1889.

NEW ZEALAND.

ROSS CREEK RESERVOIR, DUNEDIN

(REPORT ON), BY THE DISTRICT ENGINEER.

Laid on the Table by the Hon. E. Mitchelson, with the leave of the House.

The District Engineer, Dunedin, to the Engineer-in-Chief.

Sir,— Public Works Office, Dunedin, 30th July, 1889.

Agreeably to instructions contained in your telegram of the 10th instant, informing me that the Minister wishes me to make a preliminary investigation into the question of the safety of the Ross Creek Reservoir, and to report as to whether I advise a thorough examination, which will probably necessitate the emptying of the reservoir, and whether I think the emptying of it will show where the leak is, I have the honour to report that I have inspected the reservoir, made all necessary surveys, and obtained all the information possible as to its construction.

The work was commenced in May, 1865, in accordance with the designs of Mr. Ralph Donkin, Engineer to the Dunedin Waterworks Company, and carried on under him till June, 1866, when he left the service of the company, and was succeeded by Mr. James M. Balfour, the then Colonial Marine Engineer, who superintended the works to their completion in November, 1867, Mr. John McGregor, C.E., acting as his assistant, and Mr. James Crawford, as inspector of works, under both Mr. Donkin and Mr. Balfour. The contractor for the work was Mr. David Proudfoot. The reservoir when full contains 50,000,000 gallons. The water was turned into the main on the 9th December, 1867, on which date the works were opened. Ultimately they were purchased from the Company by the Dunedin City Corporation.

To explain more fully my remarks I attach the following drawings: No. 1, Plan showing the position of the reservoir in relation to the city; No. 2, Plan and cross-sections showing embankment, cross-sections through it, puddle-trench, &c.; No. 3, Plan showing how pipes (supply and scour) are laid through embankment; No. 4, General plan of reservoir, upper basin, outflow of leaks, &c.

On drawing No. 1 are figured in blue the levels—taken from the railway datum, namely, 47ft. below high-water mark of Dunedin Harbour—from Pelichet Bay Railway-station, up the Leith Valley, through Woodhaugh and the reservoir creek to the top of embankment of the reservoir. From Pelichet Bay to the junction of Duke Street with King Street, near the Water-of-Leith Bridge, there is a rise of 74·70ft., with a further rise of 44·57ft. to Woodhaugh Bridge. From Woodhaugh Bridge to junction of reservoir creek with Water of Leith, 33·56ft. From this junction to outflow of leak below reservoir, 126·26ft., being up a narrow rocky gorge, averaging about one chain and a half in width from about the level of road to waterworks; and from the outflow of leak to the top of embankment, 95·47ft.; or a total height above rail-level at Pelichet Bay of 374·56ft.

Drawing No. 2 shows the position of the embankment, toe of outer and inner slope of same, by-wash, storm-water channel, well-tower, bed of creek under embankment, longitudinal section of embankment, cross-sections through same, surface of ground under embankment, depth of puddle-trench when finished, enlarged cross-section showing batter of inner and outer slopes of embankment, width and position of puddle-wall, and development of east and west walls of by-wash.

Drawing No. 3 is the most reliable one I can obtain showing how the pipes (supply and scour) are laid under the embankment—namely, on masonry pillars 4ft. square, founded on the solid rock, through the bed of the creek, and masonry blocks on the hard ground. The pipes, I am informed, were specially cast for this work, and were 6ft. in length between the joints when laid, the joints coming between the pillars. Puddle was well rammed between and all round the masonry pillars, blocks and pipes, and the trench filled in for 2ft. above with best puddle procurable. The supply-pipe is 12in. in diameter, and the scour 9in. Mr. Balfour contemplated putting in a culvert to carry the pipes through, and, I am informed, had actually drawn out the plans for one, but afterwards altered his mind, and put in the pipes as above described, probably on the plea of economy. It would undoubtedly have been better had he adhered to his former opinion, and at the same time put in a much larger scour-pipe. It must be borne in mind that these works were constructed by a Company, and in all probability the expense was kept as low as possible.

The puddle-trench shown on drawing No. 2 was taken out in 1865 and the puddle-wall proceeded with along with the embankment, which was formed in 1ft. layers. A roller was not used to consolidate the bank, in the usual way, as it proceeded, but it was carted over in all directions instead. The trench was cut 4ft. into the solid rock, where the embankment crossed the creek, and for some distance beyond; and I am informed by the Inspector that rock was met with in the bottom of the trench generally throughout between cross-sections Nos. 4 and 11, the material between 11 and 13 being of a clayey nature mixed with hæmatite, and that between 4 and 2 rock of a more or less shattered nature.

When the trench was cut a spring, or running water, was met with between cross-sections Nos. 2 and 3, which was allowed to run down the trench, and was used for mixing the puddle. On the 25th November, 1867, some time after the completion of the embankment, the reservoir was filled up and nearly running over the by-wash, and on the 26th the Inspector observed water running over the surface of the ground on the outside slope of embankment, between cross-sections Nos. 2 and 3.

By reference to the cross-sections of the embankment it will be observed that its outer toe is well tied into the rising ground; in fact, in one or two places to rocky spurs.

Drawing No. 4 is a general plan showing the reservoir and its surroundings.

During the month of July, 1886, Professor Black, of the Otago University, reported to the City Council on the alleged leak from the reservoir; as also did Mr. Robert Hay, M.Inst.C.E., of Dunedin, in September of the same year. I attach a copy of each of those gentlemen's reports, together with Mr. Hay's tables showing the result of daily measurements of the supposed leak, and rainfall from the 28th July to the 26th September, 1886, inclusive. Professor Black's tables 1, 2, and 3 are printed along with his report.

On drawing No. 4 are shown the dry stone-wall, cut in face, shaft, drive, and pipe referred to in Mr. Hay's report; and by inspection of his tables it will be seen that the total flow during the twenty-four hours fluctuates, irrespectively of the depth of water in the reservoir, and that the flow is governed chiefly by the state of the weather, rain, &c. I have shown on this drawing a surface-drain from the upper basin along the foot of the slope on the west side of the reservoir and discharging itself into the reservoir creek below the bridge. This drain also intercepts the water from a small gully near the watchman's house, and, no doubt, in time of wet weather, carries a considerable amount of water which must, more or less, percolate into the old spoil-bank and made ground shown on plan and find its way to the outflow of leak. A very considerable amount of material has been deposited in and around the toe of the outer slope of the embankment from excavation taken from the upper basin about 1875, thus materially increasing the area of the outer slope, into which a portion of the rainfall penetrates, and must find its way to the low ground at the outflow.

When on the ground I noticed a depression in the pitching of the inner slope of embankment, and I have endeavoured to show it by means of the longitudinal section D, A, E and the cross-section A, B, C, both of which are represented on this plan. I asked the caretaker, Mr. Gillies, who has resided at the reservoir for the last twenty years, and he states that it is many years ago since he first observed it, and is not aware that it has increased. The cross-section A, B, C is nearly over the bed of the creek, which can be verified from drawing No. 2, and it becomes a question if this depression did not take place through subsidence of the embankment shortly after its construction.

The 4in. tile-drain shown on drawing, and known as the "concealed pipe," discharges water when the reservoir is within 2ft. 2in. of being full, and is about the spot referred to by the Inspector in his statement of finding water running over the surface of the outer slope of embankment between cross-sections 2 and 3, on the 26th November, 1867, which clearly shows that this has been a weak point in the embankment ever since its construction.

In the third paragraph of Mr. Hay's report he states: "On the first occasion (28th July) when I measured the flow of the supposed leak there was a depth of 18ft. 1in. in the reservoir, and the total discharge from the three flows 139·7 gallons per hour; and the last measurement taken by Dr. Black before the water was turned into the reservoir (after having been emptied, with the exception of a small pool) was 222·1 gallons per hour." On the drawing I have shown the position of this pool, as described by Mr. Gillies, the caretaker, who states that it is about 170ft. long, averaging 40ft. wide towards the lower end. When the reservoir was emptied during Dr. Black's investigations a trench was cut from the pool to the scour-pipe, and when water ceased to run into the scour-pipe the depth in the lower portion of the pool was 10ft., with the length and width as above stated. This pool being the lowest ground is doubtless the bed of the old creek; in fact, its position points to this when comparing drawing No. 4 with No. 2. The water in the bottom of the pool stands 32·8ft. above the outflow of supposed leak, and 10ft. below the mouth of scour-pipe.

The first gauging of the alleged leak by the City Surveyor was taken on the morning of the 8th April, 1875, the discharge for the twenty-four hours being 8,020 gallons, with a depth of water in the reservoir of 25ft. 8in. I append a table (A) on which this gauging is shown, as also gaugings from the 15th March, 1882, to the 26th July, 1889, four of which I have taken myself, on the 22nd, 23rd, 24th, and 25th instant, averaging 4,210 gallons for twenty-four hours, with an average depth in the reservoir of 31ft. 7in., no rain having fallen from the 18th instant, when there was ·04 of an inch, the weather since being fine days and frosty nights. (See Table B.)

As before stated, that the flow fluctuates in accordance with the state of the weather, I append a table (C) from the Meteorological Observer, Mr. H. Skey, showing the amount of rainfall during the months of March and April, 1875, from which it will be observed that ·14 of an inch fell during the previous twenty-four hours from the morning of the 8th April; nevertheless, the months of March and April were comparatively dry.

With reference to the safety of the reservoir, by inspection of the tables showing gaugings of flow and rainfall, it will be observed that so far back as April, 1875 there was a large quantity of water issuing from the outflow of supposed leak, and that up to date, extending over a period of fourteen years, the quantity has been a variable one, governed more or less by the state of the weather, and has not been at all a steadily-increasing one.

The site chosen for the reservoir is a remarkably good one, the embankment being near the foot of a valley at the commencement of a narrow, rocky gorge, and the outer slope of bank in several places abutting against rocky spurs. From all I can learn the seat of the embankment is good ground, and it has been carried out with the utmost care. It is unsatisfactory, however, to

know that such a large quantity of water is met with at the outflow; and, in order to trace the source from which it comes, I would suggest that the upper basin and the reservoir be emptied during the dry season, leaving only the pool; and that a staging be erected over this pool, and the water pumped from it and passed through the scour-pipe, which could be quickly done by using a small engine. Measurements of the flow should be taken previously to and during the pumping operations. This would conclusively prove whether there is any connection between the reservoir and the outflow. If such a connection exists—and assuming that the old bed of creek intersected by the puddle-wall is thoroughly sealed by the puddle being taken 4ft. into the solid rock, and the pipe-track cut through solid rock, also in the bed of the creek, and thoroughly puddled—I would feel disposed to seek for the leak by sinking a shaft through the embankment where shown by × to a depth exceeding that of the bottom of the pool, driving under the bye-wash; and if the flow were found here would cut a trench right up to the surface, and under the bye-wash to a short distance beyond the storm-water channel into the solid ground, filling it up with the best clay puddle procurable, thus forming a continuation of the puddle-wall. At the same time, if the bulk of the water were not found after having sunk the shaft at ×, I would recommend extending the drive put in by Mr. Hay towards the puddle-wall, which doubtless would prove whether or not the water is coming through the embankment.

During heavy floods the upper basin has become filled to such an extent that the water overflowed its embankment into the reservoir, which caused the storm-water channel to be so strained that it was unable to carry off the flood-waters. This, to my mind, is a decided element of danger, and should not be allowed to exist. Provision should at once be made to carry off this surplus water by either constructing a new storm-water channel on the western side of reservoir or enlarging the existing one. I would favour the enlarging and strengthening the existing one, selecting from the excavation the best of the clay, to be tipped into the pool to act as puddle, and generally seal over the pool, so that all the water in the reservoir would find its way to the scour-pipe, and thus allow the reservoir to be emptied and cleaned out at any time.

I am of opinion that if these recommendations are given effect to the reservoir would be perfectly safe.

I am, &c.,
E. R. Ussher, M.Inst.C.E.,
District Engineer.

The Engineer-in-Chief, Wellington,

Enclosure No. 1.

Table A.

Memorandum of Gaugings at alleged Leak, Ross Creek Reservoir.

Date.	Gallons discharged per 24 Hours.	Depth of Water in Reservoir.	Date.	Gallons discharged per 24 Hours.	Depth of Water in Reservoir.
		Ft. in.			Ft. in.
1875—April 8	8,020	25 8*	1884—May 20	6,648	40 9
1882—March 15	6,480	30 4	June 3	7,200	39 2
" 18	5,232	27 10	" 10	6,648	37 6
" 20	4,800	28 9	July 8	6,168	39 5
" 22	4,320	27 8	" 15	5,064	38 9
" 28	3,456	24 7	" 22	4,320	38 2
April 1	3,698	21 7	1886—Feb. 22	4,200	15 0
" 4	4,700	19 9	" 23	4,050	16 10
" 5	3,456	18 5	" 24	4,056	17 8
" 7	2,736	16 3	" 25	3,926	17 1
Sept. 18	5,760	41 8	" 26	3,840	16 6
" 20	5,568	41 1	" 27	3,716	15 11
Oct. 4	5,760	37 0	" 28	3,551	15 4
" 11	4,536	34 6	March 1	9,600	14 9
" 18	4,320	31 9	" 2	4,670	15 10
" 25	4,656	29 3	" 3	3,638	17 1
Nov. 1	3,600	26 5	" 4	3,797	16 6
" 8	3,456	21 4	" 5	3,756	15 10
" 10	3,312	19 3	" 6	3,563	15 3
15	3,456	18 4	" 7	3,456	14 7
22	2,784	16 5	" 8	3,388	13 11
" 29	2,618	13 6	" 9	3,229	13 2
Dec. 5	2,880	10 5	1889—June 26	7,056	23 3
" 6	2,544	11 0	July 5	6,696	27 2
" 11	2,064	9 2	" 6	6,384	27 1
" 13	2,616	9 2	" 8	7,704	27 1
" 20	2,784	14 6	" 9	7,488	27 10
" 23	2,328	14 6	" 10	6,888	28 4
" 25	2,616	14 6	" 15	12,552	29 9
1883—Jan. 25	8,208	45 0	" 16	11,280	29 9
" 30	8,640	43 7	" 17	9,144	30 0
Feb. 7	11,520	42 5	" 18	7,632	30 2
" 14	13,296	40 8	" 19	6,528	30 11
Oct. 24	7,968	44 0	" 20	5,808	31 7
Nov. 7	8,640	40 4	" 22	4,584	31 10
Dec. 20	14,400	46 0	" 23	4,320	31 5
1884—April 28	8,208	45 0	" 24	4,084	31 2
May 6	7,200	42 10	" 25	3,850	31 10
" 12	6,912	41 7	" 26	3,650	32 4

* First recorded.

Enclosure No. 2.

Table B.

SHOWING the RAINFALL in Glenleith from the 2nd June, 1889, to the 23rd July, 1889, taken by Henry Skey, Esq., Government Meteorological Observer. Collected at 9 a.m. for twenty-four hours previously.

	Inches.		Inches.
1889—June 2	0·004	1889—July 2	0·032
" 6	0·010	" 4	0·120
" 10	0·012	" 7	0·660
" 11	0·060	" 8	0·040
" 12	0·060	" 11	0·344
" 13	0·016	" 15	0·300
" 19	0·080	" 18	0·040
" 20	0·120	" 19	
" 23	0·770	" 20	
" 24	0·302	" 21	Nil.
" 26	0·042	" 22	
" 27	0·260	" 23	
" 28	0·188		
" 30	0·014		
Total	1·938	Total, up to 23rd	1·536

23rd July, 1889. H. SKEY.

Enclosure No. 3.

Table C.

SHOWING the RAINFALL in Glenleith from the 1st March to the 30th April, 1875, taken by Henry Skey, Esq., Government Meteorological Observer.

	Inches.		Inches.
1875—March 4	0·300	1875—April 2	0·090
" 5	0·020	" 6	0·030
" 6	0·010	" 8	0·140
" 14	0·680	" 13	0·020
" 15	0·280	" 15	0·350
" 17	0·020	" 17	0·180
" 20	0·310	" 23	0·720
" 21	0·160	" 24	0·380
" 24	0·120	" 25 to 30	Nil.
" 27	0·010		
Total	1·910	Total	1·910

H. SKEY.

Enclosure No. 4.

COPY OF PROFESSOR BLACK'S REPORT.

Professor BLACK to His Worship the MAYOR and CITY COUNCIL, Dunedin.

GENTLEMEN,— The University, Dunedin, 26th July, 1886.

I have the honour to report that, in accordance with your instructions, communicated to me by Mr. Mirams, the City Engineer, I have taken tests and made observations to determine whether the water from the flow at the foot of the reservoir-embankment and at the lower pool is derived from the reservoir or is merely due to independent springs.

The tests on which I rely are—(1) the comparative hardness; (2) the proportion of (*a*) lime, (*b*) solid matter, (*c*) organic matter in the water from the different sources after being thoroughly filtered through filter paper; (3) the temperature of the several sources; and (4) the ammonia test.

The ammonia test is one that requires a great deal of careful and delicate manipulation in the laboratory on the samples of water taken. The principle of the test is this: One part of ammonia in a hundred million parts of water can be appreciated by the Nessler test.

As much ammonia was put into the reservoir-pool on Friday morning, the 16th instant, as would, when diffused, taint the fifty or sixty thousand gallons then in the pool with one part of ammonia in 440,000 parts of water. This is 200 times as much ammonia as the smallest proportion that can be with certainty appreciated by the colour test with Nessler.

Samples of the water were taken from the reservoir-pool, and each of the three branches of the supposed leak, as well as from the upper reservoir before the ammonia was put in; and samples were taken daily, sometimes twice a day, from each of the branches of the supposed leak. Samples were also taken several times during the week from the lower pool and from the Ross Creek above the upper reservoir, from School Creek spring, and from the paper-mill spring. All the samples were taken to the laboratory, and tested for hardness, total solids, organic matter, and lime. They were also tested by the Nessler test for ammonia.

The result of the ammonia test was as under: (*a.*) The west branch and the supposed leak did not show decided signs of ammonia, but there was a slight indication of it, so small, however, as to be within the limits of error; and it must therefore be neglected. The conclusion, so far as this ammonia test is concerned, is, therefore, that there is no connection between the west branch of the supposed leak and the reservoir. (*b.*) Both the middle and east branches of the supposed leak showed decided indications of ammonia on the morning of the 18th, and more decided still on the 19th, lessening on the 20th and subsequent days. The increased indications on Monday morning, the 19th, I was not expecting, because the water was let into the reservoir from the upper reservoir on the evening of the 18th; so that there must have been something like a million gallons of water, if not more, in the reservoir when the middle and east branches showed most strongly the ammonia coming through.

The result, however, clearly and conclusively establishes the theory that the middle and east branches communicate with the reservoir.

The oxide of iron yellowish slime collecting on the stones over which the water from the middle and east branches flows is another indication in support of the same theory. This yellow scum and deposit, however, point to the probability that the water does not all (even if any) come through the puddle-wall, but that it works a passage for itself down through the sediment in the bottom of the reservoir, and then along the old bed of the creek below the puddled wall altogether; and this theory is supported by the absence of any trace of clay in these flows.

There is a continual diminution of flow from the west branch during the whole period of eight days, quite irrespective of the depth of water in the reservoir. This depth was slowly increasing from Thursday the 15th to the afternoon of Sunday the 18th, at which time the water was turned in from the upper reservoir. From the 18th to the 24th the depth had increased from 11ft. 8in. on Monday the 19th, to 17ft. on Thursday the 22nd, at which depth it has remained since.

In the middle and east branches there is very considerable fluctuation in the amount and flow —reaching the maximum in the middle branch on the 22nd, four days after the water from the upper reservoir was turned into the lower reservoir, and maintaining itself nearly the same, but not quite so great, ever since.

In the east branch there is a sudden fall from 33 gallons to 17·8 gallons per hour between the 16th and 17th; a gradual increase from the 17th to the 20th; nearly the same, but a shade less on the 21st; and then a rapid decline to the 24th, on which day it did not amount to one-third the quantity found on the 16th.

It is outside my province to pronounce an opinion on the amount of flow as depending on the depth of water in the reservoir, and on the amount of rainfall lately. I might, however, point out the constant but slight diminution of the flow from the west branch (which is chiefly from springs probably) and the irregularity of the flow from the middle and east branches, as if the flow from these latter was in a state of disturbance, in some kind of sympathy with the disturbed state of the reservoir and the varying depth of water in same.

The opinion I have formed from the tests and observations as a whole is—(1) That the greater part of the flow from the middle and east branches of the supposed leak is derived from the reservoir; (2) that a small proportion of the water from the west branch is also derived from the reservoir; and (3) that it is chiefly under or round outside the puddled wall, and not through it, that the flow travels.

Mr. Mirams (the City Engineer) and Mr. Gillies (the caretaker) gave me every facility and assistance in my investigations.

Tables and tests and observations are attached.

I am, &c.,

His Worship the Mayor and City Council of Dunedin.

JAMES BLACK.

Sub-Enclosure No. 1 with Enclosure No. 4.

TABLE I.—Statement of Flow in terms of Gallons per Hour from Supposed Leaks and Lower Pool; also, separately, Number of Gallons per Hour from Middle and East Branches, and from all three Branches at Foot of Walls taken together.

Dates on which Flow was measured.	Number of Gallons per Hour from West Branch of Supposed Leak.	Number of Gallons per Hour from Middle Branch of Supposed Leak.	Number of Gallons per Hour from East Branch of Supposed Leak.	Number of Gallons per Hour from Lower Pool.	Sum of Gallons per Hour from East and Middle Branches together	Sum of Gallons per Hour from all three Branches. together.
July 16 ...	168·4	20·6	33·1	...	53·7	222·1
„ 17 ...	166	22·3	17·8	...	40·1	206·1
„ 18 ...	163·5	21·6	20·2	...	41·8	205·3
„ 19 ...	163	26·2	24	220	50·2	213·2
„ 20 ...	162·5	27	25·9	227·8	52·9	215·4
„ 21 ...	157·7	26	25·1	216	51·1	208·8
„ 22 ...	156·5	27·8	17·6	213	45·4	201·9
„ 23 ...	152·5	26·9	16·9	224·5	43·8	196·3
„ 24 ...	149·5	25·7	10·8	220·4	36·5	186

The flow for the 16th July was measured by Mr. Mirams, assisted by Mr. Gillies, in my presence. The flow of the 17th, 18th, and 24th was measured by me, assisted by Mr. Gillies. The flow on all the other days was taken by Mr. Mirams and myself together, assisted by Mr. Gillies. In several cases the result recorded is the average of several trials.

Sub-Enclosure No. 2 with Enclosure No. 4.

TABLE II.—Table showing the Degree of Hardness, and the Proportions of Total Solid Residue, Lime and Organic Matter in the Reservoir-pool, the three Branches of Supposed Leak, and School Creek Spring, and Paper-mill Spring, all taken on Saturday, 17th July.

	Degree of Hardness.	Carbonate of Lime in Solution, in Grains per Gallon.	Total Solid Residue left on boiling-down, in Grains per Gallon.	Organic Matter, in terms of Grains per Gallon.
Reservoir-pool	3·4	1·9	6·5	2·1
West branch	4·7	2·5	9·0	1·3
Middle branch	4·4	2·2	8·0	1·5
East branch	4·3	2·1	8·1	1·7
School Creek spring	7·0	4·1	11·2	1·1
Paper-mill spring	6·4	3·9	11·0	1·0

All the above results are consistent with each other, and with the theory that part at least of the water of the three branches of the flow is derived from the reservoir. The evidence in each separate case is stronger for the middle and the east branches than for the west branch.

Sub-Enclosure No. 3 with Enclosure No. 4.

TABLE III.—Temperature of (*a*) Reservoir, (*b*) Supposed Leaks, and (*c*) School Creek Spring and Paper-mill Spring, on Wednesday, 21st July, between 10.45 a.m. and 11.40 a.m.

	Temperature in Degrees Fahr.	Difference in Degrees Fahr. between Supposed Leaks and Temperature of Reservoir.	Difference in Degrees Fahr. between Supposed Leaks and Average Temperature of Springs.
Reservoir	41·9	...	...
School Creek spring	51·8	...	...
Paper-mill spring	50	...	...
Average of springs	50·9	...	...
West branch	48·02	6·12	2·88
East branch	47·5	5·6	3·4
Middle branch	47·3	5·4	3·6

The temperature of the supposed leaks was taken at their point of issue from the foot of the embankment; and the result tends to confirm the theory that part, at least, of the water of each of the three branches is derived from the reservoir.

The evidence, in harmony with all the other tests, is stronger in the cases of the middle and east branches than in the west branch.

Enclosure No. 5.

COPY OF MR. HAY'S REPORT.

Mr. R. HAY, M.Inst.C.E., to the TOWN CLERK, City of Dunedin.

SIR,— Dunedin, 27th September, 1886.

I received your instructions on the 27th July to examine and report fully to the Council on the alleged leak from the Northern or Ross Creek Reservoir. I commenced work on the following day, and have now the honour to forward the result of my investigations, and, in doing so, shall endeavour to confine your attention to the plan of operations as pursued by myself, trusting my descriptions will be sufficiently clear to enable your Council to traverse the same grounds in their minds as I have followed in person.

On visiting the locality I found water issuing at three points from the foot of a dry stone retaining-wall situated on the original bed of the creek, the wall evidently having been built to prevent a slope of loose clay and boulders coming in contact with the water from the bye-wash shoot that discharges into the stream-bed at this point. This wall, it must be clearly understood, is not the foot of the reservoir-dam or embankment; but the level of the outflow of the supposed leak is actually 47ft. below the toe of the exterior slope of the dam proper, while the water that issues from the wall is 42ft. below the outlet of the scour-pipe at the well-tower, and 91ft. below the surface of water in the reservoir when full. As previously stated, water flowed from the wall in three distinct streams, which for reference sake may be designated the west, the middle, and east branches; and these have been separately gauged or measured every morning from the 28th July to the 26th September, and their various discharges duly recorded, together with the rainfall and corresponding depths of reservoir in the tables attached.

On the first occasion (28th July) when I measured the flow of the supposed leak there was a depth of 18ft. 1in. in the reservoir, and the total discharge from the three flows was 139·7 gallons per hour; and the last measurement taken by Dr. Black before the water was turned into the reservoir (after having been emptied, with the exception of a small pool) was 222·1 gallons per hour.

and the daily gaugings show a constant diminution of discharge until 3rd August (111·8 gallons per hour), the reservoir having in the meantime been allowed to obtain a depth of 23ft. 4in.

The east branch on the 2nd August had almost ceased to run, and had to be collected into a small spouting to facilitate the measurement of such a small discharge—namely, 3½ gallons per hour.

A glance at the tables will show, therefore, that between Dr. Black's measurement on the 16th July and mine on the 3rd August, there was a decrease of discharge from the alleged leak of 2,644 gallons per diem, or nearly one-half of the total flow on the 16th July; and this diminution of discharge took place with increased depth of water in the reservoir of 23ft. 4in.

On the 3rd August the weather broke up, after a protracted spell of exceptionally dry weather, and wet weather prevailed almost daily for the remainder of the month. On the 11th August the discharge from the supposed leaks became very considerable, especially from the east branch, and an excellent opportunity was afforded for tracing the course of the flow; and I commenced excavating at the outlet of the east branch, following up the run of water. In about three hours the men exposed a small stone-culvert, 15in. by 6in. (from which the east flow was issuing), about 12ft. back from the face of the retaining-wall, the mouth being partially closed, but on removing the obstruction (a displaced side-wall stone) the water came away freely, and it became apparent that the east branch was flowing from an old artificial channel that must have been built not later than 1875, when the upper basin was constructed, and the material excavated therefrom tipped over the outer face of the main reservoir-dam.

While the work of relieving the culvert was going on I turned my attention to the west branch, which began to show decided symptoms of diminution; and by the time the east-branch culvert was completely cleared out the run from the west branch almost ceased, and I found, on further examination, that it had only consisted of the overflow from the east-branch culvert, and that the east and west branches were derived from one and the same source. This also at once accounted for the theometrical observations, giving a uniform average temperature for the east and west flows. The middle branch also decreased, and it was found that the water drained by it was derived from a swampy piece of ground at the back of the wall, the culvert carrying the east branch not having been placed at a sufficiently-low level to drain the same.

The search for the source of the supposed leakage was thus considerably simplified, the three flows having been proved to be practically one stream within a few feet of the point of issue.

The excavation in the face was continued until the 3rd September, and the water followed up, still being carried by the culvert for a distance of 30ft. until it reached the face of the old pitching that formed the foot of the loose material originally obtained from the main reservoir-excavations. The culvert ended at this point, and the water divided into two branches—one exuding from the reef in the east spur in the form of a spring; the other branch turning to the westward, following the original course of the creek.

It may be here noted that all the water found its way to the face along the original creek-bed, amongst the boulders and clay that had been obtained from the reservoir-excavations, and tipped into the gully.

The excavations now being some 18ft. deep required the shifting of so much stuff that I determined to sink a shaft at a distance of about 80ft. from the face at the most likely point to reach the running water again, and I was fortunate enough to strike the run in the centre of the shaft, and had it followed by a heading for a distance of about 15ft. towards the embankment. This operation enabled me to gauge the flow of the supposed leak at three points—namely, at the outlet into the creek and at places 30ft. and 80ft. nearer the dam—and I found, on measurement, that the latter discharged one-sixth to one-third of the total quantity gauged at the outlet, the remainder being supplied between the 30ft. and 80ft. points from the rocky spur on the east side.

In endeavouring to arrive at a conclusion with respect to the source of the flow that was alleged to be a leak from the reservoir it was necessary to take into consideration three factors—first, local drainage or soakage of surface-water; second, springs; third, leakage from the reservoir.

Whatever quantity of the flow was due to leakage, drainage was bound to be represented in a greater or less degree proportionally to the collecting area and rainfall, while the supposition that springs either of near or distant origin also formed part of the flow was a fair one for consideration.

With regard to the drainage, it naturally follows that from an area of one acre, a large portion being made ground and of a porous nature, that a considerable proportion of the rainfall on the surface must find its way to the lowest point at the outlet in the creek at the foot of the dry wall, it being remembered that 1in. of rainfall over an acre of ground amounts to 22,600 gallons, and the average annual rainfall from 33in. to 35in. The actual area of land that must drain itself towards the old course of the creek-bed is as nearly as possible one acre.

Then, as to the contributions from springs, the gaugings show a total discharge (calculated between dates when the reservoir was not affecting this flow) that was greatly in excess of the amount of the observed rainfall on the available drainage-area, even supposing that the whole of the rain had found its way to the outflow of the supposed leakage.

As a means of eliminating as far as possible the element of drainage and springs in order to arrive at the balance due, if any, to leakage, the whole of the flow from the foot of the wall was divided in such a manner that it could be measured in five portions; and the sources of four having been carefully examined, tested, and satisfactorily proved, the only one remaining in doubt was the flow in the shaft, which in conjunction with the others was also gauged, a commencement being made at this particular point with nearly a full reservoir—namely, a depth of 48ft. 4in.—when the flow was 180 gallons per hour. This quantity decreased steadily until the water in the reservoir was reduced to a depth of 36ft., the discharge then being 38·1 gallons per hour, with a total flow at the main outlet of 205·9, or about the same amount as was registered with an empty reservoir.

I will now detail what, in my opinion, is the origin of the outflow that has been the cause of the present investigation.

Commencing at the upper part of the dam, I shall first take what has been called the "concealed pipe." The run of water through this pipe commences when the water in the reservoir rises

to a height of about 46ft., and it attains its maximum discharge when the basin is full (48ft. 8in.), and the flow reaches a total of 8,640 gallons per twenty-four hours. This undoubtedly proceeds from the reservoir, and I believe percolates under the pitching and side walls of the overflow, as I had the joints of the stones forming the floor well grouted with cement and sand before the water covered them. I excavated for the outlet of the escape on exterior face of embankment, and found the water issuing in a constant stream from a joint in the main reef.

Another contributor to the main outflow was tapped close to the shoot in the east spur, and it furnished an average supply of 1,680 gallons per diem with a full reservoir, which decreased to 127 gallons after a fall of 13ft. in the water-level. I am satisfied that part of this flow proceeds from the reservoir, though in wet weather it is considerably augmented by surface-water.

At the main east branch the principal feeder supplies about one-half of the total outflow, and the water emerges from the main reef in the east spur; and I have no doubt that the run is all derived from springs and local surface-drainage after the storage-water in the reservoir has fallen to certain levels. This supply, with a reservoir depth of 48ft. 4in., reached a total of 291·9 gallons per hour, decreasing to 85·7 gallons, with a depth of 36ft.

Having detailed the various operations I have had recourse to and their results, I will now state the conclusions I have come to after having looked into the matter from every point of view—(1.) That there is no leakage from the reservoir through the puddle-wall of the dam. (2.) That there is an escape or leakage of water from the reservoir round the puddle-wall on the east side, percolating through the rocky spur, which is of an extremely broken and shattered nature, and finding its way to the lowest level along the original creek-bed to the main outflow at the face of the dry wall. (3.) That the leakage occurs in the upper portion of the reservoir at the east side from the level of the overflow to a point not lower than about one-third of the depth. (4.) That if there is any soakage through the floor of the reservoir it is of an infinitesimal quantity, and may be entirely disregarded.

The question now arises whether any risk is incurred in allowing a leakage of the kind indicated to exist without taking the necessary remedial measures.

In considering this question, it must be remembered that the only point that still admits of any doubt is the run of water at the shaft, which decreased to 38 gallons per hour when the reservoir had still 36ft. of water impounded, and of this quantity only a proportion was due to leakage, and it is not as if the water was oozing from the embankment, but it is now running almost 35ft. below the toe of the bank alongside the solid reef.

The actual source of this water can very easily be proved by extending the drive I have commenced about 30ft. further, following up the run; but in the meantime I am of opinion that no immediate danger exists, but think it would be prudent for the Council to undertake at some convenient time certain extensions or additions to the puddle-wall on the eastern side of the dam as may be found advisable on stripping the surface.

The reservoir-dam is designed in the usual manner, with inner and outer slopes of 3 to 1 and 2 to 1 respectively; and if the work has been carried out faithfully, which I have no reason to doubt, I am satisfied it is sufficiently secure for the required purposes, especially as it is greatly strengthened by the rocky spur that abuts the outer face of bank.

The pipes (supply and scour) are at present carried through the artificial embankment; but I think this is a dangerous method, as, in the event of a burst in the pipes within the dam occurring during the night-time, considerable damage might be incurred before the accident was discovered. The pipes have been tested lately, and do not show any sign of leakage.

It may not be out of place in this report to point out generally for the Council's information some improvements that might be effected at the works of the northern reservoir that would materially conduce to the safer and more efficient working of the water-supply. In the first place, an additional bye-wash should be constructed on the western side of the reservoir, as the present one, in time of flood, is insufficient to carry away the storm-water without some portion being turned into the reservoir; in fact, on the occasion of the late flood on the 18th August the upper basin overflowed its embankment, running over into the main reservoir. It must also be borne in mind that the chance of a waterspout bursting on the watershed that supplies Ross's Creek is by no means a remote one, and an enormous body of water and *débris* may be precipitated into the reservoir without much warning; and every facility should be available for meeting such an emergency. The phenomenon referred to actually occurred in several places some twelve months since within a few miles of the Flagstaff Range.

Another much-needed addition is a large scour-pipe, the present one, 9in. in diameter, being of little practical use; and, in the event of any necessity arising for quickly emptying the reservoir or lowering the water-level, the present appliances would be incapable of making any appreciable difference in the height of the water under a considerable period of time, the 12in. main and the 9in. scour being the only available outlets from the reservoir. In addition to the element of safety gained by carrying out this supplementary work, the power of being able to change the water in the reservoir expeditiously from time to time as opportunities occur, is also a useful and valuable advantage.

The tables appended show the actual discharge from the west, middle, and east flows separately and combined from the 28th July to the 26th September, together with the depth of reservoir; and also rainfall extending over the same period, which Mr. Skey was good enough to supply me with, and, as my gaugings commenced at 8.30 a.m., and Mr. Skey's observations are taken at 9 a.m., within half a mile of the reservoir, they are especially valuable and applicable in the present instance.

The plan herewith shows the points at which the various excavations were made, and will explain itself.

I have to express my thanks to the Corporation officials, who have cheerfully rendered me every assistance during my investigations; and I must apologize to the Council for the length of time I have occupied; but it was utterly impossible to arrive at a satisfactory conclusion earlier on account of the broken weather experienced during the last few weeks.

I remain, &c.,

The Town Clerk, City of Dunedin. R. Hay, M.Inst.C.E.

Sub-Enclosure with Enclosure No. 5.

TABLE showing the Results of Daily Measurements of the Supposed Leak from the Northern Reservoir.

Date.	Flow from West Outlet, in Gallons per Hour.	Flow from Middle Outlet, in Gallons per Hour.	Flow from East Outlet, in Gallons per Hour.	Total number of Gallons per Hour from the Three Outlets.	Total Flow for 24 Hours in Gallons.	Rainfall for 24 Hours preceding each Gauging, in Inches.	Depth of Water in Reservoir, in Feet and Inches.	Remarks, Weather, &c., at time of Gauging.
1886.								
July 16	168·4	20·6	33·1	222·1	5,330·2	Nil	Nil	Dr. Black.
" 28	111·9	23·5	4·3	139·7	3,332·8	"	18·1	Frost.
" 29	106·7	23·5	4·1	134·3	3,223·2	"	21·0	"
" 30	101·9	25·1	4·0	131·3	3,144·0	"	22·6	Fog.
" 31	94·9	25·4	3·7	124·0	2,976·0	0·03	23·4	"
Aug. 1	89·3	22·8	3·7	115·8	2,779·2	Nil	23·4	Cloudy.
" 2	86·4	21·9	3·5	111·8	2,683·2	0·17	23·4	Showers.
" 3	85·0	23·0	3·9	111·9	2,685·6	0·14	23·4	"
" 4	126·7	25·8	67·6	220·1	5,282·4	0·50	23·7	Snow and sleet.
" 5	131·3	23·9	257·1	412·3	9,895·2	0·52	25·9	Fine.
" 6	126·3	22·8	202·2	351·3	8,431·2	Nil	27·0	"
" 7	126·3	22·0	154·9	303·2	7,276·8	0·18	28·3	Rain.
" 8	1,147·7	40·7	1,997·2	3,185·6	76,454·4	2·40	38·6	"
" 9	1,147·3	31·9	1,989·8	3,169·5	76,068·0	0·88	39·6	"
" 10	531·2	22·9	1,178·0	1,732·1	41,570·4	0·08	39·8	"
" 11	293·8	19·0	732·2	1,045·0	25,080·0	0·01	39·8	Fine.
" 12	46·6	22·9	1,452·0	1,521·5	36,516·0	0·90	40·2	Rain.
" 13	27·5	14·7	1,275·4	1,317·6	31,622·4	0·10	39·8	Fine.
" 14	65·7	17·0	1,883·0	1,965·7	47,176·8	0·81	39·10	Rain.
" 15	20·1	12·2	1,675·3	1,708·1	40,994·4	0·21	39·3	Showers.
" 16	17·3	12·8	1,102·6	1,132·7	27,184·8	0·53	39·8	"
" 17	103·6	16·8	2,537·5	2,657·9	63,789·6	0·92	39·9	Rain.
" 18	*	*	*	*	*	4·26	..	Bye-wash carrying flood-water from Ross Creek.
" 19	*	*	*	*	*	4·60	..	
" 20	9·3	8·7	2,321·4	2,339·4	56,145·6	0·32	41·0	Rain.
" 21	2·3	7·8	1,677·5	1,687·6	40,502·4	0·15	40·0	"
" 22	Nil	7·1	1,478·7	1,485·8	35,659·2	0·23	39·3	"
" 23	2·1	9·1	929·1	940·3	22,567·2	0·44	39·7	"
" 24	0·8	8·3	736·6	745·7	17,896·8	0·02	39·9	Fine.
" 25	0·7	7·8	794·6	803·1	19,274·4	0·18	39·7	"
" 26	0·7	6·5	630·0	637·2	15,292·8	0·28	39·10	Snow showers.
" 27	Nil	6·2	530·3	536·5	12,876·0	0·23	39·8	Snowing.
" 28	2·4	6·0	448·5	456·9	10,965·6	0·27	39·6	Snow 3 inches deep.
" 29	2·8	7·8	980·5	991·1	23,786·4	0·26	39·8	Fine, snow melting.
" 30	Nil	7·4	980·5	987·9	23,709·6	Nil	39·7	"
" 31	"	9·2	794·6	803·8	19,291·2	"	39·10	"
Sept. 1	"	5·5	630·0	635·5	15,252·0	"	42·0	Fine.
" 2	"	5·0	530·4	535·4	12,849·6	0·06	43·6	Light showers.
" 3	"	4·9	530·4	535·3	12,847·2	0·11	46·6	Light rain.
" 4	"	5·0	630·0	635·0	15,240·0	0·01	48·4	Water from the drain running into east branch.
" 5	"	6·2	530·4	536·6	12,878·4	0·13	48·2	Fine, water in the drain connected with shoot.
" 6	"	5·2	530·4	535·6	12,854·4	Nil	48·7	Fine.
" 7	"	5·1	580·3	585·4	14,049·6	"	48·8	Fine, reservoir full and running over crest.
" 8	"	5·2	490·9	496·1	11,906·4	"	48·2	Fine.
" 9	"	6·2	432·0	438·2	10,516·8	"	48·2	"
" 10	"	6·5	470·0	476·5	11,436·0	0·02	48·4	"
" 11	"	5·1	470·0	475·1	11,402·4	0·13	48·0	Fine, rain during night.
" 12	"	4·9	432·0	436·9	10,485·6	Nil	48·0	Light showers.
" 13	"	4·7	432·0	436·7	10,480·8	0·03	48·0	"
" 14	"	4·6	385·7	390·3	9,367·2	0·03	47·11	Fine.
" 15	"	4·8	415·4	420·2	10,084·8	Nil	47·10	"
" 16	"	4·8	348·4	333·2	8,476·8	0·11	46·0	"
" 17	"	4·9	311·5	316·4	7,593·6	Nil	45·3	"
" 18	"	5·4	317·7	323·1	7,754·4	0·10	45·3	"
" 19	"	5·0	297·2	302·2	7,252·8	Nil	45·3	"
" 20	"	4·9	267·7	272·6	6,542·4	0·05	43·5	Raining.
" 21	"	4·8	238·2	243·0	5,832·0	Nil	40·8	Fine.
" 22	"	4·8	220·4	225·2	5,404·8	"	38·4	"
" 23	"	4·8	201·1	205·9	4,941·6	"	36·0	"
" 24	"	5·0	432·0	437·0	10,488·0	0·75	34·4	Raining heavily.
" 25	"	5·0	522·6	527·6	12,662·4	0·08	31·11	Fine.
" 26	"	5·0	415·4	420·4	10,089·6	Nil	28·6	"

* No gauging possible.

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