal speed is 16 revolutions per minute. They have jet-condensers, and the feed-water is supplied to the boilers at a high temperature. The cylinders are 0.9 metre (2 feet 11 inches) in diameter, with a length of stroke 1.8 metre (5 feet 11 inches), and the pumps 0.262 millimetres (10.32 inches) in diameter, having the same length of stroke as the engines. The cylinders are steam-jacketed, variable expansion being effected by two independent slide-valves, one valve for admitting and exhausting the steam, and the other for cutting off at any point of the stroke. Steam is supplied by six double-flued boilers with Galloway tubes at a pressure of 5.25 atmospheres (78 lbs.).

The water is raised to a height of 109 metres (358 feet) through a pumping-main 0.60 metre (24 inches) in diameter, 2.17 miles in length, into a reservoir near the village of Derkos. It is built in

four compartments, having a total capacity of 1,043,539 gallons, and a depth of water of 10 feet. The walls are of limestone rubble, the piers for the arches being of squared stone. Bye-pass pipes and valves are arranged so that the conduit can be supplied direct, without the water passing into the reservoir. On leaving this point the water flows by gravitation through a built aqueduct and siphon-pipes a distance of 26·66 miles to the service-reservoir

FIG. 1.

Siphon Inlet-Chamber.

Section on line G H of Fig. 2. Scale $\frac{1}{2}$ inch = 1 foot.

at Ferekeui, on the high ground at Pera, the top-water level of which is 295 feet above the sea. There are a few short lengths of tunnel on the line of the same form as the aqueduct. The continuity of the aqueduct is broken by valleys fifteen times on the way to Ferekeui. Cast-iron siphon-pipes 24 inches in diameter are therefore laid across them. Their general arrangement in the inlet- and the outlet-chamber is shown by Figs. 1 to 4. The conduit is 5 feet 3 inches in height by 3 feet 5 inches wide. Like the reservoirs, the aqueduct is of rough rubble limestone, rendered in

cement up to the springing of the arch, the crown of which together with the exterior of the siphon-chambers is floated over with a layer of hydraulic lime-mortar. The siphon-wells are rendered in cement up to the water-level.

At the inlets of the longest siphon-pipes, there are buildings with accommodation for an attendant. Sluices are fixed at each of these stations, to shut off the water from each section of pipe in the event

FIG. 2.

Siphon Inlet-Chamber.

Section on line E F of Fig. 1. Scale $\frac{1}{4}$ inch = 1 foot.

of fracture. The formation through which the aqueduct passes is chiefly schist, which is of considerable depth resting upon carboniferous limestone. This schist or slate rock is in many parts extremely hard, and has given much trouble to dislodge. The surface soil is principally clay. For the present, only one siphon-pipe 24 inches in diameter has been laid down, which is sufficient for the present supply of 13,333 cubic metres (2,933,260 gallons); as the demand increases two more will be added, the three pipes giving the full supply for which the aqueduct has been con-

structed. In the fifteen siphons before mentioned there is a length of about 6·66 miles of cast-iron pipes, and about 20 miles of aqueduct and tunnels.

The difference of level between the reservoir at Derkos and the service-reservoir at Pera is 19·50 metres (64 feet). This gives a fall of 2·4 feet per mile, which is proportioned between the aqueduct and the pipes.

In order to supply Chichly, the highest part of Pera, it has been necessary to construct a small reservoir at the former place, the

FIG. 3.

Siphon Outlet-Chamber.

Section on line C D of Fig. 4. Scale $\frac{1}{2}$ inch = 1 foot.

top-water level of which is 114·50 metres (375 feet) above the sea. To accomplish this a turbine has been fixed at a point 82 feet below the Ferekeui reservoir, a supply-pipe 0·40 metre (16 inches) in diameter being led therefrom to the turbine. This gives the necessary power to work the pumps, and raise the water to a height of 162 feet, which gives ample pressure for this district. The water for working the turbine is led into the main for furnishing the European shores of the Bosphorus.

There are three equilibrium reservoirs for the villages of the Bosphorus, all of which are constructed in two compartments; the details are as follow :—

—	Capacity of each Division.	Depth of Water.	Height above Sea.
	Gallons.	Feet.	Feet.
Arnautkeui	550,000	13·77	170·50
Boyadkeui	330,000	10·82	137·77
Kiretche Bournou	165,000	10·82	105·00

The reservoirs at Ferekeui and Chichly are also built in two divisions, each compartment of the former holding 1,760,000

FIG. 4.

Siphon Outlet-Chamber.

Section on line A B of Fig. 3. Scale $\frac{1}{4}$ inch = 1 foot.

gallons, and having a depth of water of 16·40 feet. The latter contains 770,000 gallons to the compartment, and has a depth of 16·40 feet. All six are covered reservoirs, built of limestone rubble and rendered with a thickness of 1 inch of cement mortar to the top-water line.

There are thus three services, one high at Chichly, another intermediate, at Ferekeui, and the third low for the Bosphorus; by an arrangement of valves they can all be coupled together and the water made to circulate. Loaded safety-valves are fixed on the pumping-main and self-acting double air-valves on the siphon-pipes on all the crests, and wash-out-valves in the depressions; lead and yarn joints have been employed throughout.

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The transport of the large pipes was a matter of difficulty, owing to long distances to be traversed, and the badness of the roads in winter, but more especially from the trouble of obtaining labourers. The breakage in discharging the pipes and castings from the steamers to the lighters (there being no quays suitable for vessels to come alongside), and from the latter to the shore was very great at the commencement. The siphon-pipes were $\frac{1}{16}$ inch thick, and weighed on an average 19 cwt. each.

It may be thought that the quantity of water provided is very small for such a population as that of Constantinople; but no industry worthy of the name is carried on. No breweries nor works of any kind require large supplies of water, the only large consumers being the hotel and restaurant proprietors, and a fair supply for the Sultan's palaces. Too much reliance must not be placed upon the whole of the native population, amongst a large portion of which great poverty prevails, taking the water. The Author believes that the company will have a far greater sale for the water in the European than in the native quarter of the town.

The distributing pipes within the city vary in diameter from 0·35 metre (13·8 inches), to 0·06 metre (2·4 inches). The prices paid per lineal metre for laying and jointing the pipes, exclusive of excavation and filling in, were:—

Diameter of pipe	{ 0·60 0·50 0·40 0·35 0·30 0·25 0·20 0·15 0·10 0·08 0·06											
in metres . . }												
Price in francs .	4·45	3·75	3·26	3·08	2·79	2·74	2·37	1·93	1·28	1·01	0·52	

The laying of most of these pipes was a tedious undertaking, principally from the number of sewers met with every few yards, and the trouble of diverting and making them good; there was no possible means of avoiding them. They were encountered at varying depths, and crossed the streets in the most erratic manner. In numerous cases the houses had to be shored up where the pipes passed at close quarters, as many of them have hardly any foundations, and there was danger of bringing them down altogether. The dead-ends of the small pipes are connected to other mains wherever practicable, to prevent the water becoming stagnant.

A limited number of fire-hydrants has been fixed. These are of the screw-down kind, with gun-metal spindles and loose valves with leathern washers enclosed in lock-up surface-boxes. The number, however, will have to be greatly augmented, as the fires occurring in the city are very numerous, and the loss of life in

consequence is very great; and, up to the present time, no practical means have been adopted for extinguishing them.

The house-services are arranged on the French system, with the clip round the service-pipe, and the plug-cock screwed into it, the piping is of lead, varying from 13 to 55 millimetres (0·51 inch to 2·16 inches) in diameter.

In the town-mains, the pressure of water is equal to a head of from 50 feet to about 280 feet in the low parts of the city.

The consumers will be chiefly supplied by Frager's double piston meter. The average charge per cubic metre (220 gallons) will be 3·5 piastres, 7¼d. (2s. 8¾d. per 1,000 gallons), special arrangement being made by the year for the larger consumers.

The works were commenced in the spring of 1883, and were completed in January 1885, and opened on the 26th of that month.

Mr. Paul Bouton, Ingénieur en Chef des Ponts et Chaussées of Paris, was the Chief Engineer and Director of the works. The aqueduct and the reservoirs were carried out by local contractors—the average cost of the aqueduct per lineal metre having been 95 francs.

The engines and boilers were constructed by La Compagnie de Fives-Lille (Nord), France, for 600,000 francs. Messrs. Dalmas & Cie., of Marseilles, supplied the house-service fittings, and all laying on to the houses. The pumping-main, siphon-pipes, distributing-mains, and special castings, in all about 9,340 tons of cast-iron, were supplied by Messrs. R. Laidlaw & Sons, and Messrs. Thomas Edington & Sons of Glasgow. The sluice-valves, sluices, hydrants, &c., have been provided by the Glenfield Company of Kilmarnock, N.B.

At the present time (October 1886) four thousand houses in Pera are being supplied by this company, equal to a consumption of about 50,000 gallons of water per day; and it is anticipated that this quantity will be more than doubled within the next twelve months.

The Paper is accompanied by several diagrams from which the Figs. in the text have been prepared.