1880.
NEW ZEALAND.

THE FLOODS IN THE TAIERI RIVER

(REPORT OF THE COMMISSION ON).

Presented to both Houses of the General Assembly by Command of His Excellency.

The COMMISSIONERS to the Hon. the MINISTER for PUBLIC WORKS.

SIR,— Dunedin, 7th June, 1880.

In accordance with your letter of instructions dated the 29th January, 1880, we have the honor to report as follows:—

The Taieri Plain is a large tract of alluvial land, surrounded by high ranges; the Taieri River winding through it from Outram, where it debouches from the mountains to the Lower Taieri Road Bridge, when it passes through a gorge in the coast range to its mouth. The lower end of the plain is very low, being about the level of high-water mark. The Taieri is bounded on the south-west by the Waihola and Waipori Lakes, into the latter of which the Waipori River empties itself. At its upper end the plain rises more rapidly, so that at Outram it is considerably higher, the Taieri River winding through it in a very tortuous channel. The banks at the margin of the river are several feet higher than the adjacent country, and there are several old watercourses and creeks intersecting the plain, which appear to be abandoned river channels. Above Greytown the plain extends for several miles in a north-easterly direction, with a gradually rising surface, through which the Silverstream flows into the Taieri, passing through a large lagoon and much swampy land near its point of junction.

This plain, together with the whole of the Taieri and Waipori River areas, as well as the country round Waihola, is drained by the Lower Taieri River, which passes through the coast range for a distance of six miles. This portion of the river varies from 6 to 10 chains in width, and from 16 feet to 30 feet in depth. The tide flows up this gorge with considerable velocity, raising the level of the Taieri in the plains, as well as the Waipori and Waihola Lakes. The rise of spring tides at the East Taieri Bridge, six miles from the sea, is about 4 feet 6 inches, or only three-quarters of the range upon the coast, their influence being felt as far as Greytown, seven miles above East Taieri Bridge and thirteen from the sea.

The total drainage area of the Taieri River is about 2,070 square miles. Of this, the Waipori River area, together with the country round Waihola, amounting to 290 square miles, drains directly into the Waipori and Waihola Lakes, the area of which is about six square miles. These lakes are sufficiently large to act as regulating reservoirs for the flood waters of the Waipori River, so that they are not liable to cause inundations on the plains.

The Taieri River, which is the immediate cause of these inundations, drains an area of 1,730 square miles, receiving also the melting snow from several lofty mountain ranges; consequently the floods which give rise to the damage on the plains accrue chiefly towards the end of spring and middle of summer.

There appears to be no record of the rainfall in the Upper Taieri basin. It is, however, most probably much less than on the coast. Mr. J. T. Thomson takes it to be 34 inches per annum, which is probably over-estimated. The floods seem to be produced by heavy storms of short duration, or by warm rains from the north-west melting the accumulated snow of the winter.

The floods of the Taieri have been reported upon by Mr. J. T. Thomson, late Surveyor-General, Mr. W. N. Blair, C.E., of the Public Works Department, and Mr. Barr, C.E.; various works having been suggested by these gentlemen to mitigate their disastrous effects.

Mr. J. T. Thomson in 1870 gave a very full and accurate description of their causes and effects, which are not annual in their periods of occurrence, but take place at intervals of from two to five or six years: the accidental accumulation of snow lying late in the spring, melted by a heavy north-west rain-storm, or a three days' south-west storm, occurring after a period of previous rain, being necessary for the production of an extraordinary flood capable of inundating the plains. When this occurs the flood water, bursting from the mountain gorge at Outram, breaks over the river banks, spreading over the western portion of the plain, whence it rapidly flows eastward, accumulating over an area of about thirty square miles, where it lies until drained off through the Lower Taieri Gorge. According to Mr. Thomson, this gorge is not capable of carrying off the flood water as rapidly as it is precipitated from the mountains, so that it lies on the eastern side of the plain and on the Waipori and Waihola Lakes from one to three days, according as it is or is not obstructed in its discharge by the tides and wind. At the time when Mr. Thomson's report was written, the western or higher part of the plains was settled and under cultivation, but the eastern low-lying portion consisted of swamps and lagoons. He therefore recommended that a new and direct channel should be cut for the Taieri River from Outram to the Waipori Lake, which would have had the effect of drawing off the floods from the upper portion and concentrating them in the low-lying parts, thereby securing the former at the expense of the latter. Since that date these low lands have been reclaimed and settled upon to a considerable extent, so that the remedy proposed by Mr. Thomson would now be scarcely admissible.

Messrs. Barr and Blair suggested the construction of one or more storage reservoirs in the upper parts of the river in order to check the floods; and Mr. Blair, having examined the river, indicated several sites suitable for this purpose.

Mr. E. B. Cargill, in a letter addressed to the Hon. the Minister for Public Works, proposes to erect sluices in the gorge of the Lower Taieri, in order to arrest the inflow of the tides, and by this means to lower the average height of the water inside them. He proposes to construct a solid dam up to low-water level, above which, between high and low water, would be sluice or tide gates. By this means he contends that the rise of the water level inside the sluices would be limited to six hours' accumulation of the water in the river, and that the discharge of floods would not be obstructed in consequence of the tide having been kept out; and in any case that if the floods did rise over the land, as they were of short duration, they would do no harm, only having the effect of refreshing and fertilizing the land. This proposal does not appear to consider fully the interests of settlers in the higher portions of the plain, who, while receiving no benefit from the lowering of the permanent tides, are seriously damaged by the floods.

The discharge of a high flood is not stopped by even the highest spring tide, as is proved by the former rising about 3 feet above its level at East Taieri Bridge, the velocity of discharge only being checked, while upon the turn of tide there is a full discharge of the flood water over the whole sectional area of the river channel, the outgoing current extending to the bed of the river, which is between 16 feet and 30 feet deep at low water.

The obstruction of a solid dam raised to low-water mark would reduce the sectional area of the river to the amount of the width into the depth of the tidal range, plus the additional height of the flood, which, by reducing the hydraulic mean depth of the channel, would greatly diminish the velocity, thus causing a heaping-up of the water on the upper side to the extent of raising its surface level during flood at high water about 3 feet, and at low water about 6 feet higher than would occur if there was no obstruction. Thus, the level of high floods being raised, the time occupied in their discharge would be considerably increased by such a weir. Were the sluices so constructed as to open down to the bottom of the river, the results would not be so serious, though they would still offer great obstruction.

In the River Witham, at Boston, in England, such sluices are considered to be a great mistake.

Sir John Hawkshaw, who was called upon to report on the drainage of the Fens, recommended the removal of the sluices, as he and other engineers preferred strengthening the banks, and using sluices on the drains only. It has been found that the sluices caused the river to silt up its bed in such a manner as seriously to interfere with the drainage of the country. The bed of the river silts up to such an extent as to block the sluice doors in summer-time, and which has to be dredged out at great expense, as the impounding of the water behind the sluices and using it to flush the channel was not found to have sufficient effect.

Under certain conditions a rising tide may not have the effect of even checking the discharge of a high flood: it is not impossible that it might increase it, depending, as it does, on the relation between the slope of the water surface, the hydraulic mean depth, and the sectional area of the channel.

In the case of the Taieri, having a bar at its mouth where the channel meets the sea, it is very much shallower than some distance higher up, the consequence of which is that its width is greatly increased in order to compensate for the diminished depth; but the relations which must exist between the width at the mouth, the surface slope, and depth at the same place, together with the width, surface slope, and depth at any given point further up the river, in order to obtain the same discharge at all places, present an exceedingly complicated problem, which could only be solved approximately after the most careful measurements and surveys, requiring considerable time to accomplish, and when ascertained would have little practical value. It may, however, be easily inferred that the whole sectional area of the river channel is necessary for the discharge of the water it has to convey, for if it were not so the bed would silt up till the river had adjusted it to its requirements. In the meantime, the owners of property on the Western Plain have procured an Act of Parliament empowering them to levy rates for the construction of works in order to protect their land. A Board of Conservators was formed, which has accomplished the erection of an embankment from Outram Gorge to the Henley estate, upon the right bank of the river. After a few failures, this embankment withstood the last flood of 1879, from Outram to a short distance below the boundary of the Henley and West Taieri Districts only; the remainder, having been constructed since that date, is still untried. The portion that was then completed effectually protected the western parts of the plains on the right bank. It was ascertained, however, that these protective works had caused the flood to rise unusually high upon the opposite side of the river, which was not protected; that the railway bridge below Outram was seriously endangered; the railway station at Greytown and the line itself below that point was flooded to a considerable depth. This gave rise to complaints from owners of property upon the left bank, and from the Working Railway Department, in answer to which the present Commission was appointed by the Government to inquire into the means of alleviating the probable effects of future floods upon those lands; the owners of land upon the right bank being confident that the embankments erected will protect them.

It would seem evident that the anticipations of owners on the right bank, that they can protect themselves, are well founded, but as they have in no way been made responsible for the effect of their works, they do not appear to have taken it into their consideration, there being, consequently, a considerable amount of injustice suffered by the people on the left bank.

In order to keep flood water off the land, it must be confined between embankments erected upon both sides of the river, and thus confine a large body of water which previously spread itself across the country. The space allowed between these banks and their height must therefore be so proportioned as to contain it; but at the same time, should both sides of the river be embanked in the manner hitherto adopted, such space would be too confined, and would result in the flood level being raised many feet, to the great risk of destruction to the bridges spanning the river, the railway works, as well as the increased risk of damage resulting from breaches in the embankment, owing to the elevation of the flood water above the plain. Consequently, in order to economize land in the width between the embankments, also to reduce the cost and risk in constructing them so high, it would be advisable, if possible, to arrest a portion of the high floods in the upper parts of the Taieri, thus giving time for the escape of water from the lower areas. With this view, the sectional area of the river and the height of embankments shown upon the accompanying plans have been calculated to convey a flood equal to that of 1868, as gauged by Mr Thomson, less the amount withheld in storage reservoirs, as will be hereafter explained.

With regard to the flood discharge of the Taieri River, Mr Thomson, in his report, states that he gauged it at Outram, after the flood of 1868, and gives the amount as 6,700,000,000 cubic feet per twenty-four hours, which is equivalent to a depth of 1·66 inches, running off the drainage area of 1,730 square miles in the same time: this is equal to 4,653,000 cubic feet per minute, or 2,690 cubic feet per minute per square mile. This discharge appears to be an exceedingly high one from so large a drainage area, spread over a period of twenty-four hours. Messrs. Reid and Duncans gauged the surface velocity of the river above Outram Railway Bridge, where the flood waters were confined between two embankments, while the flood of 1879 was at its maximum, and from which they have calculated the discharge to be 3,750,000 cubic feet per minute. From the same surface velocity and cross section supplied to us by them we make the discharge slightly less, owing no doubt to our having allowed a less mean velocity; such discharge is equivalent to a depth of 1·34 inches running off. After careful consideration we have deemed it advisable to adopt Mr Thomson's measurement as the maximum flood discharge to be provided for at the moment of highest flood where proposing works upon the Plains required to withstand an extreme case. The maximum flood discharge per twenty-four hours we have taken at 4,020,000,000 cubic feet, or 1,613 cubic feet per minute per square mile; or a depth of 1 inch of rain running off.

The flood discharge of the lower Taieri channel through the gorge we have endeavoured to arrive at as accurately as possible, though we can at best only form a rough approximation from observations, cross sections, and levels, taken in so short a time as was at our disposal. The flood discharge at high water we make 1,837,739; and at low water, 2,540,056; or an average of, say, 2,188,717 cubic feet per minute, which is equivalent to 3,152,000,000 per twenty-four hours.

In the following table we have shown the different areas, with the estimated discharges per twenty-four hours, and equivalent depths of rainfall running off, the quantities being in millions of cubic feet:—

	Area Square Miles.	Depth Run off in Inches.	Millions Cubic Feet per 24 Hours.
Upper Taieri, above lower dam ...	800	1·00	1,860
Lower Taieri, below lower dam ...	930	1·00	2,160
Waipori	290	1·25	842
Silverstream	50	1·50	173
Total flood-water discharged on plain...			5,035
Average discharge of Lower Taieri channel			3,152
Daily accumulation on the plain			1,883

The total maximum amount of flood water lying on the lower end of the plain, as recorded by Mr. Thomson, being 4,586,000,000 cubic feet, divided by the daily accumulation, shows that the water should occupy nearly three days in rising to its greatest height. This result would, however, be somewhat modified by the state of the tide and direction of the wind at the mouth of the river.

The method of constructing storage basins in the upper reaches of rivers has been practised in certain parts of Europe, notably on the affluents of the River Loire, where in 1711, at the dyke of Pinay, seven miles above Roanne, and at the Chateau de la Roche, works of this description were erected. The dam of Pinay was referred to by the late Emperor Napoleon in a letter to M. Rouher, then Minister of Public Works, after his visit to the inundated districts in the Valley of the Loire in 1856, wherein he cited it as an example; it having been the means of saving Roanne both in 1846 and 1856 from complete disaster, having kept back the flood water at the dam to a height of 70 feet above the ordinary river level. Many other examples could be named, the most prominent of which is, perhaps, the dam of Fahrens, across the Valley d'Enfer, above the Town of St. Etienne, which was constructed of rubble masonry 170 feet in height, at a cost of nearly £200,000. As, however, this work serves the double purpose of protecting the town from inundation, as well as a water supply for manufacturing and domestic purposes, it is remunerative, paying, some years since, 2½ per centum on the outlay. It is not generally advisable to combine these two duties, their requirements being in direct opposition. For protective purposes the reservoir is only required to hold a quantity equivalent to a maximum flood, when in order to render it again serviceable for the same purpose the stored water must be discharged rapidly, while for useful purposes a certain quantity must be always maintained, thereby reducing its storage powers necessary to intercept a flood. By constructing a work very much larger than is required for protective purposes, it could be made to fulfil both duties, but at a heavy cost, only warranted under exceptional circumstances.

The most suitable site for a reservoir in the case of the Taieri is at the gorge below the junction of the Kyeburn, a little below the outlet of the Taieri Lake. Mr. Thomson, in his report, referred to this site, but was of opinion that the probable deposit of silt brought down by the floods would rapidly fill up the basin. In order to prevent this, it is proposed to excavate an outlet capable of draining the lake, thereby inducing the river to form for itself a channel through its bed, along which the silt and gravel would be conveyed through the sluices in the dam, and so to the lower reaches of the river. Moreover, as the reservoir would never be filled for more than a week at one time, the finer particles of silt would only have had time to deposit themselves to a very slight extent. Another site has been surveyed at the Hogburn, a few miles higher up the river. The construction of a reservoir there would prove more expensive than at the Taieri Lake site, owing to it being necessary to construct two dams in order to pond up the water. Its capacity is also less, with a dam of equal height. Mr. Blair surveyed the two reservoir sites, but in his interim report he only provided for the construction of the one at the Taieri Lake. We find, however, that the two are necessary, and have estimated accordingly. The adoption of two moderately small reservoirs close together, instead of one large one, will also enable them to be made self-acting. As the two reservoirs require the same treatment, the following description will serve for each: In recommending the description of dam that should be erected, we are of opinion that a masonry or concrete structure is the safest and most reliable one to adopt, for the reason that, when called upon to act spasmodically, and possibly at long intervals, an earthen embankment is not to be trusted for many reasons; it would, in fact, be highly dangerous. Its action should as far as possible be rendered automatic, and not dependent upon the services of any individual; in order to carry out which idea the dam should be provided with a certain number of sluices constantly discharging an ordinary flood, but only a small proportion of an extraordinary one, thus enabling it to clear itself of water within a given time, but, meanwhile, only allowing so much of a high flood to escape as could be safely borne by the lower reaches of the river. By this means its action could be rendered certain, and the constant expense of a paid watchman avoided, though it would to a certain extent impair its usefulness, as could the whole of water be retained during the heaviest rush of a flood, by closing all the sluices, the lower parts of the river would be entirely free of water flowing from the area above the dam as long as the reservoir remained unfilled. A considerable difficulty would be experienced by a watchman placed in charge of the sluices, as he could hardly discriminate between what promised to become an extreme flood and one of ordinary dimensions during the first few hours of its rush, when above all other times he should be able to decide as to whether or not they should be closed.

Before describing the work proposed, and in order to explain why it is only contemplated that an amount of flood water equivalent to 1 inch will flow off the area draining into this reservoir during twenty-four hours, it will not be out of place to insert a table illustrating some of the heaviest floods experienced in mountainous districts, where the general character of the country is of a much more rugged and precipitous nature than that under consideration. With the exception of that at Lake Wakatipu, the particulars of which were observed by Mr. H. P. Higginson, C.E., the information is obtained from Beardmore's Manual of Hydrology.

Locality.	Area of Basin. Sq. Miles.	Run off Area in 24 Hours. Inches.	Cubic Feet per Minute per Sq. Mile.	—
Arve, Geneva ...	772	1·02	1,645	Most precipitous and snow-bound, 8 days' rain.
Adda, Como ...	1,670	·60	1,015	May, 1856.
Ticino, Maggiore ...	2,420	·96	1,576	
Geneva Lake ...	3,000	1·02	1,650	Two days' flood, 17th and 18th September, 1840. Rainfall at Geneva, 2·83 inches in 24 hours.
Como Lake ...	1,728	·63	1,037	
Maggiore Lake ...	2,495	1·83	2,950	21st and 22nd October, 1857, unprecedented flood, principally due to melting snow.
Geneva Lake ...	3,000	·90	1,375	Five days' duration, 1856; Rainfall at Geneva, 1·476 inches in 24 hours.
Wakatipu Lake ...	1,200	1·44	2,323	Resulting chiefly from warm rain melting snow, 17th and 18th November, 1877. Rainfall at Queenstown for two days, 2·27 inches., from N.W.

It will be seen from this that in only two cases has the flood materially exceeded the amount which we have resolved to adopt as a safe estimate.

Many instances could be quoted of still heavier floods in India and other tropical climates, even in the European Alps, where the drainage area is very much smaller, so that comparison cannot be fairly made. The above-quoted examples are in five cases from measurements made upon lake surfaces, consequently are less liable to error than when made upon flooded river channels.

The estimated capacity of the Taieri Lake reservoir, measuring to the crest of the dam 45 feet above the bed of the river, amounts to 2,400,000,000 cubic feet; the upper reservoir, as far as can be ascertained, holds about 1,800,000,000, the two together 4,200,000,000 cubic feet. The proposed site at Taieri Lake furnishes a basaltic rock foundation of a tolerably hard character, though not sufficiently compact to withstand the action of the water without protection. The rock appears to overlie a bed of firm river deposit, dipping up stream, the former apparently affording a considerable vertical depth at the foundations of a watertight nature. This can only be accurately determined by boring. That at the upper site is also stock of much the same character. It is proposed to construct these dams of cement concrete, the height from foundation to the maximum flood level being about 50 feet.

A subsidiary earthen embankment is necessary at the Taieri Lake site for a few chains in length, and about 12 feet in height, in order to protect a low saddle from the overflow of the water when at its highest level. This, however, calls for no description.

The sluices for the discharge of the water should be in the centre or deepest portion of the dam; they are six in number, with 50 square feet of water-way each. These would be constantly open, and at each side of these a sluice of the same water-way furnished with lifting shutters to be worked by hand from the top, which could be raised in order at any time to hasten the emptying of the reservoir, should it be found necessary.

Immediately above these eight sluices the dam itself would act as a surplus weir, with a crest 100 feet in length, the over-falling water descending the sloping wall on to the body of water about 10 feet in depth that at the same time is being discharged horizontally below with great velocity, and which would be sufficient to break the shock of the discharge over the crest and protect the masonry apron extending probably a chain below the dam.

Taking the flood discharge from the upper area as before stated, less the discharge from the Kyeburn, and the six sluices constantly discharging, the upper reservoir would require one and three-quarter days to fill, assuming that a maximum flood were flowing throughout the time, but, as a flood usually requires some hours in order to acquire its full dimensions, we may safely say two days. Should the flood at the end of these two days not have commenced to subside, the surplus weir would, combined with discharge from the sluices, be capable of passing the full quantity into the lower reservoir, where the discharge from the sluices of the upper one, together with the flood discharge from the Kyeburn area, would already have commenced to accumulate. By the time the lower reservoir was full, which would occupy the same time as the upper one, the flood would have continued for three and a half days at a full flow, which is most improbable; but supposing it to occur, the surplus weir would still be able to discharge the amount flowing in. These two reservoirs would at the end of that time, when both were full, require about eleven and a half days to discharge their contents—about double the time that would be necessary had they been on different branches of the river, and the contents of the upper one not obliged to pass through the lower one. Their effect would be (as will be hereafter shown) to reduce the amount of an extreme high flood by nearly one-half where it debouches on the plain at Outram.

We have previously estimated the daily accumulation of water upon the plain not capable of passing through the Lower Taieri Gorge at 1,883,000,000 cubic feet in twenty-four hours, but by the construction of the storage reservoirs it will be reduced thus:—

	Millions Cubic Feet per 24 Hours.	
Average flood discharge at Outram	4,020	
Withheld in the reservoirs	1,428	
Reduced flood at Outram		2,592
Average flood from Silverstream		173
Average flood from Waipori		842
Reduced flood at Taieri Gorge		3,607
Average discharge at Taieri Gorge		3,152
Daily accumulation		455

Therefore the amount of 455,000,000 cubic feet per twenty-four hours represents what the river is not capable of discharging so long as a high flood lasts. This, however, does not allow for the increased discharge through the Lower Taieri Gorge, which will probably result from the effect caused by the flood banks proposed to be constructed, which will raise the flood level over that portion of the river and the Waihola and Waipori Lakes. As this height is very problematical we will leave it out of the calculation. The above amount of 455,000,000 cubic feet must therefore disperse itself over the surface of the lakes, which, including the low swampy land between them, amounts to about nine square miles, and which will raise the surface level 1 foot 9 inches per twenty-four hours. This rise is met by the height to which it is hereafter proposed to construct the railway embankment between the bridges on the Henley Estate and the flood stop-bank, which, commencing near the Waihola Railway Bridge, skirts the lakes, and is continued to the Lea Canal, thereby entirely enclosing the whole of the land behind the railway.

With regard to the embanking of the river on the plain we have met with great difficulty. As previously stated, we recommend that a certain proportion of the floods should be stored in reservoirs, the balance being, where possible, restricted to certain limits between embankments. Having been obliged to adopt extreme high floods as the quantity to be provided against, and after intercepting nearly the whole of the water flowing off the Upper Taieri area, we still have a much larger quantity to deal with than the ordinary river can convey; consequently must protect, by embankments placed according to circumstances, as much of the land as possible.

The system of embanking flood waters would in the present case of the Taieri, without the assistance of storage reservoirs, be practically impossible. It might succeed for a few years and protect the land from a flood of the magnitude of that of 1879, but one like that experienced in 1868 would most probably obliterate the greater part of the work. We, therefore, feel bound to recommend no half measures, but only what seems capable of withstanding such a flood as that of 1868, which we take to be as follows:—

	Feet per Minute.
Running off upper area	2,083,600
„ lower „	2,569,400
Maximum discharge at Outram	4,653,000

Then, with two reservoirs capable of holding about 4,200,000,000 cubic feet, or a maximum flood of three and a-half days' duration, we have to provide against a discharge at Outram of the whole flow from the Lower Taieri area, plus the discharge of sluices in the Taieri Lake dam, which latter would only commence to discharge heavily after the upper reservoir had become full and had overflowed into the lower one, which amount, together with the flow from the Kyeburn basin, would represent the water accumulating in it for the first one and a half days. Taking the Kyeburn area as 140 square miles, and 1 inch running off, the yield would be at the rate of 225,866 cubic feet per minute.

	Cubic Feet per Minute.
Average discharge from sluices in the upper reservoir	312,000
„ „ Kyeburn area	225,866
Amount flowing into lower reservoir	537,866

It would be exceedingly difficult to say what amount would be discharged from the sluices in the lower reservoir during the time, as it depends entirely upon the storing capabilities of the bottom of the reservoir, which would regulate the rapidity with which the water level was raised. In order to discharge the whole amount the water must be nearly up to its highest level, while the sluices when running full can discharge 228,000 cubic feet per minute; consequently we shall not be far from correct if we take the average discharge from the lower dam at 300,000 cubic feet during the time that the upper reservoir was filling.

The following table will show the reduced amount of flood water at Outram, based upon the foregoing:—

	Cubic Feet per Minute.
Maximum flow from lower Taieri area	2,569,400
Estimated discharge from lower reservoir	300,000
Reduced maximum flow at Outram	2,869,400
Least capacity of river channel	1,081,248
Amount of water overflowing banks	1,788,152

Consequently during the first day and a half of a flood, which is the time the upper reservoir would take to fill, the above would represent the maximum discharge of the river; while by the time the lower reservoir had commenced to fill, the flood water from the lower Taieri area would have run off, and the increased discharge of the sluices consequent upon the rise in the lower reservoir would not be felt.

The amount of overflow from the river, as shown above, occurs between Outram Railway Bridge and Greytown, and is most difficult to provide for. It must be enclosed by parallel embankments, constructed far enough apart to give the necessary water-way, or be allowed to spread itself over the area of the land adjoining the Silverstream, as has hitherto been the case, rejoining the river lower down in conjunction with the Silverstream at Greytown, where its capacity is larger.

We have endeavoured to adopt the former alternative, but we find that, in order to obtain the required additional sectional area of water-way, the new embankment would have to be placed a considerable distance back from the river, in low ground, owing to the river bank being so high that no water-way can be obtained without doing so. This would expose the best land to the action of the floods protecting the low swampy ground only. It would also be enormously costly, as the banks would be 12 or 14 feet high, and have the disadvantage of deep water running alongside them. The discharge of this portion of the river could be increased by enlarging the river channel itself, but the cost of such an undertaking precludes its adoption. We therefore reluctantly recommend that from Outram Railway Bridge, as far as Greytown, the Silverstream area be left open, and on the other side of the river that the existing banks be maintained in their present position and at their present level.

Opposite Greytown Railway Station the river channel is very much confined now that an embankment has been constructed on the western side, the high ground being also in close proximity on the other: there is no space available for the flood water, except in the channel itself. The flood of 1879 rose here some 15 inches above the rail level in the station, and was running with considerable velocity, owing to the contraction having pounded up the water over the Silverstream area. This becomes very evident upon examining the longitudinal section of the river attached. Upon this section the levels of that flood are denoted as observed by the Engineer of the West Taieri Board of Conservators, and it will be noticed that above the point in question the surface of the flood was very flat, while below there was a considerable fall. We therefore consider it absolutely necessary that from this point down to the Taieri Railway Bridge the existing embankments should be removed, and constructed some distance further back from the river, on the line shown upon the plan, and to the height denoted upon the longitudinal section. At the same time the flat land between the hills and river must be left open, thus affording sufficient flood water-way to pass the maximum amount discharged on to the plains. The embankment from a little below the boundary between the West Taieri and Henley Districts, having been constructed since last flood, the level of water during that time is no indication of what it will be when the next occurs. We have therefore shown upon the longitudinal section the probable raised flood level, and the height the embankment should be constructed to withstand it.

At the Taieri Railway Bridge, near Otakia, the channel is most seriously contracted, so much so that there is no possibility of even an ordinary flood passing that point without damaging either the flood embankment or the land upon the opposite side, including the railway works. We have indicated upon the plan the position to which this embankment should be removed, and at the same time point out that it will involve the construction of about 20 chains of flood openings for the railway on the south bank of the river. This should be sufficient to enable the flood waters to pass without destroying he land and railway works. Below this point, the water being upon the eastern side of the railway, we propose to raise the railway embankment the whole distance between the two bridges, to the levels shown; such culverts as are necessary for the drainage of the Henley estate being protected by shutters, thereby converting the railway into a flood bank.

From a point near the Waihola Railway Bridge, the flood bank constructed by the Henley proprietors should be raised to the same height as the railway bank, and carried at that height to the Lea Canal, or far as it is necessary to shut out the raised flood waters of the lakes.

There can be a little doubt that the discharge of a flood would be greatly assisted by straightening the channel of the river, and by cutting through many of the loops and bends, thereby increasing the velocity of the current. This would be an exceedingly costly work, as would also the enlarging of the channel in narrow places; though both matters would produce a beneficial result.

In order to render the area of water-way effectual between the stop-banks and the railway from Greytown downwards, it is necessary that the present stop-bank be removed, and the high portions of the river bank itself cut down and removed wherever tending to obstruct the free flow of the current over them. The soil so removed could be used for the construction of the new work. The embankments should be constructed with flat slopes of, say, to 2 or 2½ to 1, well sown with grass, and preserved from damage by cattle. No scrub or bushes of any description should be permitted to grow thereon, and everything affording cover to rabbits or other vermin should be eradicated from the existing banks. This is most important, as one rabbit-hole will be sufficient to cause a serious breach.

The position occupied by the river is exceedingly unfavourable for preserving the surrounding country from floods, as, in consequence of the river flowing upon a ridge of high grounds, its banks are raised many feet above the neighbouring land. To move the river into a new position upon lower ground would afford greater facilities for embanking it, but the enormous cost of doing so precludes our seriously considering it. It would be, moveover, extremely difficult to confine the river in a straight channel, and prevent it from adopting its natural winding course.

A deputation from the Henley Board of Conservators waited upon the Commission, and pointed out the difficulties with which they had to contend. They had continued the construction of the stop-bank made by the West Taieri Board entirely in self-defence, as, had the work been stopped at the boundary between the two districts, they would have suffered the effects of the full discharge of a flood in such volume as to most likely destroy the land. They were fully aware of the serious contraction of the flood water-way at the railway bridge near Otakia, and in consequence feared a serious increase in the depth of the floods upon the land between the railway and the river from Otakia to East Taieri Road Bridge. They advocated the construction of a stop-bank along the river side between these two points in order to shelter themselves. They also represented that high tides aggravated the effect of floods, and that the construction of storage reservoirs would have the effect of prolonging the periods that the water would take to discharge, thereby keeping their land longer under water than would be the case if left free to cover the plain and discharge itself to sea. They seemed to consider that nothing more was necesssry than to lower the high-tide level, as a periodical high-flood would do them far less harm than a long continuance of reduced flood, which would be high enough to prevent their drains from discharging perhaps for may weeks, thereby rendering the land sour and useless. A high flood would, as is generally the case, only last a few days, when their drains would run off the water and leave the land if anything improved by the process. This argument refers entirely to the low-lying land at Henley, which is little or nothing above the level of a high spring tide. We gave these statements our earnest attention, and have carefully considered their merits, while forming an opinion as to the general treatment which we propose.

We now give the following abstract of what we recommend should be done:—

The construction of two storage reservoirs on the Upper Taieri basin.

That the existing embankments from Outram to Outram Railway Bridge be left as now constructed.

That from thence to Greytown, on the right bank, the present stop-bank be allowed to remain, and on the left bank that no works be undertaken, but that the water be allowed to find its way as usual to Greytown.

From Greytown to Taieri Railway Bridge on the right bank, the existing stop-banks be removed to the position shown on plan, giving more water-way, and that all high portions of the river bank be cut down, so as to give a free flow to the water across the bends, while on the left bank the area between the river and railway be left open as necessary flood water-way.

That immediately beyond the Taieri Railway Bridge, 20 chains of flood opening be substituted for the present embankment, which must be removed.

That the railway embankment between the two bridges be raised to the level indicated, and supplied with flood-gates at all culverts.

That from the railway embankment near Waihola Railway Bridge, the present stop-bank be raised to the level shown, and continued to the Lea Canal, or as far as is necessary in order to join high ground.

We do not recommend the raising of the railway at any other place than as above indicated.

We estimate the cost of these works approximately from such data as is at our command, as follows:—

Two storage reservoirs	£66,000	0	0
Constructing stop-bank, Greytown to Otakia, on right bank ...	10,000	0	0
Removing existing stop-bank, and cutting down high river banks	2,000	0	0
Twenty chains flood openings at Otakia	6,000	0	0
Raising railway embankment between Taieri and Waihola Bridges	9,000	0	0
Raising stop-bank round Henley, from railway to the Lea Canal	2,800	0	0
Total estimated cost	£95,800	0	0

It becomes necessary to consider whether a complete scheme of protection afforded to the Taieri Plain generally is worth the great expense that must be incurred, and also, with respect to the works already carried out, whether the plain in its original state, allowing the flood waters free scope to spread themselves more or less over the whole of it, was not preferable to any partial scheme, confining them in one locality to the detriment of another.

The former, being what we propose should be done, has a disadvantage in causing a considerable area of the best land to be exposed to the floods, which cannot possibly be avoided, unless sufficient flood water can be impounded to reduce the volume to what the channel on the plain is capable of conveying without overflowing the banks. This can only be effected by the interception of the drainage from the basins of the Sutton, Deep, and Lee Streams, the principal tributaries of the lower portions of the Taieri. We have considered the possibility of doing this, but have ascertained that these river basins afford no suitable sites for reservoirs, their slope being very great, and valleys extremely narrow.

The probable damage that would be incurred by land exposed outside the proposed flood banks is more imaginary than real, as the construction of the two reservoirs will have a marked effect upon the height to which the floods will rise, considerably reducing also the time that the land would remain under water; while, if laid down in grass and used for pasture, an occasional flooding of short duration would be of great service in recruiting the soil. There would also be no risk of losing stock, which has hitherto been the case, owing to the proximity of the flood bank.

It may, in conclusion, be remarked that after careful survey and levels have been made of the Silverstream area, it is possible that a considerable portion may be embanked without too much encroaching upon the space necessary for the passage of the floods, but which will nevertheless resolve itself into the question whether the cost of the works required will not be out of proportion to the good effected. From the information at our disposal we find ourselves unable to reply to this, so that we prefer recommending that at this point, where the river channel is so defective, ample water-way be allowed by leaving the whole area open as at present. The cost of embankments in this locality would be very heavy, because of their height, the necessity that exists for carrying them up both sides of the Silverstream as far as the railway, the provision that would be necessary for carrying off the drainage from the surrounding hills, and in consequence of the works which would be required for the passage of the water flowing down the Owhiro Creek, which would have to be discharged through large sluice-gates inserted in the flood bank.

The area of land exposed to floods, deducting the Waipori and Waihola Lakes, and low land in their vicinity, is about forty square miles, of which twenty-eight square miles will be protected by the proposed works, and twelve square miles left exposed, which will include all the land on the Silverstream area, as well as what lies between the proposed flood stop-banks and the hills from Greytown to the East Taieri Road Bridge.

Taking the estimated cost as before shown to be £95,800, it will amount to about £7 5s. per acre that will be protected. In addition, however, to the land that will be benefited by these works, it must be borne in mind that about eight miles of the Dunedin–Invercargill Railway will be saved the cost of repairs necessary after each successive flood. The railway bridge over the Taieri River on the Outram Branch line will also be protected, and possibly saved from complete destruction. The road bridge over the river at Greytown may also be saved from further damage, though it would be a decided advantage to the free flow of the current were it swept away, as the original portion of the work is little better than a dam tending to obstruct the flood water, thereby increasing the evil effects felt there owing to the contracted nature of the river channel.

It will be noticed that the effect of the proposed works leaves a portion of the plain still unprotected and liable to be flooded. The calculations are, however, based upon data afforded by an extremely high flood, which is of exceptional occurrence. The flood of 1879 was not a remarkably high one, nevertheless the discharge of its water at Outram Railway Bridge was estimated at 3,750,000 cubic feet per minute. The effect of the works now proposed is calculated to reduce an extremely high flood to the moderate dimensions of a discharge at Outram of 2,869,400 cubic feet per minute, a result which we think is satisfactory when all the circumstances of the case are carefully considered.

We have, &c.,
C. Napier Bell, M. Inst. C.E.
H. P. Higginson, M. Inst. C.E.
W. N. Blair, M. Inst. C.E.

The Hon. the Minister for Public Works, Wellington.

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