was poorly furnished in this respect, but any figures giving the results obtained from the use of the pit mentioned in the Paper would be misleading, owing to its being only in partial use and only applicable to one sewer in which the flow was not readily ascertainable. The question raised by Mr. Cuthbert Brown as to the drainage of the extensive area north of London was an exceedingly complex one and beyond the scope of the Paper. Many proposals had been made, dating back as far as 50 years, for dealing with the problem, and whether the drainage would ultimately be received into the London system, or be taken by a separate outfall to the Thames, or continue to be treated separately by the various authorities as at present, was a matter for further investigation. The Author welcomed Mr. Brown's reference to the legislation under which the London sewers had been constructed. Generally speaking, it had been possible to carry out the works on the lines dictated by engineering considerations, to the public benefit and without damage to the interests of any class of the community. Supplementing the information given in the Paper, the Author would observe as a matter of history that when the pumping-station at Pimlico was built, it was the intention to pump part of the low-level sewage on to land near the Pimlico station and treat it there, and the lifts were arranged accordingly. It was a matter for congratulation that this proposal did not mature. Somewhat akin to it was a decision of the Metropolitan Board of Works to purchase a large area of land in the neighbourhood of the Abbey Mills pumping-station, for the purpose of building a large deep reservoir to receive storm-water from the low-level sewer, to be pumped by degrees with the station's plant after the period of greatest flow was over. Land was actually bought, but this proposal also never matured. The Author.

Correspondence.

Mr. Kenneth Allen, of New York, had visited the Barking works some 4 years ago, and had been shown the cast-iron gates which admitted the sewage to the thirteen precipitation channels. These gates were of unusual size, but, in spite of their 25 years of service, it was stated that they had remained almost perfectly tight, and had never required repairs of any kind. That seemed typical of the thoroughness with which the Main Drainage Mr. Allen.

Mr. Allen. Works had been studied, designed and built, since their inception by Sir Joseph Bazalgette over 60 years ago. The question of disposal had probably received more extended and exhaustive consideration here than elsewhere, and the treatment-plants at Barking and Crossness were the largest of their kind. But from the fact that they were built prior to a period replete with increased knowledge and improved methods of sewage-treatment, there were no doubt many details that would be modified if they were designed afresh to-day. Nevertheless, it was significant that, in spite of various propositions that had been brought forward from time to time for a radical change in method, the works remained to-day in operation with but minor modifications of the original plan and with reasonably satisfactory results.

The Paper led one to infer that the trend of practice was in favour of the substitution of centrifugal for reciprocating pumps in handling the London sewage. The simplicity, compactness, comparative freedom from clogging and low first cost of the former, combined with an efficiency that approached that of high-duty reciprocating pumps, had already made their use for sewage almost universal in the United States, a notable exception being in the Ward Street station at Boston. Among the larger sewage-pumping installations in the United States using centrifugal pumps might be mentioned that at Washington, D.C. (partly for storm-water), with a total capacity of 613 million imperial gallons per day, those of the Metropolitan (Boston) Sewerage Works with a combined capacity of 395 million imperial gallons per day, and those at New Orleans (partly for drainage) with a combined capacity of 1,283 million imperial gallons per day. The absence of valves and the economy of operation with moderate lifts that seemed to be attained by the Humphrey gas pumps which Mr. Allen had seen at Chingford soon after their installation, had suggested their possible adaptability to sewage-works, but he was not aware that they had been used for such service.

The effect, on the condition of the Thames, of the substitution of plain sedimentation in place of chemical precipitation under Sir Maurice Fitzmaurice in 1912, was interesting in bringing out very clearly the superiority of the latter method in reducing the putrescible matter, colloidal and in solution, which formed so large a part of the whole, although nearly as effective clarification by the removal of solids was obtained, even with shorter "channel hours," by employing plain sedimentation. With a stream having a large oxidizing capacity the cheaper and quicker method by plain sedimentation was preferable, but with the low percentage of dissolved oxygen found in the Thames during warm weather near the Barking and Crossness outlets that appeared to be unadvisable as a continuous procedure. The removal of the finer solid particles and the colloids was a matter of importance, as had been clearly pointed out by Dr. Arthur Lederer of Chicago.[1] From experiments carried on for the Sanitary District of that city by settling 4 hours and subsequent filtration through one layer of filter-paper there resulted the following averages from nine experiments:— Mr. Allen.

		Total.	Volatile.
Solids in Crude Sewage		607	311
Suspended Matter—			
Original		167	101
After Settling		61	46
	Crude.	Settled.	Filtered.
Oxygen consumed	37	26	20·1
Organic Nitrogen	10·1	..	4·3

From these results he found an "actual improvement in the sewage from the standpoint of a prospective nuisance" of but 31 per cent. by a removal of 63 per cent. of the total suspended matter, or 54 per cent. of the suspended volatile matter, while there was an improvement of 143 per cent. by filtration. In other words, sedimentation alone provided an improvement from the standpoint of dilution far less than was indicated by the percentage of solids removed, while "the removal of an additional small quantity of suspended matter not capable of settling, by simple filtration[2] would improve the liquid far out of proportion to the percentage of volatile matter removed." The conclusion drawn from these experiments was that "in domestic sewage from a large area, the finely-divided slowly-settling suspended matter and pseudo-colloidal matter not capable of settling, made up the greater part of the putrescibility, due to the suspended and colloidal matter." The economy in the omission of chemicals on works of the magnitude of those in London, when river conditions permitted, was, however, evident, and Mr. Allen was of opinion that in the course of time some substitute, probably biological in nature, would be adopted.

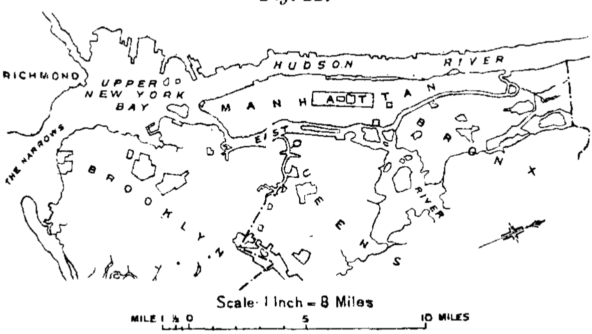
The City of New York had carried on investigations for some 10 or 11 years past regarding the pollution of the harbour by sewage. The nucleus of the harbour might be said to be the

[1] "The Relation of the Putrescibility of the Settling and Non-Settling Suspended Matter in Sewage." Am. Journ. Public Health. February, 1912.

[2] Or chemical precipitation.—K.A.

Mr. Allen. Upper Bay (*Fig. 11*)—a basin covering 20 square miles—into which flowed the Hudson river on the north and the Passaic river via the Kill van Kull on the south-west, and which was connected with the ocean by way of the Narrows on the south, and by way of the East river and Long Island Sound on the north-east. The Hudson and East rivers were also connected by the Harlem river, which formed a tidal passage through the city separating the boroughs of Manhattan and The Bronx. With the tidal waves entering both through the Narrows and through Long Island

Fig. 11.



Sound, and with the upland flow from the Hudson and Passaic rivers, the hydraulic conditions were variable and intricate. Of the several parts of the harbour perhaps the lower East river, or that part between the Harlem river and the Upper Bay, was most nearly comparable with the Thames as regards pollution; although in the case of New York this reach of maximum pollution lay in the heart of the city, whereas in London it was 8 or 10 miles distant. The following comparative figures might be of interest:—

	Thames, near Barking and Crossness.	Lower East River.
Approximate width	2,000 feet	2,500 feet.
Tidal range	20 feet	42 feet.
Tidal flow, average	2,250 million cubic feet	4,000 million cubic feet.
Sewage tributary, 1911–12, per day	323 million imperial gallons—Tank Effluent	205 million imperial gallons—Crude.
Dissolved oxygen, average	20 per cent.	40 per cent.
Minimum	5 per cent.	4 per cent.

Mr. Allen.

In the lower East river the sewage was discharged at about 125 points along the water front without treatment. With the rapid currents the diffusion was good, but the river presented a less favourable appearance than the Thames, on account of scum and floating solids. While the average oxygen continued to reach about 85 per cent. of saturation year after year in winter, the minimum summer values had dropped from 29 per cent. in 1912 to 4 per cent. in the summer of 1916, indicating a rapid approach to a condition when local nuisance might be expected if preventive measures were not taken.

Studies of the Metropolitan Sewerage Commission several years ago showed that the important navigable waterways intersecting the city, together with the high land values, would preclude any plan for collecting all the sewage of New York to one or even two disposal points as in London. The subject might be best considered as several independent problems with conditions as to topography, density and character of population and available points of disposal, as diverse as possible. The crux of the solution depended on the digestive capacity of the water. In their studies concerning this point the Commission received valuable advice from, among others, Dr. W. E. Adeney, with especial reference to a desirable standard of cleanness for the harbour, and from Dr. Samuel Rideal, regarding the supply of oxygen available for purification in its waters. Dr. Gilbert F. Fowler and Mr. John D. Watson were later consulted regarding plans for relief. These gentlemen all recognized the necessity for carrying out extensive works at an early date, if New York harbour was to be kept in a condition inoffensive to the senses and suitable for a great maritime port. The extensions to the system of interborough rapid transit, now being carried out at a cost of $350,000,000, and the Catskill water-supply at a cost of $177,000,000 more, constituted so great a drain on the city's financial resources that other extensive improvements were postponed wherever possible, and in the matter of main drainage those portions only were likely to be built in the near future that were actually required to avert a nuisance. The subject was being studied by the Board of Estimate and Apportionment, and a general scheme was being formulated to which final plans would conform, but the initiation and carrying out of the work was left to the separate boroughs, of which three—Manhattan, Brooklyn, and Queens—abutted on this part of the lower East river. So far as these studies had proceeded, it was believed that local sedimentation on the west or Manhattan side, and interception of the sewage from the eastern shore to some other point, would

Mr. Allen. suffice to maintain the river in a satisfactorily clean condition for an indefinite period.

Mr. Haile. Mr. WALTER H. HAILE referred to the Author's statement that in periods of flood upwards of 2,000 million gallons per day, and in times of drought possibly less than 400 million gallons per day, flowed over Teddington weir.

As one of Mr. Haile's duties on the engineering staff of the Thames Conservancy was the computation of hydraulic statistics, he would observe that these figures were a little misleading. In fact, the question might well be asked why a river so large as the Thames could reach a state of flood with a discharge only five times that of a state of drought.

When the river was flowing bank-high, and all the weirs were fully drawn, the discharge at Teddington weir was 4,500 million gallons daily. The river was in a state of general flood when upwards of 6,000 million gallons was flowing over Teddington weir. In times of drought the flow fell to 100 million gallons daily, or less. The Author's drought figure of 400 million gallons was rather above an average summer daily flow. The following figures might be of interest for purposes of comparison. In 1916, when the greatest annual discharge on record was reached, the average daily flow was 2,241 million gallons at Teddington Weir. The average daily discharge at the weir for the last 34 years was 1,231 million gallons.

Mr. Hazen. Mr. ALLEN HAZEN, of New York, was much pleased with the concise statement of the development of the sewage-disposal problem in the world's greatest city. The conservative and rational view that was taken as to the practical effects of pollution, and of what it was worth while to do in avoiding them, would be very helpful at this time. Mr. Hazen visited the London outfalls many years ago. He remembered particularly Mr. Dibdin's admirable explanation of the significance of dissolved oxygen in its relation to odours, accompanied by a practical demonstration, the necessary tests being carried out on the inspection boat. He had since repeatedly used this method as a criterion of conditions in American waters, and was interested to note that it was still regarded as the best measure of the condition of the river as regards its liability to cause a nuisance.

The population sewered to New York harbour included the greater part of the city of New York, and also a large population beyond the city limits and in New Jersey. The total population sewered to the harbour approached that of London drained to the Thames, being probably between five and six millions, Mr. Hazen.

There were two tidal entrances to the harbour, one from Long Island Sound and the other from the ocean. Of these, the one through the Narrows from the ocean brought by far the larger quantity of water. The tidal flow in New York Harbour was 5·3 times as great as the mean tidal flow of the Thames at the outfalls as reported by the Author.

There were two important points of difference in the discharge. (1) The New York sewage was discharged without treatment of any kind; (2) it was discharged at innumerable outfalls scattered all along the water fronts of several shores of the East and North rivers and of Newark Bay, and no considerable part of it was concentrated at any one locality. This distribution of the discharge at a great number of points no doubt aided the harmless dispersion of the sewage. The tidal currents were strong and the tidal volumes were large at practically all of the points where sewage was discharged. The concentration of sewage in different parts of the harbour varied considerably, and analyses showed important differences; but in no important part of the harbour had the pollution proceeded so far as to exhaust the dissolved oxygen, and in the larger harbour spaces the remaining margin was wide.

Studies of tidal phenomena in New York Harbour[1] indicated that about 28 per cent. of the entire volume of the tidal flow was new water. A part of this was fresh water coming from the Hudson and other tributary rivers. This, perhaps, averaged 8 per cent. to 10 per cent., but varied greatly at different seasons of the year. The balance of the new water, 20 per cent. more or less, was sea-water. The total amount of new water was practically the same whether the flow of fresh water was great or small. As the amount of fresh water increased, the flood-tide was reduced, and the amount of new sea-water entering was diminished. In summer, when river flows of fresh water were reduced, the flood-tide increased, and the total volume of new entering water was maintained. As a practical proposition, the amount of river-flow had little to do with the dilution that was obtained or with the conditions that were found in the harbour. While at times the fresh water played a considerable part in the dispersion of the sewage, it was the new sea-water that was the main subject of reliance. It was estimated that the new water, fresh and salt, entering New York Harbour was equal to a steady flow of 76,000 cubic feet per second.

[1] Transactions Am. Soc. C.E., vol. 76, p. 2094.

Mr. Carkeet James. Mr. C. CARKEET JAMES believed the London Main Drainage Scheme to be the largest in the world, and considering its magnitude it was a most economical undertaking. He found little to criticize in the Paper, but there was one point to which he would refer. There was no mention in the Paper of ventilation. Would the Author give some information as to how the London sewers were ventilated? London was a very healthy city, and if its sewers were not ventilated, it was a remarkable tribute to the success of the scheme. He would ask also, what was the practice in regard to the disconnecting trap—though possibly this latter point might have nothing now to do with the County Council. If disconnecting traps were not insisted on it was conceivable that the ventilation was through the house-pipes. He noticed reference made to the disabilities of the Worthington pumps at Abbey Mills. He had had the same experience in Bombay, where a large installation of these pumps was erected in 1894 in connection with the drainage of that city.

Would the Author kindly say what the stand-pipes at Abbey Mills were? Did the Author favour centrifugal pumps rather than reciprocating pumps for sewage?

With regard to Mr. Binnie's remarks that a particular kind of centrifugal pump was used in connection with the Cairo drainage, up to the time of the completion of the works in 1915 no such pump had been used so far as Mr. James's knowledge went, though it was of course possible that it might have been in 1916, after he had left.

Mr. Kershaw. Mr. G. B. KERSHAW observed that from the title of the Paper he was a little uncertain as to whether discussion was invited regarding the actual treatment-works and tank-effluent disposal. Since, however, some sections of the Paper were concerned with these subjects, he assumed that it would be in order to refer to them.

The fact that the conversion of the original settling-tanks to the continuous-flow system resulted in increasing the production of sludge threefold, would, at first sight, appear to be at variance with the generally accepted relative efficiencies of quiescent and continuous-flow settlement. When, however, it was remembered that the tanks employed for quiescent settlement were some 800–1,200 feet long by 30 feet in width, the wonder was that any appreciable amount of sludge was retained, since the scouring effect of the velocities set up by decanting tank-liquor from what was to all intents and purposes a series of relatively narrow channels, must have carried the bulk of the suspended matter out of the tanks, Mr. Kershaw.

In the absence of figures of analysis showing the suspended solids in the sewage and tank liquor, it was not possible to form any very definite idea of the efficiency of the present method of treatment.

He would be glad to know how the flows of sewage at Barking and Crossness were determined. He gathered that the total volume of storm-water and sewage discharged through the storm-water outlets represented, roughly speaking, some 20–25 per cent. of the total annual rainfall. This question of the volume of polluting liquid discharged from storm overflows was a matter of considerable importance, by reason of the load of putrescible suspended matter which the liquid almost invariably contained; this might settle in more or less stagnant water, and continue to deprive the water of its oxygen.

He was under the impression that some work carried out for Lord Iddesleigh's Commission by Dr. Adeney on the Thames, near the London outfalls, had demonstrated that the river-water there was de-aerated to a greater degree than could be attributed to the tank-effluents from Barking and Crossness. It seemed to Mr. Kershaw extremely probable that "back numbers" of suspended matter, derived from storm overflow discharges and tank-liquor, might have been responsible for the unaccounted-for oxygen deficit, especially when it was borne in mind that the river-traffic was constantly disturbing some of these solids. Fortunately discharges from storm overflows were intermittent.

The question of storm overflows had come into some prominence before the International Joint Commission of Canada and the United States of America, in connection with the water-supply of the cities and towns lying on the shores of the Great Lakes and the Niagara river, where sterilization of screened sewage or tank liquor had been suggested as a means of safeguarding water-supplies taken in lower down. In such cases, sterilization, with storm overflows discharging in rainy weather, would obviously lead to a very false sense of security amongst water-consumers, especially when it was considered that the raw river-water not infrequently received only chlorine treatment before reaching the consumer.

Respecting the disposal of the tank-effluent, he would like to know whether the mingling of the land and sea waters approached anything like completeness, or did stratification occur to any extent, the fresh water tending to flow over the saline? In the case of non-tidal rivers receiving a fairly definite amount of pollution, it was generally found that a point existed below the sewage-liquor outfall, where the effect of the pollution of the river-water began to be neutralized by re-aeration from the atmosphere, Mr. Kershaw. Re-aeration was chiefly a question of velocity of flow, depth and mixing; and solubility of oxygen a matter of temperature. This "critical" point, as it might be termed, usually receded towards, or extended from, the outfall, at different seasons of the year, being generally nearest to the outfall in hot weather. It would be of interest to learn whether such a point existed in the Thames below the effluent outfalls; it would probably be somewhat masked by the oscillations of the tides. He noticed that the Author observed "the test for dissolved oxygen absorbed in 5 days, as recommended by the recent Royal Commission, is stated not to have yet been found altogether applicable to the conditions found in tidal waters." If test was expressly meant, there was no difficulty whatsoever in carrying out this test either with salt water, or with a mixture of salt and fresh waters. If by "test" was meant "standard," there would still appear to be no very obvious reasons why standards on similar lines, although not necessarily identical with those already proposed by the Commission, should not be applied to tidal waters. Such standards would obviously have to be fixed after the local conditions of each case had been carefully considered. A general standard designed to cover each and every river and estuary would be very undesirable.

The Fourth and Seventh Reports of the 1898 Commission dealt with the discharge of sewage into tidal waters, and some general recommendations with regard to supervision and control, both of sewage-outfalls and shell-fish beds were made. The general conclusion arrived at by the Commission was, that the case of each river and estuary was a problem by itself, and that it would not be practicable to fix by enactment any standard or standards which would be generally suitable to the widely differing conditions of differing cases. It might be useful to mention that the general standard of the 1898 Commission was that "an effluent in order to comply with the general standard must not contain as discharged more than 3 parts per 100,000 of suspended matter, and with its suspended matters included must not take up at 65° F. (18·3° C.) more than 2·0 parts per 100,000 of dissolved oxygen in 5 days." In arriving at the dissolved-oxygen figure for the general standard, the quality of the diluting river-water was taken at the figure 0·2, as representing a river-water which was neither exceptionally polluted nor exceptionally pure. That was to say, that the river-water was assumed to take up 0·2 part of dissolved oxygen per 100,000. One litre of fresh water at 16° C., fully saturated, contained about 7 cc. of dissolved oxygen, and 1 litre of sea-water, similarly saturated, contained about 5·6 cc. Parts

Mr. Kershaw.

per 100,000 (by weight) $\times$ 7 = cc. per litre. Therefore 0·2 part per 100,000 was equivalent to 1·4 cc. per litre; subtracting this from 7 cc., 5·6 cc. was left, and this was the quantity of dissolved oxygen which a 0·2 river-water would contain at 16° C., or some 80 per cent. of saturation. Similarly, a 0·4 river-water—and a water which habitually took up more than 0·4 part per 100,000, would be liable to cause a nuisance—would only contain 7 cc. − 2·8 cc. = 4·2 cc. of oxygen per litre, or some 60 per cent. of saturation.

It might be instructive to turn to the figure for dissolved oxygen kept in mind by the Metropolitan Sewerage Commission of New York, when considering the degree of cleanliness deemed necessary for the harbour waters. The Commissioners say (1912 Report, p. 70): "Except in the immediate vicinity of docks, piers, and sewer-outfalls, the dissolved oxygen in the water shall not fall below 3 cc. per litre of water. Near docks and piers there should always be sufficient oxygen in the water to prevent nuisance from odours." (*Note.*—With 60 per cent. of sea-water and 40 per cent. of land water, and at extreme summer temperature of 80° F., 3 cc. of oxygen per litre = 56 per cent. of saturation.)

He would point out that it must be most carefully borne in mind that the figure for dissolved oxygen proposed by the 1898 Sewage Commission in their general standard (2 parts per 100,000) referred to the effluent alone, and not to a mixture of effluent and river-water. He might be wrong, but there appeared to be some confusion with regard to this point, where the Author stated that "The large seasonal variation in the proportion of oxygen dissolved in the water, which in the winter and spring months reaches a high percentage for long periods when even the five days' absorption test yields results even superior to those recommended by the Royal Commission as applicable to a non-tidal river. . . ."

The standard recommended by this Commission respecting dissolved oxygen, as applicable to non-tidal rivers, was, that the effluent should not take up more than 2 parts [1] per 100,000. If the water of the Thames took up anything approaching 2 parts per 100,000 (14 cc. per litre), it would be past praying for.

The 1898 Sewage Commission described further special conditions as regards dilution where the general standard might either be relaxed or suspended. They were as follows:—

"If the dilution, while not falling below 150 volumes, does not

[1] This figure of 2 parts was only intended to apply to effluents discharging into a volume of water of more than eight times the volume of the effluent. For a smaller dilution than 8 to 1 more stringent standards were foreshadowed.

Mr. Kershaw. exceed 300, the dissolved oxygen absorption test may be omitted and the standard for suspended solids fixed at 6 parts per 100,000. To comply with this test no treatment beyond chemical precipitation would ordinarily be required.

"If the dilution, while not falling below 300 volumes does not exceed 500, the standard for suspended solids may be further relaxed to 15 parts per 100,000. For this purpose tank treatment without chemicals would generally suffice if the tanks were properly worked and regularly cleaned.

"With a dilution of over 500 volumes all tests might be dispensed with, and crude sewage discharged subject to such conditions as to the provision of screens or detritus tanks as might appear necessary to the Central Authority."

Apparently in dry weather the ratio of the present volume of effluent per 24 hours from Barking and Crossness to the tidal flow per 24 hours past the outfalls was—assuming complete mixing—about 1 to 107 during spring-tides; falling to about 1 to 95 during neaps; and it would seem that when the oxygen content of any body of water was reduced almost habitually to under 50 per cent. of saturation in dry weather, for a considerable stretch of river below the sewage-liquor outfalls, whilst on occasion the water was almost entirely deprived of oxygen, it was time to take steps to remedy such conditions.

Mr. Leitch. Mr. D. C. Leitch asked what data were available, in the present case, for the estimation of storm-water discharge, where provision had been made for it by relief sewers or pumping-plant. The estimation of the maximum volume of storm-water, to be dealt with in any section of a drainage system, was a matter of great difficulty and uncertainty. It depended on the maximum intensity of rainfall, the duration of heavy showers, and the area over which they extended. The relation to one another of these three factors was obscure, the combination which gave the maximum rate of discharge had to be chosen in each particular case. Showers of maximum intensity, but limited as regards duration and area, might not give so considerable a discharge as moderate rates of fall more extended in time and space. Moreover, owing to differences in area, shape, contour and nature of surface, the results of experience on one drainage-area were seldom applicable, in any considerable degree, to another. The figures given on page 39 appeared to apply only to storm-water reaching outfalls and pumping-stations from the entire area drained and during periods of 24 hours.

It was not clear why the dockization of the Thames should, as the Author said, render the drainage of London an insoluble problem. No doubt it would entail considerably more pumping; but the lifts were small, and, assuming that there was in other respects a considerable balance of advantage in favour of dockization, this objection alone would hardly condemn it. Mr. Leitch

It seemed rather remarkable, in view of the very moderate lifts and the well-known inconvenience of using reciprocating pumps for sewage, that the latter were originally selected for the stations at Pimlico, Deptford and Crossness. Apparently, under the conditions at these stations, so far as they were disclosed by the Paper, centrifugal pumps would have had an efficiency fully as high, and would have been preferable as regards first cost and convenience of working. Table III showed a lower cost of pumping where the engines had been compounded; but the figures did not include capital charges. With these, increased by cost of compounding added, the difference would perhaps be reduced or disappear. Apparently economy in fuel, although considered a sufficient reason for compounding the original engines, was not thought to justify the substitution of more efficient and modern pumping-plant.

Mr. B. MEEK asked if the Author would state on what basis the amount of rainfall to be dealt with by the sewerage system as it existed at present was arrived at. At the bottom of page 37 it was said: "The actual discharging-capacity of the present outfall sewers, as duplicated by the London County Council after dealing with the sewage of the present population (nearly $5\frac{1}{2}$ millions) and adding 50 per cent. for variation in rate of flow, is now slightly over $\frac{1}{2}$ inch of rain in 24 hours reaching the sewers over the entire area drained." Did the discharging-capacity of the sewers referred to mean the discharging-capacity at the outfall after storm-water had been dealt with by the storm-water overflows along the routes of the sewers, or did it only refer to the discharging-capacity of the intercepting sewers without reference to the storm overflows? If the latter, and the intercepting sewers themselves could deal with $\frac{1}{2}$ inch of rainfall in 24 hours, when the storm overflows came into action a much greater rainfall must be capable of being dealt with by the sewerage system as a whole. The depth of the southern outfall sewer No. 2 and the high-level sewer No. 2 were said to be 135 feet and 125 feet. Would the Author say what special provisions were made for descending and ascending the manholes on these sewers? Were spiral stairs inserted, or were step-irons with landings used? Mr. Meek.

Mr. L. F. MOUNTFORT referred to the choice of gas as a motive power for the storm-water pumps, and the rejection of electricity as a motive power. It would, he thought, be generally admitted that for the conditions to be met with in a storm-water pumping- Mr. Mountfort.

Mr. Mountfort. station, the use of electricity purchased at any reasonable figure offered the best solution, from the point of view of prompt starting and minimum capital expenditure. For a station which was practically standing idle for about 99 per cent. of the time the latter point was important.

From the figures given it would appear that the maximum demand on any station (excluding Abbey Mills) would not exceed 500 kilowatts, and the supply of this power, even if required at all stations in the shortest possible time, would surely not present any difficulties to the large electric-supply undertakings in the county area. He was aware that a demand having such a poor annual load-factor as $1\frac{1}{4}$ per cent. was not looked upon favourably by electric-supply authorities, and it might be that the supply was only obtainable upon a maximum-demand basis involving a prohibitive minimum annual charge. He would be glad if the Author could give a little more information upon this point, and also if he could state the average rate of flow in the main sewers in terms of the dry-weather flow rate, when the storm-water pumps came into operation.

With regard to pumping sludge with centrifugal pumps, difficulties were usually experienced on the suction side of such pumps, which were due not so much to the nature of the liquid dealt with as to its lack of uniform consistency. Sudden variations in the density of the sludge as it was drawn to the suction pipe, caused cavitation troubles in the pump, and necessitated frequent stoppages unless a positive head could be maintained on the suction side, by placing the pump below the water-level in the pump-well, which was not always possible and entailed increased expenditure.

He would be glad if the Author could give some further explanation of the very great difference in cost per million gallons lifted 1 foot (Table III) between the Abbey Mills pumps, and those at the Crossness, Deptford and western pumping-stations. These costs did not include capital charges, and assuming that wages and maintenance costs were no more than usual, it would appear that the actual overall efficiency of these pumps was considerably in excess of those at the other stations.

On p. 33 the Author gave the average water content of the sludge as 92 per cent. Mr. Mountfort was aware how difficult it is to obtain reliable figures of this description, when dealing with very large volumes of sludge, without recourse to very elaborate methods of sampling, and it would be of interest to know how this figure had been ascertained. An error of 1 per cent. in the figure for the water content might easily involve an error of

12 or 15 per cent. in the estimation of the actual solid matter contained in the sludge. Mr. Mountfort.

On p. 36 it was stated that the dry-weather flow was found to be $15\frac{1}{2}$ per cent. less than the average daily flow. Could the Author state what maximum rate of flow in terms of the dry-weather flow was included in the figure for average daily flow?

Many who read this Paper would be surprised to find from the statement on p. 41 that the natural flow of the River Thames in time of drought was only about 40 per cent. in excess of the dry-weather flow of sewage. The Author had remarked on p. 12 that the tidal flow was of fundamental importance in dealing with the drainage problem, and it would appear that it was of even greater importance in regard to the question of the standard of purification required.

The Hon. R. C. Parsons.

The Hon. R. C. PARSONS remarked that many years ago the question of the pumping of the London sewage occupied his attention; and while he was connected with the late firm of Messrs. Easton & Anderson, he designed the storm overflow pumps which were erected by the Metropolitan Board of Works at Effra Creek about the year 1877. At that date the difficulties referred to by the Author, of fibrous matters obstructing the valves of the reciprocating and the passages of the rotatory pumps, were experienced, but no effectual means of avoiding them was then discovered.

Some years ago he was called upon to lay out an extensive sewerage system in which it was necessary to place pumping-stations in thickly populated areas, where the screening of the sewage and the removal of the solid matters were practically inadmissible. He then devoted his attention to the question of the construction of a centrifugal pump which would pass all solid and fibrous matters contained in the sewage. The Stereophagus centrifugal pump was the result, and a large number of these were now in operation for the pumping of unscreened sewage and sewage-sludge. As the principle of this pump was fully described and illustrated in *Engineering* of April 5th, 1912, it was unnecessary to refer to it in detail: he would merely state that it was fitted with a conical impeller and a steel knife, and between the edges of the blades of the former and the latter all fibrous and solid substances were sliced up, so that they might pass through the passages of the pump. It was found also that sand, and even stones, were passed through the Stereophagus pump without damaging the cutting blade. The efficiency of this pump was similar to that of the ordinary centrifugal referred to in the Paper, but this was main-

The Hon. R. C. Parsons. tained, even after considerable wear had taken place, by moving the impeller forward, which could be done whilst it was in operation. A test of an 8-inch Stereophagus pump was made by passing through it fibrous matters such as were found in sewage, and interposing a screen in the effluent with bars spaced even wider than those referred to by the Author, and this became completely choked in a few minutes, whilst the interior of the pump remained free from obstruction.

Mr. Roechling. Mr. H. ALFRED ROECHLING observed that when the late Mr. Joseph Gordon, M. Inst. C.E., at the time Chief Engineer to the London County Council, asked him in 1889 to recommend a formula suitable for calculating the discharging-capacities of the London outfall sewers, he suggested Kutter's complete formula with the coefficient of "rugosity" $n = 0 \cdot 015$. That recommendation had been confirmed by the gaugings of the Northern outfall sewer reported by the late Mr. Santo Crimp in his Paper before The Institution in 1897, the calculated maximum discharge being only 2·41 per cent. under the actual result by gauging. Applying this formula to all the old and new outfall sewers, he had found that their combined maximum discharging-capacity, when running full to 95 per cent. of their total depths, was 1,369,255,320 gallons in 24 hours, a result which was about 10 per cent. below the figure of 1,502,000,000 gallons given by the Author. He would point out, however, that owing to insufficient pumping-power at Crossness, the maximum that could be dealt with at the present time was not his calculated figure, but only 1,211,329,984 gallons in 24 hours. The London County Council had now at work about thirty sewage pumping-engines, with a combined capacity of about 763 million gallons in 24 hours, most of the sewage being pumped twice over, and about thirty-two storm-water pumping-engines, with a combined capacity of about 706 million gallons in 24 hours. According to the figures given by the Author for the last 3 years ending March 31st, 1914, it appeared that the average daily flow in this period amounted to about 303 million gallons, which would correspond with an average daily dry-weather flow of about 256 million gallons. Of this volume about 30 million gallons seemed to have been due to infiltration.

Mr. Roechling calculated that the outfall sewers could at the present time deal with a rainfall of 0·44 inch in 24 hours over the whole drainage-area, which provision would become smaller from year to year, and that the storm-water pumping-stations could deal with a rainfall equivalent to 0·32 inch per day over the whole drainage area. At the time of the maximum flow of sewage the outfall sewers could only take 0·016 inch of rain per hour, which Mr. Roechling. was equivalent to 0·38 inch of rain per day. From the Author's figures he estimated that during the last three years the volume of storm-water that reached the Thames annually was about 14,000 million gallons within, and 18,000 million gallons below, the County boundaries at the outfalls, which with the dry-weather flow of sewage amounted to about 125,000 million gallons per annum, equivalent to an average daily flow of about 343 million gallons. What became of this liquid filth? Could the Thames deal with it, or did it pollute the river. He was satisfied that serious pollution resulted from it.

At Teddington the average daily flow of the Thames was, according to the figure supplied by the London County Council to the 1898 Commission, 977 million gallons, and the minimum flow amounted to only 154 million gallons on the 14th August, 1887. Below this point he estimated, from the statements and figures laid before the 1882 Commission, that the flow of the river, that was, the progress of the water towards the sea, was within the County boundaries at the rate of about 2,137 million gallons in 24 hours, and below them in the neighbourhood of the outfalls at the rate of about 2,348 million gallons. These figures, though challenged by the Metropolitan Board, had in the main been adopted by the Commission. The upland water was principally the true measure of dilution, and this was admitted by the Author (p. 40). Bearing this in mind Mr. Roechling estimated, from the figures previously given, that within the County boundaries the sewage (average dry-weather flow only) was diluted with about eight times its volume, and below them at the outfalls with about nine times its volume. Allowing for previous sewage contamination on a moderate scale he found that the volume of water at the outfalls mentioned by the Author gave about 10 dilutions. Before the 1882 Commission the late Sir Joseph Bazalgette spoke of 150, and the late Mr. Henry Law of 261 dilutions. These were based on the erroneous assumption that the whole of the water into which the sewage was discharged was clean water, whereas it was water containing many previous days' discharges of sewage, the latter being in various stages of decomposition and putrefaction. The dilutions which the 1898 Commission suggested for non-tidal waters would in this case probably lie between 200 and 300.

It was admitted by the Metropolitan Board of Works before the 1882 Commission that the river was polluted from Teddington to Southend. Amongst the conclusions and recommendations of the 1882 Commission he would mention the following:—

Mr. Roechling. The suspended matters were primarily the cause of the trouble.

The discharge of crude sewage into the Thames all the year round was at variance with the original intention and with the Ministerial pledges given on behalf of the Metropolitan Board of Works in the House of Commons when the 1858 Act was passed.

It was neither necessary nor justifiable to discharge crude sewage into any part of the Thames.

As a *preliminary and temporary* measure the liquid portion of the sewage, after previous deposition or precipitation, might at first be suffered to escape into the river at the present outfalls; but as a *permanent* measure it would have to be further purified later on, which, according to the then state of knowledge, could only be done successfully on land.

If suitable land in sufficient quantity and at a reasonable cost could not be obtained, then the liquid, after the previous removal of the solids, might be discharged into the river at a point at least as low down as "Hole Haven."

The Commission also drew attention to the fact that under the Act of 1858 the Metropolitan Board were bound to avoid causing any nuisance, and were liable to indictment in case of the infringement of this provision.

The Metropolitan Board of Works was succeeded by the London County Council in 1889, and all that had been done in the 33 years that had elapsed since the date of the second report of the 1882 Commission was the removal of about 75 per cent. of the suspended solids and the taking of the sludge out to sea to Barrow Deep and now to Black Deep. The suggested temporary measure had been turned into a permanent one. As to the result of this partial treatment of the sewage, some information was given in Mr. Dibdin's Paper[1] read in 1897 before The Institution, which the Author had brought up to date by a few figures. The most complete information on the subject, so far as he knew, was to be found in the fourth report and in Appendix VI to the fifth report of the 1898 Commission. The results then disclosed by very painstaking bacterial and chemical examinations differed very little—except for the partial removal of the solid matters—from the state found in 1882; they showed that the Thames between Teddington and Southend was still more or less a polluted river. It was also stated before the Commission that the trouble was now caused by the dissolved matters. On behalf of the Port Sanitary Authority of London it was urged that the effluent at Barking and Crossness

[1] Minutes of Proceedings Inst. C.E., vol. cxxix, p. 80.

was not a pure effluent but capable of considerable improvement. Mr. Roechling.
The tankage provided at Barking and Crossness was admittedly very small in 1897 and was considerably more so now, as it had not been increased since then. The tank accommodation now amounted both for the north and south to only 14 per cent. of the total daily flow, which gave very high velocities of flow through the channels. Usually the velocity was only about a few inches per minute, but he found that for the average daily flow of London sewage it was about 4 feet per minute, and when the outfall sewers were running full it rose to about 18 feet per minute. The latter velocity was more like a race through the tank, and would carry forward into the effluent any sludge that might happen to be at the bottom of the channels. Under these conditions the results must be poor.

All these remarks clearly showed that the Thames was a polluted stream, the maximum pollution being at the outfalls. Instead of constructing proper treatment-works, the London County Council, for the sake of cheapness, were utilizing the Thames as their sewage-disposal works, with the result that the self-purifying powers of the water were to such an extent overtaxed that it required a stretch of 25 to 27 miles of river to bring about sufficient purification. Even under the most favourable conditions the self-purification of rivers was a very complicated process, consisting probably, as he had previously pointed out, of about eight main stages, during some of which putrefaction was produced. The pollution was bound to become more serious from year to year, as the daily volume of sewage was increasing annually at the rate of about 5 million gallons per day. He thought it was time that the River Thames ceased to be the carrier for the liquid filth of the metropolis, and that the original intention of the Metropolitan Board of Works, the Ministerial pledges given on its behalf, and the conclusions of the 1882 Commission, should at last be carried into effect. In spite of all this, it appeared from the Paper and official publications that the London County Council were so satisfied with the work done for them by the Thames that they proposed to abandon, if not wholly, at any rate for a considerable portion of the year, the treatment with chemicals. This practically meant that they intended to revert to the condition of things which brought about the 1882 Commission, and to treat its condemnation as of no account. Nothing had been altered since then except that the sewage-flow had increased many times, and if the Council carried out their intentions it would probably mean a deposit of some 116,000 tons of suspended matters (about $1\frac{1}{2}$ million tons of wet sludge) annually on the river-bed.

Mr. Roechling. Mr. Roechling would now like to make one or two observations concerning the conception or the plan underlying the main drainage scheme of London. He had previously given some figures illustrating its magnitude, and he would like to add a few further particulars. The drainage-area was only about 1,500 acres less than the area of the County of Rutland, and 1 inch of rain produced over 2,000 million gallons of water. By far the greater part of the surface was impervious, so that the rain-water had to be carried off underground by the sewers; but to convey such a large volume of rain-water, together with the sewage, to one or two outfalls far away was practically an impossibility. The difficulties in this respect were brought about by the enormous size of the scheme, and this prevented the introduction of the separate system, and made a very small rainfall provision in the outfalls and frequent discharges through storm overflows an unavoidable necessity. The length of the main intercepting and storm-water sewers was now 370 miles, and with all the branch sewers the total length could not be far short of 3,000 miles. The cross-sectional area of the outfall sewers was about 647 square feet, and to discharge the volume brought forward by them at the time of the maximum flow in an open channel with a velocity equal to that of the Thames—about 3 feet per minute—would require, when flowing 20 feet deep, a width of nearly $\frac{1}{2}$ mile. The length of the intercepting sewers, together with the outfalls, varied from 10 to 18 miles, and their cost from about £4 to £31 per lineal foot, including special works. Their depth below the ground was in places very considerable, from 52 to 135 feet, and tunnelling was resorted to wherever possible. The total capital cost of the main drainage up to 31st March, 1914, amounted to $12\frac{1}{2}$ million pounds, which gave an overall cost of nearly £34,000 per mile of London County Council's sewers.

All this clearly showed that the constitution of one or two vast drainage-areas made a proper provision for rainfall in the outfall sewers a practical impossibility, required very cumbersome and expensive plant, and made extensions very difficult and costly. In the case of London, the Author had stated that the extensions made during the last few years had entailed a great many practical difficulties, and that they would last for many years to come. This meant that some of the provision then made was not necessary for many years to come, and Mr. Roechling thought such a procedure was unsound from an economic point of view, as money that might still be doing remunerative work elsewhere was locked up in financially unremunerative work. He thought excessive drainage-areas were only justified when their creation entailed corre-

Mr. Roechling.

spondingly large advantages, such as the cheap disposal of the sewage at one or two outfalls. Where this was not the case, he did not think vast and cumbersome works were justified; and his experience led him to conclude that the economic limit of a scheme was governed by a certain size of area and population, the latter probably lying between 250,000 and 500,000, but depending on each individual case. Only comparative estimates could settle this point definitely for each locality, and when this limit had been reached the advantages gained were not commensurate with the expenditure. In such a case it became necessary to split up the drainage-area into several independent areas; and an ideal scheme was probably one which avoided the laying of long and deep sewers near the river in water-logged ground with heavy lifts at pumping-stations, and provided for easy and comparatively cheap extension at the time when it was actually required.

In the case of London it had been established by two Royal Commissions and, indeed, by the investigations of the London County Council itself, that the Thames was a polluted river, and Mr. Roechling could not help thinking that in this case the economic limit of the scheme had long been reached, and that it would be wise in future not to add any fresh areas, but to cut off portions when required and to form them into separate and independent drainage-areas. He would point out that it was originally intended to treat the sewage of the co-called "Western Division" including Fulham, Chelsea, Brompton, Kensington, Shepherd's Bush, Hammersmith and part of Acton, in its own neighbourhood, rather than incur the costly process of carrying it to Barking and lifting it twice on its route to that place. He was, therefore, not suggesting anything new but reviving an old idea. Historically speaking, the first attempts at sewering were by means of independent sewers taken generally at right-angles and the shortest way to the river. This created the system of a large number of independent sewers and outfalls vertically to the river. The next step was the system of intercepting sewers along the river cutting off from it and intercepting the vertical sewers, and establishing one or two main drainage areas. This system was probably still the correct one for small towns. For all large towns, especially when the sewage had to be properly treated, a third system, of a number of independent drainage-areas instead of one or two, was the correct one.

Whatever opinions might be held as to the design of the London scheme and the necessity for taking the polluting sewage out of the Thames, Mr. Roechling agreed that from the commencement the

Mr. Roechling. carrying out of the scheme and the construction of the works had been beyond praise.

Mr. Silcock. Mr. E. J. SILCOCK expressed the opinion that for sewage-pumping rotary pumps were almost always preferable to reciprocating. He thought that too often a fetish was made of high mechanical efficiency, and that other considerations were overlooked. There were no doubt cases where the quantity of sewage to be pumped, the height of lift and the cost of fuel, were such that high efficiency was the ruling factor, and then reciprocating pumps would be used; but these cases were of rare occurrence. Even under such circumstances, whilst it might be desirable that those units dealing with the dry-weather flow might be of a reciprocating type, yet all standbys and stormwater pumps should be rotary, as the increased flexibility obtained, and the absence of valve-trouble, combined with low initial cost, more than compensated for any loss of efficiency during the comparatively limited time during which such units were running. With regard to the use of centrifugal pumps for sludge-pumping, in his experience they were satisfactory when of 6 inches diameter, or larger, but he did not recommend them of a smaller size for such purposes. He had found that the ability to deal with sludge was increased by reducing the sectional area of the suction-pipe by about one-third its area at its inlet end by means of a nozzle, and by using a length of flexible suction-pipe so that the nozzle could be moved about in the sludge-tank.

The question whether or not it would ever be necessary to carry the purification of the metropolitan sewage to a more complete stage before discharge into the river, was a problem which could not be determined without a good deal of investigation checked by actual experience; but, provided that there was no injury to the health of the community, it would be a great waste of public money to attempt to purify the River Thames so that its native fauna should be revived. The value of a few problematical salmon would be very small when compared with the immense cost of a full purification of the London sewage: certainly, under existing circumstances, all that was essential was done.

The Author. The AUTHOR, in reply, thanked Mr. Kenneth Allen and Mr. Allen Hazen for their remarks on the London main drainage system, and for their valuable and interesting information as to the sewerage question at New York. There was, of course, much similarity in the problems presented by the sewage-disposal of these two cities, both by reason of the immense volume to be dealt with and the proximity of both places to tidal waters.

Mr. Allen's amplification of the benefits to be attained by

The Author.

chemical precipitation at times when there were greater demands upon the oxidizing capacity of the waters that ultimately received the effluent were especially interesting and voiced the Author's views; and Mr. Hazen's information showed especially the important part played by inflowing sea-water as a purifying agent in conjunction with the flow of upland waters.

Ventilation, referred to by Mr. Carkeet James, was a large subject. The London sewers were ventilated, and provision had been made for more ventilation than was given at the present time, by open gratings spaced at intervals of about 600 feet along the lines of the sewers. Many complaints had, however, been received in regard to these, over a number of years. Speaking generally, these complaints have resulted in openings being closed entirely and columns or stack pipes, 6 to 12 inches in diameter or rectangular and 30 to 45 feet high, being erected in some convenient place. The cumulative effect of this action had been to reduce the amount of ventilation generally, probably with the result of increasing the odours at any particular place. Public opinion had gone a great way in compelling this action, and a wholesale reopening of closed ventilators might, if decided upon, be productive of good results. In this direction, however, it was difficult to take any decided steps: an odour, probably harmless in itself, nevertheless had effects on the sensibilities of the public that could not be ignored. The interesting fact remained, however, that on one important section of the London sewers which was ventilated on an average at every 180 feet, none were closed, and no complaints had, to the Author's knowledge, been received as to objectionable odours for at least 37 years. From all points of view the more extensive the ventilation system the more satisfactory would be the results. Manhole-covers would not be disturbed by air-pressure in times of heavy storms, and working in the sewers would be facilitated, although in this respect probably less ventilation was required than might at first be thought necessary. Intercepting traps on house-drains were universal in London, although the inspection of these or their provision rested with the Borough Councils; their use, however, was made obligatory under the by-laws issued by the London County Council.

The stand-pipes at Abbey Mills were 4 feet in diameter and 39 feet high, fixed on the pump deliveries, and open-topped. They replaced air-vessels, which were found to be a source of great trouble, becoming filled with corks and floating debris, and eventually bursting. The stand-pipes were of some service in neutralizing the pulsations of the pumps.

The Author. In reply to Mr. Kershaw's question as to the method of determining the flow of sewage at Barking and at Crossness, at Barking the effluent was measured, as it flowed over the weirs at the end of the precipitation channels, by means of Kent meters. At Crossness the quantity was computed from the pump-revolutions; weirs would probably be fitted in the future as at Barking. The risk of any great degree of pollution arising from intermittent and comparatively speaking infrequent storm-discharges in the Thames could not, in the Author's opinion, be judged by conclusions drawn from data afforded by tideless or still waters. With regard to Mr. Kershaw's remarks on stratification, the Author was advised that no evidence of such had been found, although many experiments had been made to this end at many places. Professor Way's evidence in 1883 before the Royal Commission on Metropolitan Sewage Discharge was to the same effect. Re-aeration was doubtless governed by the same conditions as in all other actions of this kind. The oscillation of the tides led to the formation of zones rather than points. The 5-days' absorption test of the Royal Commission could obviously be carried out on any sample of water; but what was intended to be conveyed in the Paper was that the "limiting figure" proposed by the Royal Commission was not altogether applicable to conditions in tidal rivers, and in the Thames especially, by reason of the much greater opportunities for absorbing oxygen in that river, as compared with rivers of the class to which the Royal Commission figure was intended to refer. As Mr. Kershaw justly remarked, a general standard designed to cover each and every river and estuary would be very undesirable; and the fact that re-aeration was continually occurring must not be forgotten when considering his remarks at the bottom of p. 90 and the top of p. 91. It was the "limiting figure" which, although not recommended as a standard for non-tidal waters, was nevertheless the basis of the conclusions of the Royal Commission that was alluded to by the Author as not having been reached in certain of the winter months. The difference between conditions existing in a small quiet stream and those in the Thames, where extensive mixing action took place, was all-important. The physico-chemical aspect of the phenomena involved in such questions had been discussed lately by Mr. J. H. Coste, of the Staff of the Medical Officer of Health of the London County Council in a Paper presented to the London Section of the Society of Chemical Industry, and not yet published.

Mr. Leitch's observations as to estimation of storm-water discharge had been dealt with generally by the Author in his reply to the discussion, and Mr. Leitch had summarized the difficulties

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attendant upon the problems involved in connection with this branch of the subject. Since the Paper was written a rainstorm of an intensity only equalled by one in 1878 had occurred on the 16th June, 1917. The centre of this storm lay over the Campden Hill and Paddington districts, where the maximum intensity reached the abnormal figure of 4·70 inches. The whole rain of the storm fell in scarcely more than 2 hours, while south of a line from Wimbledon to Victoria Park no rainfall was experienced. Happily this storm occurred at low-water time, and experience of one or two of these would, the Author thought, convert Mr. Leitch to the Author's views on the dockization question. With reference to the type of pumps selected at the stations, it must be remembered that these installations were designed about 50 years ago.

With regard to Mr. Haile's remarks on the flow of the upland waters of the Thames, the Author's figures were not intended to be extremes. The quantities of 2,000 and 400 million gallons a day might perhaps have been referred to as high-flow and low-flow figures.

In reply to Mr. Meek's question, the figures given at p. 39 were the discharging-capacity of the outfalls in times of rainfall. Any water taken by the special storm relief-sewers was additional to this. The conclusion that the system as a whole could deal with much greater rainfalls than $\frac{1}{2}$ inch in 24 hours was correct. In the deep manholes referred to, straight up and down galvanized iron ladders with landings at intervals of about 15 to 20 feet were provided.

Mr. Mountfort's remarks as to electricity *versus* gas as a motive power had been dealt with by the Author in his reply to the discussion. Obviously in the event of electric power becoming more universal and more plentiful in quantity in London, conditions might arise to warrant different treatment in the future. With regard to the difference in cost per million gallons lifted 1 foot (Table III) between the four pumping-stations, the Author preferred to consider the average cost per million gallons dealt with at each station. Standing charges were practically the same if the sewage was lifted about 20 feet as at Crossness, and about 37 feet as at Abbey Mills. It was only the coal bill that really showed a substantial difference.

Mr. Roechling's criticism of the design generally of the London system was comprehensive and interesting; the Author appreciated the commendation he awarded to the carrying out and construction of the works. The Author believed, however, that the discharging-capacity of the outfall sewers was in reality nearer to the figures

The Author. he had put forward than those calculated by Mr. Roechling. The findings of the Commission which reported 35 years ago on the further treatment of effluent were quoted. Decidedly, if any money had been spent since 1882 on further purification of the effluent it would, as events had shown, have been unnecessary. Mr. Roechling's criticisms were destructive and not constructive, but the suggestion that the provision made in recent extensions for future requirements was uneconomical because it was not at present required was not, in the Author's opinion, well founded, for the very reason alluded to by Mr. Roechling as forming a part of the expense. The many practical difficulties to be overcome in construction had been such that it would be decidedly uneconomical to overcome them several times in succession by constructing smaller works suitable only for a short period.

The idea of splitting London up into separate drainage-areas might facilitate the storm-water discharge, but would necessitate a multiplication of sewage-treatment installations. The experience of the last 10 or 20 years had been that those responsible for such installations in the outer London area were only too anxious to get rid of them and of the disabilities they entailed by asking the London County Council to take their sewage into the London system. The question of separate drainage-areas, or a combined area for London and the outer ring, was, however, one of the problems of the future.

With Mr. Silcock's remarks on pumping-machinery, and as to further purification of effluent, the Author was in agreement; he would merely add that Mr. Silcock's remarks as to striving for high mechanical efficiency applied also, in his opinion, to the various types of centrifugal pumps.

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20 February, 1917.

Sir MAURICE FITZMAURICE, C.M.G., President, in the Chair.

The discussion upon Mr. G. W. Humphreys's Paper "The Main Drainage System of London" was continued and concluded.
