

Mr. SIMPSON, V.P., said, that the subject of the Paper touched upon the practical question of the best time for gauging: he did not think, that any arbitrary rule could be fixed, and he had himself adopted the plan of taking the gaugings, six times a day. The best rain gauge was a good large reservoir. As soon as leisure would permit, he would endeavour to establish a self-regulating gauge, similar to the tide gauge at Sunderland, which should indicate the flow of water as compared to the fall of rain, during every second of time.

Mr. CAWLEY said, his practice was to gauge six, or eight times a day, over a notch-board with a thin edge.

No. 853.—“Results of a series of Experiments on the Discharge of Water by Overfalls, or Weirs.” By THOMAS EVANS BLACKWELL, M. Inst. C.E.

THE establishment of certain natural laws, in hydraulics, has occupied the attention of philosophers, from the days of Galileo to the present time, and although the great principles, which now form the groundwork of modern hydraulic science, are indisputably settled, yet much remains to be done by practical men, towards applying the necessary corrections for special circumstances; this is only to be accomplished by a faithful record of facts, and in engineering there is perhaps scarcely any branch, where there is a greater want of them, than in that of hydrodynamics.

This deficiency was particularly felt by the Author of this Paper, in the case of weirs, or overfalls, established, by order of Parliament, for regulating and measuring the flow of water into a canal. As frequent doubts and disputes had arisen, the following experiments were undertaken for determining, by absolute trials, the discharge that might be expected from such orifices, and as the opportunities for making such experiments are not of frequent occurrence, the results were carefully recorded, in order to submit them in detail, for the consideration of the Institution.

The first set consists of a series of two hundred and forty-three experiments, made on overfalls of 3 feet, 6 feet, and 10 feet in width, with heads from 1 inch to 14 inches, and with the varying circumstances of having, for the overfall bar,—1st, a thin plate; 2ndly, a plank 2 inches thick; and, 3rdly, a crest 3 feet in breadth. These were all made on the Kennet and Avon Canal, in July 1850.

The second set was made in conjunction with Mr. Simpson, (V. P. Inst. C. E.,) who has kindly permitted the results to be placed on record; the series consists of about seventy experiments

made on an overfall of 10 feet in width. These were made at Chew Magna, Somerset, also in the summer of 1850. Although in some respects, as being made over a bar 2 inches thick and 10 feet long, many of the experiments are apparently parallel, in both cases, they must be separately considered, on account of some peculiar circumstances which will be stated.

Before considering these experiments in detail, it may be well to review, briefly, some of those previously made by English and continental observers, and the practical deductions which had been arrived at by the writers on this subject.

The most scientific series of experiments, on the discharge of fluids through orifices, have been made by foreign observers, and their labours must be familiar to Hydraulic Engineers; but the Chevalier Du Buat, Eytelwein, MM. D'Aubuisson and Castel, and MM. Poncelet and Lesbros, have made the principal observations on the passage of water over weirs.

Those of Du Buat, in 1779, were but few in number, and were on overfalls of $18\frac{3}{4}$ inches wide, with an extreme depth of $6\frac{1}{4}$ inches.

In 1827 and 1828, MM. Poncelet and Lesbros made a very elaborate series of experiments, on the discharge of water by rectangular orifices. They were conducted in the fortifications at Metz. Of these only thirty-six related to overfalls, or 'déversoirs.' The head of water was varied from about $\frac{3}{4}$ inch up to 8 inches, and the width was constantly about $7\frac{3}{4}$ inches. They found, that the coefficient for contraction was constantly varying, as the head was increased, or diminished.

In 1834, MM. D'Aubuisson and Castel made a series of experiments, at the Toulouse water-works, with overfalls which discharged water from a rectangular canal $29\frac{1}{2}$ inches wide and of variable depth. The apertures ranged upwards to the full width, and the head varied from about 1 inch to 8 inches.

Messrs. Smeaton and Brindley conducted a set of experiments, made over a waste-board, of the width of 6 inches, and from 1 inch to 6 inches deep. These, and the experiments of Dr. Robison, quoted in the "Encyclopædia Britannica," appear to be the principal observations made and published in this country.

A comparison of the results of the foregoing experiments, and the coefficients applicable to them and to the present experiments, is given in the Appendix.

The Kennet and Avon Canal experiments were made on a reservoir, or side pond, measuring 2 acres, 1 rood, 30 poles, or 106,200 square feet in area, with a lock at each end, so that there was not any current. The weather was uniformly fine, and during six-sevenths of the time, the wind was very slight, blowing some-

what diagonally up stream, or against the course of the overfall; during the day, the wind was rougher, blowing exactly down the stream; such of the experiments, made on that day, as are given in the tables, and are used in the calculations, are reduced to the standard of the others; a means of doing so being presented by exactly parallel experiments, made on the more favourable days. It may not be uninteresting to know, that the coefficient of correction was found to be about 5 per cent.

The form of the overfall and its relative size and position on the reservoir, will be understood by reference to Plate 6, and the object in presenting this memoir being to give an accurate record of facts, which may be of practical utility, it is necessary to point out two, or three special circumstances, which may possibly, to some slight extent, have influenced the discharge, though the observations made during the progress of the experiments, would induce the belief that such influence was very small. The first is, that the water supplied from the reservoir, above the one on which the experiments were made, did not feed exactly in the same proportion as it was taken out; it was let in by the upper lock, three, or four times a-day, or as often as was requisite. The area of the reservoir, however, was so large, (106,200 square feet,) that the difference of head between the beginning and the end of any one experiment, could scarcely be perceived. The second feature is, that at some little distance above the overfall, the depth of water was reduced, by a submerged course of masonry, belonging to the dock in which the trials were made, and which rose to within 18 inches, or 20 inches of the surface. The third feature is, that the overfall was placed on the outer line of the dam, so as to obtain the requisite fall, and was not exactly in the line of one of the sides of the reservoir. These are circumstances which could not have been conveniently altered, without considerably increasing the expense of the experiments, and as the approach to the overfall was at least 40 feet wide, it was thought, that the general arrangements would fairly represent the case of discharge of water by an overfall from a large still reservoir.

Every care was taken to determine correctly the head of water acting in each experiment, and by such head is meant, throughout this Paper, the total depth, from the surface of the still water, to the crest of the bar of the overfall. The bar forming the top of the overfall was made to rise, or fall, and could be very accurately adjusted, by means of a hand-screw at each end; to this bar, which was about 12 feet in length, and 2 feet deep, were fixed two gauge-rods, working in grooves, cut in a transverse beam above. The head having been determined on, the crest of the bar was brought

exactly level with the still water in the reservoir; the line where the gauge-rods cut the top of the groove was marked with a pencil, and the required head was also measured, and marked off on the gauge-rod. A man at each end, then lowered the overfall bar down to the given head; the water was allowed to run through the waste trunk, till it had assumed a uniform regime, when at a given signal, the lid covering the gauging tank was raised, and the time of filling the tank to a given height, was accurately observed. The time was kept by two, and sometimes by three assistants, and it was registered to quarter seconds. The particular mode of obtaining the head, was in some degree a matter of necessity, arising from the desire to avoid the waste of water out of the canal, in the larger experiments.

The gauging tank had a floor of brick, laid in cement, with plank sides, and was carefully measured; its total capacity was 444.39 cubic feet. In the experiments with very small heads, the tank was only filled to a certain height, and whatever leakage there was into it, during some of the experiments, was measured in a separate vessel, and in the Tables of experiments correction is made for this, in taking the quantity discharged during each experiment.

The thin plate, mentioned in some of the experiments as forming the overfall bar, was a piece of iron fender plate barely $\frac{1}{8}$ inch thick; the plank, 2 inches thick, was square on the top, and the broad crest used, was an apron formed of deal boards, roughly planed over and fastened on to the outer edge of the plank, so as to form an uninterrupted continuation of it; the object in this case, was to approximate towards a well-constructed wide-crested weir, such as is found in rivers, &c.

The experiments tried in conjunction with Mr. Simpson, at Chew Magna, were made on a very small reservoir, which was kept constantly supplied by a pipe 2 feet in diameter, discharging from an upper reservoir, under a pressure of nearly 19 feet; the weather was generally fine,—sometimes rather windy, but as the place was well sheltered by high walls, the effect of this was not much felt. In consequence of the distance between the discharge pipe and the overfall being comparatively short, (about 100 feet,) the water must have retained some part of the velocity due to its discharge under so great a head; this was perceptible to the eye, in heads above 5 inches, or 6 inches, but the peculiar form of the reservoir prevented the amount being accurately determined. The results, however, show, that this influence must have been considerable, and that the effect of water approaching an overfall with an initial velocity is an element which should never be disregarded.

The form of this overfall reservoir is shown in Plate 6. It had wings placed at an angle of 45° , well adapted for facilitating the discharge, and the overfall bar was a cast iron plate 2 inches thick, with a square top.

The heads were measured on a bar 4 feet long, so placed diagonally in the still water, that its zero was just level with the overfall top, and its upper end was raised 1 foot above. It was divided into twelve parts, which represented inches, and it was again subdivided, so that each part was magnified four times, and one-sixteenth of an inch could be easily read. It was protected by a fender from the oscillations of the small waves in the reservoir.

The time was kept by three and sometimes by four observers, who differed but little in their registers, of which a mean was taken.

The gauging tank was a very good one, constructed for the purpose, of brick in cement, and built to hold 400 cubic feet, but by accurate admeasurement it was found to contain $389\cdot79$ cubic feet, and this quantity is used in the calculations.

In this, as in the former set of experiments, efficient means, which it is not necessary to detail, were used for conveying the water from the overfall to the tank, for registering the leakage, &c.

Proceeding then to an explanation of the Tables, it may be remarked that the observations have been classified under the several descriptions, viz., over a plank 2 inches thick, with square edges,—over a thin plate,—over a crest, resembling the top of a weir, of which the breadth was 3 feet, the position of the surfaces horizontal, and also at inclinations downwards of 1 in 18, and 1 in 12 respectively.

These main divisions were observed throughout, and the lengths of the weirs were severally 3 feet, 6 feet, and 10 feet.

The first column in the Table of experiments, shows the head, or difference of level, between the top of the overfall bar, or crest, and the level of the still water in the reservoir.

The second column shows the duration of the experiment, in seconds.

The third column shows the absolute quantity of water discharged during the experiment, correction having been made for the leakage, if any occurred.

The fourth column is the reduction of the two preceding columns, into cubic feet per second.

The fifth is the reduction of the several results of similar experiments, with the same head and length, as shown in the former column, to an average of cubic feet per second.

The sixth is a reduction of the discharge, so ascertained, into cubic feet per second, for each foot of width.

The seventh column contains the coefficient of correction, (m) deduced from the experiments and applicable to the formula—

$$Q = \sqrt{2g} H \times l H \times m \quad (I.)$$

in which

Q is the discharge in cubic feet per second,

$$\sqrt{2g} = 8.03,$$

H , the head in feet,

l , the width of the overfall, and

m , the coefficient of correction.

The eighth column contains the coefficient of correction, (k) deduced also from the experiments, and applicable to the formula¹—

$$H^{\frac{3}{2}} \times l \times k. \quad (II.)$$

in which

Q is the discharge in cubic feet per second,

l , the width of the overfall in feet, and

H , the head in inches, or the height of the still water in the reservoir, above the crest of the overfall.

The ninth column contains occasional observations, made to ascertain the height which the water rose up the face of a common 2-foot rule, held flatwise to the course of the current.

And the tenth column shows the apparent thickness of the stream of water, measured by immersing the thin slide of the rule, held edgewise to the course of the stream.

The particulars recorded in these latter columns were not taken in all the experiments, but the following are the results of those which were observed :—

First, that the head of water, above an overfall, may be ascertained approximately, but only so, by the insertion of a 2-foot rule, held against the stream on the overfall bar, and observing the height to which the water rises, as the total head above the crest.

Secondly, that the thickness of the blade of water, relatively to the total head, was much less than that which Du Buat assumed, in the theory on which his formula was based; which was, that this thickness was equal to half the total depth, from the crest to the top of the water. Indeed it much more nearly agreed with the results which Professor Robison has recorded, and which he gives as about five-sevenths of the total depth. In the present experiments it was found, that, in the case of the plank overfall 2 inches wide, the thick-

¹ This formula is the same as that in general use among English Engineers, viz., $D = H^{\frac{3}{2}} \times 5.1$, in which

D , is the number of cubic feet discharged per minute for every foot in width of the overfall.

H , the head in inches.

5.1, the constant coefficient of reduction. (The variable value of the coefficient (k) is, however, shown in these experiments.)

ness varied from six-tenths to eight-tenths, following the law of increase, as the total head increased. The exact ratios are inserted in the Tables of experiments. In each of these cases, the admeasurement was taken at the outer edge of the bar, or at the lower end of the apron, or crest.

The first twelve Tables give the results of the experiments made on the Kennet and Avon Canal, where the reservoir was large, in proportion to the overfall, and the water was still.

Table XIII. contains the result of the experiments made at Chew Magna, in Somersetshire, in which the reservoir was very small, in proportion to the overfall; it was kept continually supplied by a pipe 2 feet in diameter leading from a reservoir 19 feet above it. The columns, in this case also, have the same signification, except the two last, on which points no observations were recorded.

EXPERIMENTS ON OVERFALLS.

KENNET AND AVON CANAL—1850.

Total Depth of Water above crest.	Time.	Quantity Discharged.				Coefficients.	
		Total Quantities discharged during experiment.	Discharge per Second.	Average of Experiments.	Discharge per Second for 1 foot in width.	<i>m</i> Applicable to Formula (I.)	<i>k</i> Applicable to Formula (II.)
Inches.	Seconds.	Cubic feet.	Cubic feet.	Cubic feet per second.	Cubic feet.		

TABLE I.—Overfall, thin Plate, 3 feet long.

1	176 $\frac{1}{2}$	45.97	.260	.260	.087	.451	.087
2	124 $\frac{1}{2}$	91.94	.739	.739	.246	.450	.087
3	72 $\frac{3}{4}$	91.94	1.264	1.264	.421	.420	.081
4	96	182.94	1.906	1.906	.635	.411	.079
5	99 $\frac{1}{2}$	259.01	2.603	2.603	.868	.401	.078
6	131 $\frac{1}{4}$	441.77	3.366	3.366	1.122	.395	.076
Mean						.421	.080

TABLE II.—Overfall, thin Plate, 10 feet long.

1	177 $\frac{1}{4}$	183.90	1.038	1.038	.104	.539	.104
2	63	183.90	2.920	2.920	.292	.535	.102
3	103 $\frac{1}{4}$	444.39	4.304	4.286	.429	.428	.082
3	62	260.50	4.201				
3	42 $\frac{1}{4}$	183.90	4.352	6.755	.675	.437	.089
4	65 $\frac{1}{2}$	442.43	6.755				
5	47 $\frac{1}{2}$	442.03	9.355	9.355	.935	.433	.083
5	47 $\frac{1}{4}$	442.03	9.355				
8	26	441.77	16.988	16.909	1.691	.387	.075
8	25 $\frac{1}{4}$	441.77	16.830				
9	24	441.99	18.416	18.416	1.842	.353	.069
Mean						.445	.086

[1850-51.]

Z

EXPERIMENTS ON OVERFALLS.

KENNET AND AVON CANAL, 1850.

Total Depth of Water above Crest.	Time.	Quantity Discharged.				Coefficients.		Thickness of Sheet of Water taken at the outer edge of overfall plank, or where there was a wide crest at the outer end of such crest.	
		Total Quantity discharged during Experiment.	Discharge per Second.	Average of Experiments.	Discharge per Second for 1 ft. in width.	<i>m</i>	<i>k</i>		
Inches.	Second.	Cub. Ft.	Cub. Ft.	Cub. Ft.	Cub. Ft.			Water rose against a 2 ft. rule held flat-ways against stream.	Shown on the brass slide of rule held edge-ways.

TABLE III.—Overfall, Plank, 2 inches wide, 2 feet long.

								Inches. 1	Inches. $\frac{5}{8}$	
1	757	137.91	181	}	.180	.060	.311	.060	1	$\frac{5}{8}$
1	280 $\frac{1}{2}$	45.97	164							
1	235	45.97	195	}	.555	.185	.339	.065		
2	167	91.94	530							
2	164	91.94	561	}	1.138	.376	.375	.072		
3	159	183.90	1.157							
3	82 $\frac{1}{2}$	91.94	1.114							
3	80 $\frac{1}{2}$	91.94	1.143	}	1.695	.565	.366	.071	4 $\frac{1}{4}$	3
4	147 $\frac{1}{2}$	259.00	1.756							
4	158 $\frac{1}{2}$	258.92	1.634	}	2.537	.846	.392	.076	4	2 $\frac{11}{16}$
5	172 $\frac{1}{2}$	442.67	2.566							
5	176 $\frac{1}{2}$	442.63	2.508	}	3.363	1.121	.395	.076	5	3 $\frac{1}{2}$
6	131 $\frac{1}{2}$	443.07	3.370							
6	132	443.07	3.356	}	4.413	1.471	.411	.074	5	3 $\frac{1}{2}$
7	100 $\frac{1}{2}$	442.38	4.402							
7	100	442.39	4.424	}	5.297	1.766	.404	.078	6	4 $\frac{3}{8}$
8	83 $\frac{1}{2}$	442.30	5.297							
8	83 $\frac{1}{2}$	442.30	5.297	}	6.256	2.085	.400	.077	6	4 $\frac{3}{8}$
9	70 $\frac{3}{4}$	442.62	6.256							
10	58 $\frac{3}{4}$	442.92	7.539	}	7.492	2.497	.409	.079		
10	59 $\frac{1}{2}$	442.99	7.445							
Mean								.380	.073	

EXPERIMENTS ON OVERFALLS.

KENNET AND AVON CANAL, 1850.

Total Depth of Water above Crest.	Time.	Quantity Discharged.				Coefficients.		Thickness of Sheet of Water taken at the outer edge of overfall plank, or where there was a wide crest, at the outer end of such crest.	
		Total Quantity dis- charged during Ex- periment.	Dis- charge per Second.	Average of Ex- periments	Dis- charge per Second for 1 ft. in width.	<i>m</i>	<i>k</i>		
		Inches.	Second	Cub. Feet.	Cub. Ft.	Cub. Feet.	Cub. Ft.	Water rose against a 2 ft. rule held flat- ways against stream.	Shown on the brass slide of rule held edge- ways.

TABLE IV.—Overfall, Plank, 2 inches wide, 6 feet long.

									Inches.	Inches.
1 to $\frac{1}{16}$	487 $\frac{1}{2}$	171.23	•354	354	•059	•306	•059			
2	137	184.34	1.317	1.222	•204	•374	•072	$1\frac{1}{4}$		
2	159 $\frac{1}{2}$	179.76	1.128							
3	184 $\frac{1}{2}$	439.60	2.383							
3	183 $\frac{1}{2}$	439.62	2.396	2.396	•399	•398	•077	3		$1\frac{1}{16}$
3	184	439.61	2.389							
3	183 $\frac{1}{2}$	439.62	2.396							
3	181 $\frac{1}{2}$	439.68	2.422	3.563	•594	•383	•074	5		$3\frac{1}{2}$
3	184	439.61	2.389							
4	127	439.31	3.463							
4	120	439.60	3.663	6.890	1.150	•405	•074			$4\frac{3}{8}$
5	82 $\frac{1}{2}$	442.24	5.359							
5	86 $\frac{1}{4}$	442.15	5.126							
5	86	442.16	5.141	8.695	1.449	•405	•073	$5\frac{1}{8}$		
6	64 $\frac{1}{2}$	442.72	6.890							
6	64 $\frac{1}{4}$	442.72	6.890							
7	49 $\frac{1}{4}$	443.11	8.997	10.309	1.718	•393	•076	$6\frac{1}{8}$		
7	51 $\frac{1}{2}$	443.06	8.631							
7	52	443.04	8.520							
7	51 $\frac{1}{2}$	443.06	3.631	13.156	2.193	•359	•069	$6\frac{3}{4}$		
8	43	443.27	10.309							
8	43	443.27	10.309							
9	37 $\frac{1}{2}$	443.41	11.850	22.183	3.697	•366	•071			
9	37 $\frac{1}{4}$	443.41	11.850							
9	37 $\frac{1}{2}$	443.41	11.850							
10	34 $\frac{1}{2}$	443.03	12.950	16.356	2.726	•350	•066			
10	33 $\frac{1}{2}$	443.07	13.363							
12	26 $\frac{3}{4}$	443.32	16.515							
12	27 $\frac{1}{4}$	443.30	16.207	22.183	3.697	•366	•071			
14	20 $\frac{1}{4}$	443.58	21.890							
14	19 $\frac{3}{4}$	443.60	22.477							
Mean						•377	•072			

EXPERIMENTS ON OVERFALLS.

KENNET AND AVON CANAL, 1850.

Total Depth of Water above Crest.	Time.	Quantity Discharged.				Coefficients.	
		Total Quantity Discharged during Experi- ment.	Discharge per Second.	Average of Experi- ments.	Discharge per Second for 1 foot in width.	<i>m</i>	<i>k</i>
Inches.	Seconds.	Cub. Ft.	Cub. Ft.	Cub. Ft.	Cub. Ft.		

TABLE V.—Overfall, Plank, 2 inches wide, 10 feet long.

1	230	152.62	.665	}	.563	.056	.290	.056
1	454 $\frac{3}{4}$	207.30	.461					
2	81 $\frac{1}{2}$	172.82	2.125	}	2.129	.213	.390	.075
2	81	172.89	2.134					
3	47	177.51	3.777	}	3.803	.380	.379	.073
3	46	177.65	3.862					
3	48	177.38	3.695					
3	111 $\frac{1}{4}$	431.38	3.877					
4	67 $\frac{1}{4}$	436.53	6.491	}	6.192	.619	.401	.077
4	67 $\frac{1}{4}$	436.50	6.468					
4	72 $\frac{3}{4}$	440.76	6.059					
4	73 $\frac{1}{2}$	440.72	5.996					
4	73	440.74	6.038	}	8.774	.877	.406	.078
4	73 $\frac{1}{4}$	440.73	6.098					
5	48 $\frac{3}{4}$	438.69	8.998					
5	50 $\frac{1}{4}$	438.52	8.726					
5	51	438.43	8.597	}	10.881	1.088	.384	.074
6	41 $\frac{3}{4}$	438.72	10.512					
6	40	438.95	10.976					
6	40	438.95	10.976					
6	39 $\frac{3}{4}$	439.74	11.063	}	11.063	1.106	.384	
7	32 $\frac{1}{4}$	440.01	13.780					
7	33 $\frac{1}{4}$	439.80	13.164					
7	32	440.04	13.887					
7	32	440.65	13.885	}	13.720	1.372	.384	.074
7	32	440.65	13.885					
8	28 $\frac{3}{4}$	440.48	15.474					
8	27	440.12	16.463					
8	28	440.59	15.893	}	15.943	1.594	.365	.071
9	22 $\frac{1}{2}$	441.33	19.613					
9	23 $\frac{3}{4}$	441.16	18.575					
9	22	441.40	20.063					
10	20	441.67	22.083	}	19.417	1.942	.372	.072
10	21	441.54	21.026					
10	20	442.05	22.102					
12	15 $\frac{1}{4}$	442.29	28.529					
					28.529	2.853	.356	.069
						Mean	.371	.072

EXPERIMENTS ON OVERFALLS.

KENNET AND AVON CANAL, 1850.

Total Depth of Water above Crest.	Time	Quantity Discharged.				Coefficients.		Thickness of Sheet of Water taken at the outer edge of overfall plank, or where there was a wide crest at the outer end of such crest.	
		Total Quantity Discharged during Experiment.	Discharge per Second.	Average of Experiments.	Discharge per Second for 1 ft. in width.	m	k		
Inches	Second	Cub. Feet.	Cub. Ft.	Cub. Ft.	Cub. Ft.			Water rose against a 2 ft. rule held flat-ways against stream.	Shown on the brass slide of rule held edge-ways.

TABLE VI.—Overfall, Plank, 2 inches wide, 10 feet long, fitted with wing-boards converging at an angle of 64° .

5	45 $\frac{3}{4}$	442.11	9.664		0.966	.447	.086		
4	65 $\frac{1}{2}$	441.77	6.745		0.674	.437	.088		
2	106	260.50	2.460		0.246	.450	.087		
1	190	183.90	0.968		0.097	.503	.097		
					Mean	.459	.090		

TABLE VII.—Overfall, with Crest, 3 feet wide, sloping 1 in 12, 3 feet long.

1	254 $\frac{1}{4}$	45.97	.181	.181	.060	.311	.060	1 $\frac{1}{2}$	4
2	236 $\frac{3}{4}$	137.91	.592	.582	.194	.355	.069		
3	170 $\frac{1}{4}$	183.90	1.080	1.080	.360	.359	.069		
4	183 $\frac{1}{2}$	257.75	1.404	1.404	.468	.303	.0585	6	1 $\frac{1}{2}$
6	146 $\frac{1}{2}$	441.46	3.014	3.014	1.005	.354	.068	8	1
7	117 $\frac{1}{2}$	442.01	3.762	3.762	1.254	.351	.068	9	2 $\frac{3}{8}$
9	85 $\frac{1}{4}$	442.26	5.188	5.188	1.729	.332	.064		
					Mean	.338	.065		

TABLE VIII.—Overfall, with Crest, 3 feet wide, sloping 1 in 18, 3 feet long.

1	218 $\frac{3}{4}$	45.97	.210	.210	.070	.363	.070		
2	230 $\frac{3}{4}$	137.91	.597	.597	.199	.364	.070		
3	170 $\frac{3}{4}$	183.90	1.077	1.077	.359	.358	.069		
4	194	257.58	1.328	1.328	.443	.287	.055	5 $\frac{1}{2}$	1 $\frac{3}{8}$
5	197 $\frac{1}{2}$	440.44	2.230	2.230	.743	.344	.066	7	1 $\frac{3}{8}$
7	120 $\frac{1}{2}$	441.98	3.667	3.667	1.222	.342	.066	8	2 $\frac{1}{8}$
8	103 $\frac{1}{4}$	441.81	4.279	4.279	1.426	.327	.063		
9	86 $\frac{1}{2}$	442.23	5.112	5.127	1.709	.328	.063		
9	86	442.24	5.143						
					Mean	.339	.065		

EXPERIMENTS ON OVERFALLS.

KENNET AND AVON CANAL, 1850.

Total Depth of Water above Crest.	Time.	Quantity Discharged.				Coefficients.		Thickness of Sheet of Water taken at the outer edge of overfall plank, or where there was a wide crest, at the outer end of such crest.	
		Total Quantity discharged during Experiment.	Discharge per Second.	Average of Experiments.	Discharge per Second for 1 ft. in width.	<i>m</i>	<i>k</i>		
Inches.	Second	Cub. Ft.	Cub. Ft.	Cub. Ft.	Cub. Ft.			Water rose against a 2 ft. rule held flat-ways against stream.	Shown on the brass slide of rule held edge-ways.

TABLE IX.—Overfall, with Crest, 10 feet long, 3 feet wide, sloping 1 in 18.

								Inches.	Inches.
1 to $\frac{7}{8}$	282	169.80	.603	.603	.060	.311	.060	1 $\frac{1}{2}$	$\frac{5}{16}$
2	138 $\frac{1}{4}$	253.59	1.834	1.805	.181	.330	.064	3 $\frac{3}{4}$	$\frac{9}{16}$
2	100 $\frac{1}{2}$	178.88	1.777					3 $\frac{1}{2}$	$\frac{9}{16}$
4	83	440.24	5.304	5.304	.530	.343	.066	5	1 $\frac{1}{2}$
6	43	442.24	10.285	10.285	1.028	.362	.070	8 $\frac{1}{4}$	2 $\frac{1}{4}$
8	30	442.89	14.761	14.761	1.476	.338	.066	9	3 $\frac{1}{2}$
Mean						.337	.065		

TABLE X.—Overfall, with Crest, 3 feet wide, level, and 3 feet long.

1	265 $\frac{1}{2}$	45.97	.173	.173	.058	.301	.058	1	$\frac{7}{16}$
2	350	183.90	.525	.525	.175	.321	.062	2	$\frac{7}{8}$
3	294	260.50	.886	.886	.295	.294	.057		
4	200	258.50	1.292	1.292	.431	.279	.054	4 $\frac{1}{4}$	1 $\frac{3}{8}$
5	213 $\frac{1}{2}$	441.19	2.066	2.066	.689	.319	.061	5	2 $\frac{1}{4}$
6	158	441.23	2.892	2.840	.947	.334	.064	6	2 $\frac{1}{8}$
6	65 $\frac{1}{2}$	182.59	2.788					6	2 $\frac{1}{8}$
7	126 $\frac{3}{4}$	441.86	3.486	3.486	1.162	.325	.060		
7 $\frac{1}{2}$, 8	108	441.69	4.089						
8	107 $\frac{1}{2}$	441.71	4.109	4.109	1.369	.313	.061		
9	89 $\frac{3}{4}$	442.15	4.926	4.926	1.642	.317	.061		
Mean						.311	.060		

EXPERIMENTS ON OVERFALLS.

KENNET AND AVON CANAL, 1850.

Total Depth of Water above Crest.	Time.	Quantity Discharged.				Coefficients.		Thickness of Sheet of Water taken at the outer edge of overfall plank, or where there was a wide crest at the outer end of such crest.	
		Total Quantity Discharged during Experiment.	Discharge per Second.	Average of Experiments.	Discharge per Second for 1 ft. inwidth.	<i>m</i>	<i>k</i>		
Inches.	Second	Cub. Ft.	Cub. Ft.	Cub. Ft.	Cub. Ft.			Water rose against a 2 ft. slide of rule held flat-ways against stream.	Shown on the brass rule held flat-ways against stream.

TABLE XI.—Overfall, with Crest, 3 feet wide, level, and 6 feet long.

								Inches.	Inches.
1 to 1 $\frac{1}{2}$	405	173.37	.429	.429	.071			1 $\frac{1}{8}$	$\frac{1}{8}$
3	222 $\frac{1}{2}$	438.52	1.973	1.971	.329	.328	.063	3	1 $\frac{1}{8}$
3	223 $\frac{1}{2}$	438.58	1.961					2 $\frac{7}{8}$	1 $\frac{1}{4}$
3	221 $\frac{1}{2}$	438.63	1.978	3.068	.511	.331	.064	6	2 $\frac{3}{4}$
4	142	438.72	3.091					8 $\frac{1}{2}$	4 $\frac{1}{8}$
4	144	438.64	3.045	5.781	.963	8			
6	77 $\frac{1}{2}$	442.38	5.781						
7	61 $\frac{3}{4}$	441.91	7.150	7.150	1.191	.331	.060		
9	44 $\frac{1}{2}$	443.24	9.964	10.019	1.670			8 $\frac{1}{4}$	4 $\frac{1}{8}$
9	44	443.25	10.074						
10	39	442.84	11.360	11.360	1.895	.310	.060		
10	39	442.84	11.360						
12	29 $\frac{3}{4}$	443.21	14.900	14.965	2.495	.311	.060		
12	29 $\frac{1}{2}$	443.21	15.030						
Mean						.322	.061		

TABLE XII.—Overfall, with Crest, 3 feet wide, level, and 10 feet long.

1	339 $\frac{1}{2}$	166.93	.492	.492	.049	.254	.049	7 $\frac{1}{8}$	7 $\frac{1}{8}$
2	101 $\frac{1}{2}$	178.83	1.762	1.736	.174	.319	.061	2	2 $\frac{1}{8}$
2	104 $\frac{1}{2}$	178.68	1.710					2	2 $\frac{1}{8}$
5	59 $\frac{1}{2}$	441.43	7.450	7.450	.745	.345	.066	5	1 $\frac{1}{4}$
6	45 $\frac{1}{2}$	442.12	9.717	9.717	.972	.342	.066	6	2 $\frac{3}{4}$
8	32 $\frac{1}{2}$	442.77	13.622	13.622	1.362	.312	.060	7 $\frac{1}{2}$	3 $\frac{1}{2}$
9	26 $\frac{1}{2}$	443.08	16.879	16.879	1.688	.324	.063	8 $\frac{1}{2}$	3 $\frac{1}{2}$
10	24	443.19	18.467	18.467	1.847	.303	.059	9	4
Mean						.314	.061		

EXPERIMENTS ON OVERFALLS.

CHEW MAGNA, 1850.

Total Depth of Water above Crest.	Time.	Quantity Discharged.				Coefficients.	
		Total Quantity Discharged during Experiment.	Discharge per Second.	Average of Experi- ments.	Discharge per Second for 1 ft. in width.	<i>m</i>	<i>k</i>
Inches.	Seconds.	Cub. Feet.	Cub. Feet.	Cub. Feet.	Cub. Feet.		

TABLE XIII.—Overfall Bar, 2 inches wide, 10 feet long.

1 to $\frac{7}{16}$	560 $\frac{1}{2}$	384.71	.690	.690	.069	.394
1 to $1\frac{1}{16}$	469	384.71	.820			
bare	439	384.71	.870	.860	.086	.417
$1\frac{1}{16}$ bare	434 $\frac{1}{2}$	384.71	.880			
$1\frac{1}{16}$ good	139 $\frac{1}{2}$	398.79	2.900	2.900	.290	.455
$2\frac{1}{8}$	133 $\frac{1}{2}$	385.79	2.900			
$2\frac{1}{8}$ good	93 $\frac{1}{2}$	383.71	3.906	3.906	.391	.443
$2\frac{3}{8}$	98	383.71	3.916			
$2\frac{3}{8}$	97 $\frac{1}{2}$	383.71	3.916			
$2\frac{3}{8}$	97 $\frac{1}{2}$	383.71	3.950	4.016	.402	.447
$2\frac{3}{8}$	97 $\frac{1}{2}$	383.71	4.104			
$2\frac{3}{8}$	97 $\frac{1}{2}$	383.71	4.104			
$2\frac{3}{8}$	97 $\frac{1}{2}$	383.71	4.104			
$2\frac{3}{8}$	93 $\frac{1}{2}$	383.71	4.115	4.115	.412	.437
$2\frac{3}{8}$	92 $\frac{1}{2}$	383.71	4.148	4.148	.415	.435
$2\frac{3}{8}$	91 $\frac{1}{2}$	398.79	4.231	4.231	.423	.436
3 bare	82	885.71	4.700	4.700	.470	.469
3 to $3\frac{1}{16}$	80	385.71	4.820	4.820	.482	.483
4 bare	52 $\frac{1}{2}$	385.71	7.340	7.340	.734	
4	50	385.71	7.710			
4	50	385.71	7.710	7.680	.768	.497
4	50 $\frac{1}{2}$	384.71	7.620			
4 $\frac{1}{4}$	46	383.71	8.342			
4 $\frac{1}{4}$	46	383.71	8.342	8.358	.836	.495
4 $\frac{1}{4}$	45 $\frac{1}{4}$	383.71	8.390			
4 $\frac{1}{8}$	45	383.71	8.530			
4 $\frac{1}{8}$	44 $\frac{1}{2}$	387.75	8.770			
4 $\frac{1}{8}$	43 $\frac{1}{2}$	386.71	8.890	8.770	.877	.507
4 $\frac{1}{8}$	43 $\frac{1}{2}$	386.71	8.890			
4 $\frac{1}{8}$	44	383.71	8.721	8.721	.872	.491
4 $\frac{1}{8}$	41 $\frac{3}{4}$	383.71	9.190			
4 $\frac{1}{8}$	42 $\frac{1}{4}$	383.71	9.090			
4 $\frac{1}{8}$	43 $\frac{1}{4}$	385.71	8.870	9.017	.902	.500
4 $\frac{1}{8}$	43 $\frac{1}{4}$	385.71	8.920			
4 $\frac{1}{2}$ bare	43 $\frac{3}{4}$	385.71	8.820			
4 $\frac{1}{2}$ bare	43 $\frac{3}{4}$	385.71	8.870	8.887	.889	.483
4 $\frac{1}{2}$ bare	43	385.71	8.970			
5 bare	34	383.71	11.290	11.290	1.129	.520
$5\frac{1}{16}$	33 $\frac{1}{2}$	383.71	11.40	11.460	1.146	.521
$5\frac{1}{16}$	31 $\frac{3}{4}$	383.71	12.086	12.086	1.209	.499
$5\frac{1}{16}$ to $5\frac{1}{32}$	31	383.71	12.380	12.386	1.238	.501
$5\frac{1}{32}$	31	383.71	12.380			

EXPERIMENTS ON OVERFALLS.

CHEW MAGNA, 1850.

Total Depth of Water above Crest.	Time.	Quantity Discharged.				Coefficients.	
		Total Quantity Dis- charged during Experi- ment.	Dis- charge per Second.	Average of Experi- ments.	Dis- charge per Second for 1 ft. in width.	<i>m</i>	<i>k</i>
Inches.	Seconds.	Cub. Ft.	Cub. Ft.	Cub. Ft.	Cub. Ft.		

TABLE XIII.—continued.

5 $\frac{1}{16}$	28 $\frac{1}{4}$	335.71	13.530	13.530	1.353	•485
6	27 $\frac{1}{4}$	385.71	14.150	14.150	1.415	•499
6	27 $\frac{1}{4}$	385.71	14.150			
6 $\frac{3}{16}$	28 $\frac{1}{4}$	399.79	14.030	14.030	1.403	
6 $\frac{3}{16}$	27 $\frac{3}{4}$	398.79	14.370	14.430	1.443	•499
6 $\frac{3}{16}$	27 $\frac{3}{4}$	398.79	14.500			
6 $\frac{3}{16}$ to 6 $\frac{1}{4}$	26 $\frac{3}{4}$	399.79	14.900	14.900	1.490	•498
6 $\frac{1}{2}$	21 $\frac{1}{4}$	385.71	18.150	18.150	1.815	•515
6 $\frac{1}{2}$	21 $\frac{1}{4}$	385.71	18.150			
7 $\frac{1}{16}$	20 $\frac{1}{4}$	398.79	19.450	19.610	1.961	•478
7 $\frac{1}{16}$	20 $\frac{1}{4}$	398.79	19.690			
7 $\frac{1}{16}$	20 $\frac{1}{4}$	399.30	19.690			
7 $\frac{1}{16}$	20 $\frac{1}{4}$	399.30	19.690			
8	16 $\frac{1}{2}$	385.71	23.380	23.380	2.338	•535
8	16 $\frac{1}{2}$	385.71	23.380			
8 to 8 $\frac{1}{16}$	15 $\frac{1}{2}$	384.71	24.820	24.820	2.482	•491
8 $\frac{1}{16}$	15 $\frac{1}{2}$	384.71	24.820	24.820	2.482	•500
9	14	385.71	27.550	27.550	2.755	•521
9			
9	..	883.71	27.550			
Mean .						•480

With a view of ascertaining how nearly the discharges of water follow the natural parabolic law, several curves were projected, in which the abscissæ represented the quantities discharged per second, under the various heads shown by the corresponding ordinates. From these it was seen, that though they evidently followed the fundamental law, yet the various opposing forces called into play, as the heads and widths increased, or decreased, produced anomalies and variations from that curve, which entirely destroyed its regularity.¹

The whole of the coefficients given in the Tables, have been plotted, in such a manner as to show the mean coefficient, for each

¹ Diagrams showing these curves were exhibited at the Meeting.

set of experiments, and the variations for each change of head. (Plate 7.) This method shows in a striking manner, that no formula with a constant coefficient will give the true discharge of water by a weir. It is also interesting to observe, that whereas, in some instances, the coefficient is higher with a small head, and decreases as the head increases, in others the reverse takes place. Thus it will be seen, that where the overfall bar was a piece of thin plate, with a head of 1 inch, the coefficient was considerably higher than the mean; whilst a similar length of overfall, consisting of a plank 2 inches wide, gives the coefficient as much less than the mean; again, whilst the coefficient for an overfall formed of a plank 2 inches wide and 3 feet long, with a head of 1 inch, gives a coefficient of $\cdot 331$, the same head and length of crest of 3 feet, gives only $\cdot 301$ as a coefficient.

One of the general laws that appears to be indicated by these experiments, is that in thin plates, the coefficient is highest at the smallest head observed, and that it reaches the mean, at a head of about 3 inches; after which it continues to decrease, as the head increases.

For a plank 2 inches thick, (which represents the ordinary form of wasteboard,) these experiments show, that beginning with a head of 1 inch, the coefficient is less than the mean; that it reaches its mean earlier, as the length of the weir is greater, being in average cases, at about the head of 3 inches; and that it then rises higher than its mean, till it reaches the head of about 9 inches, when it is again depressed below the mean.

One remarkable circumstance was found to prevail in a great number of these experiments, viz., that the head of about 4 inches gave a less quantity than could be arrived at by interpolating the results of the experiments with heads of 3 inches and 5 inches. It is not easy to explain the causes tending to produce this depression; but the fact was striking and well established.

A similar result occurred, at about the same head, in the other set of experiments made at Chew Magna.

A few experiments, which were made for ascertaining the effect of converging wing-walls, will demonstrate the great advantages known to be attendant on such a form, as will be seen by comparing the results on the weir of 10 feet in length with and without such wings. The mean coefficients for the two cases were $\cdot 371$ without, and $\cdot 459$ with the wings; the splay of the wings being an angle of 54° .

CHEW MAGNA EXPERIMENTS.

The circumstances attending this set of experiments, render the discharges of them analogous to the case of a weir in a river, or in a running stream; but among themselves there are anomalies equally remarkable with those on the canal. The overfall bar was here invariably 2 inches thick, and the length was always 10 feet. The coefficients, up to a head of 3 inches, are below the mean; above that head they fluctuate considerably; but generally they keep above the main line. These anomalies are difficult to account for; the experiments having been very carefully made, and such causes of error, as might have arisen, are not sufficient to explain them; they are therefore left as facts, to be added to, or elucidated, by the researches of others.

In addition to the experiments so made, some others are shown in Plate 7, illustrative of the coefficients; they are the results of a set of experiments made by M. Castel at the Toulouse water-works, and those of MM. Poncelet and Lesbros, at Metz. The circumstances attending these cases have been before explained, and from the arrangement of the apparatus, the water must have approached the overfall with some velocity; these coefficients are a mean series, calculated from the experiments, and therefore do not show the fluctuations observable in the Kennet and Avon canal experiments.

In both of these cases, however, with a thin plate, the coefficient is higher than its mean, whilst with the head of 1 inch it reaches the mean at about 3 inches, and continues below it as far as the experiments were carried.

The Paper is illustrated by two diagrams, from which Plates 6 and 7 are compiled, and by an Appendix of Tables.

APPENDIX.

TABLE showing the VARIATION of the COEFFICIENTS for different Species of OVERFALL.

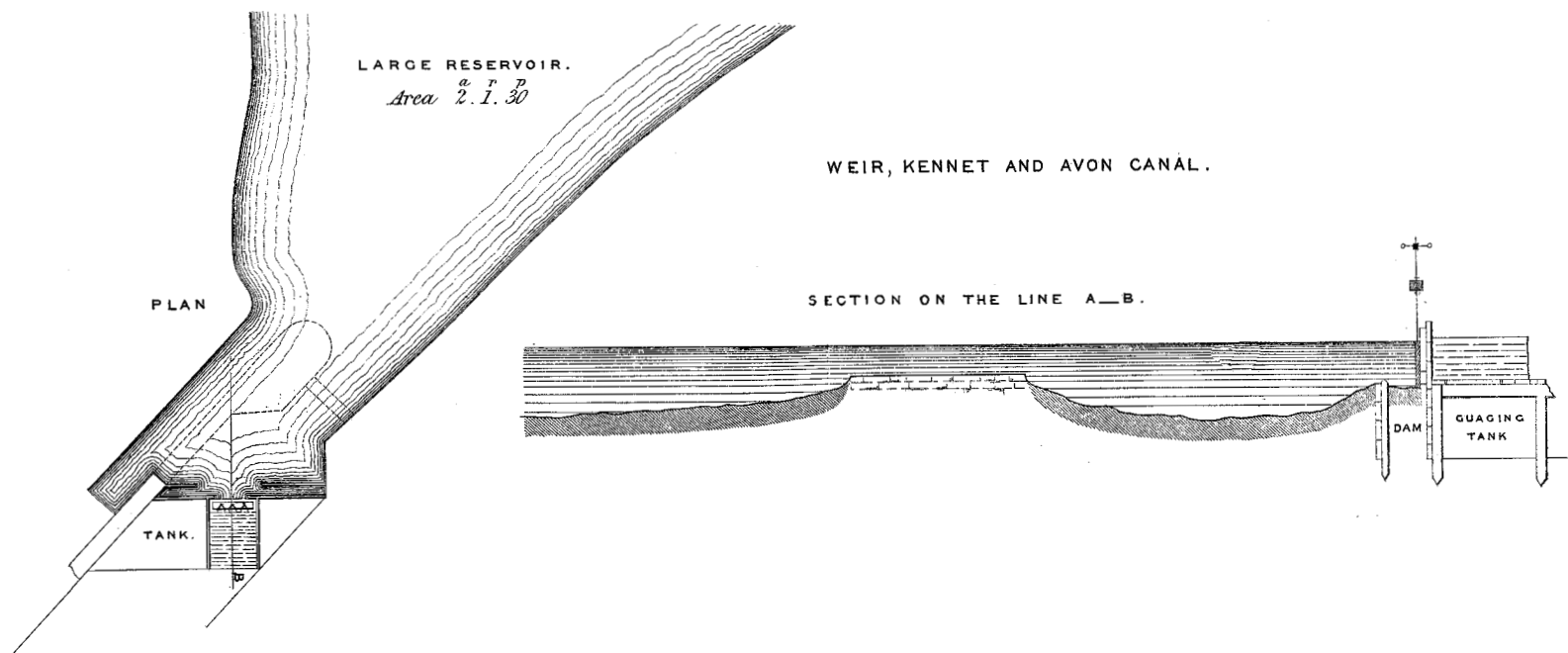
SPECIES OF OVERFALL.	Mean Coefficients.	
	<i>m</i>	<i>k</i>
Thin Plate 3 feet long	•421	•080
„ „ „ „ „ 10 „	•445	•086
Plank 2 inches wide . . . 3 „	•380	•073
„ „ „ „ „ 6 „	•377	•072
„ „ „ „ „ 10 „	•371	•072
„ „ „ „ (with wings) 10 „	•459	•090
Bar 2 inches wide (Chew Magna) 10 „	•480	
Crest 3 feet wide, slope 1 in 12, 3 „	•338	•065
„ „ „ „ 1 in 18, 3 „	•339	•065
„ „ „ „ „ 10 „	•337	•065
„ „ „ „ Level 3 „	•311	•060
„ „ „ „ „ 6 „	•322	•061
„ „ „ „ „ 10 „	•314	•061

TABLE showing the VARIATIONS of the COEFFICIENTS for different HEADS of WATER.

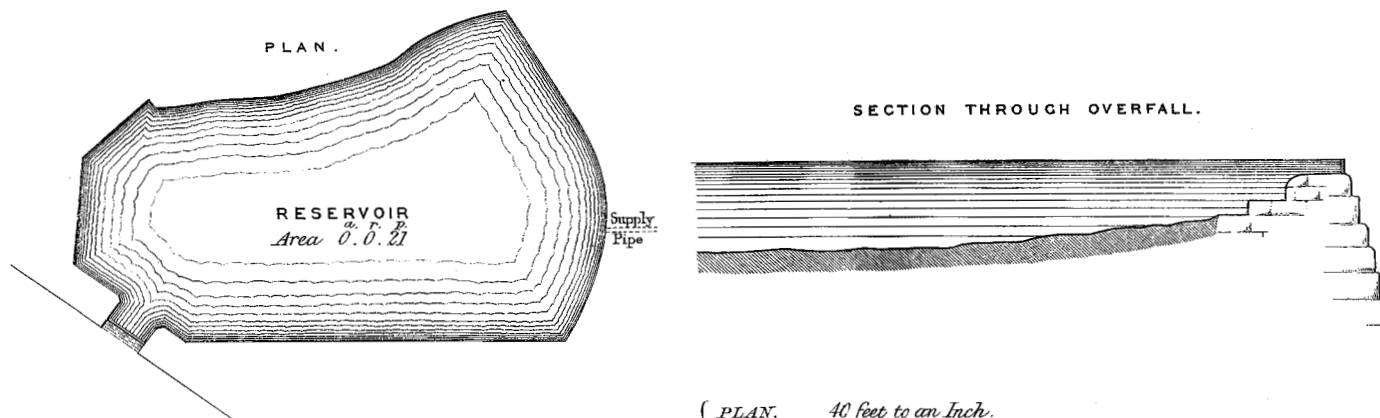
Number of Experiments.	Species of Overfall.	Mean Coefficient (<i>m</i>) applicable to Formula (I.)		Mean Coefficient (<i>k</i>) applicable to Formula (II.)	
		Head.	Coefft.	Head.	Coefft.
6 Experiments.	Thin plate 3 feet long.	1 to 3 inch.	•440	1 to 3 inch.	•085
		3 „ 6 „	•402	3 „ 6 „	•078
11 Experiments.	Thin plate 10 feet long.	1 to 3 inch.	•501	1 to 3 inch.	•096
		3 „ 6 „	•435	3 „ 6 „	•086
		6 „ 9 „	•370	6 „ 9 „	•072
23 Experiments.	Plank 2 inches thick, 3 feet long.	1 to 3 inch.	•342	1 to 3 inch.	•066
		3 „ 6 „	•384	3 „ 6 „	•074
		6 „ 10 „	•406	6 „ 10 „	•077
56 Experiments.	Plank 2 inches thick, 6 feet long.	1 to 3 inch.	•359	1 to 3 inch.	•069
		3 „ 6 „	•396	3 „ 6 „	•077
		6 „ 9 „	•392	6 „ 9 „	•074
		9 „ 14 „	•358	9 „ 14 „	•069
40 Experiments.	Plank 2 inches thick, 10 feet long.	1 to 3 inch.	•346	1 to 3 inch.	•068
		3 „ 6 „	•397	3 „ 6 „	•076
		6 „ 7 „	•374	6 „ 7 „	•072
		9 „ 12 „	•356	9 „ 12 „	•069

Table of Comparison of the Mean Coefficients, &c.—*continued*.

Number of Experiments.	Species of Overfall.	Mean Coefficient (<i>m</i>) applicable to Formula (I.)		Mean Coefficient (<i>k</i>) applicable to Formula (II.)	
		Head.	Coefft.	Head.	Coefft.
4 Experiments.	Plank 2 inches thick (with wings), 10 feet wide.	1 to 2 inch. 4 ,, 5 ,,	·476 ·442	1 to 2 inch. 4 ,, 5 ,,	·092 ·087
7 Experiments.	Overfall with crest 3 feet wide, sloping 1 in 12, 3 feet long.	1 to 3 inch. 3 ,, 6 ,, 6 ,, 9 ,,	·342 ·328 ·341	1 to 3 inch. 3 ,, 6 ,, ,, 6 ,, 9	·066 ·063 ·066
9 Experiments.	Overfall with crest 3 feet wide, sloping 1 in 18, 3 feet long.	1 to 3 inch. 3 ,, 6 ,, 6 ,, 9 ,,	·362 ·315 ·332	1 to 3 inch. 3 ,, 6 ,, 6 ,, 9 ,,	·070 ·061 ·064
6 Experiments.	Overfall with crest 3 feet wide, sloping 1 in 18, 10 feet long.	1 to 4 inch. 4 ,, 8 ,,	·328 ·350	1 to 4 inch. 4 ,, 8 ,,	·063 ·068
14 Experiments.	Overfall with crest 3 feet wide, level, 6 feet long.	1 to 3 inch. 3 ,, 6 ,, 6 ,, 9 ,,	·305 ·311 ·318	1 to 3 inch. 3 ,, 6 ,, 6 ,, 9 ,,	·059 ·060 ·061
15 Experiments.	Overfall with crest 3 feet wide, level, 6 feet long.	3 to 7 inch. 7 ,, 12 ,,	·330 ·310	3 to 7 inch. 7 ,, 12 ,,	·062 ·060
12 Experiments.	Overfall with crest 3 feet wide, level, 10 feet long.	1 to 5 inch. 5 ,, 8 ,, 8 ,, 10 ,,	·306 ·327 ·313	1 to 5 inch. 5 ,, 8 ,, 8 ,, 10 ,,	·059 ·063 ·061
61 Experiments.	Chew Magna. Overfall bar 2 inches thick, 10 feet long.	1 to 3 inch. 3 ,, 6 ,, 6 ,, 9 ,,	·437 ·499 ·505		



WEIR AT CHEW-MAGNA, SOMERSET.



SCALE { PLAN. 40 feet to an Inch.
 SECTION. 8 feet "

DISCHARGE OF WATER BY WEIRS .

Plate 7.

DIAGRAMS ILLUSTRATIVE OF EXPERIMENTS MADE ON KENNET AND AVON CANAL, AND AT CHEW-MAGNA, 1850.

EXPERIMENTS BY PREVIOUS OBSERVERS.

