Upper Murray Storage 8½ times during the latter year, while in the former the discharge represents less than three-quarters of the capacity of the dam.

Since the inauguration of the River Murray Commission the gaugings are being continued by the three States as heretofore, daily gauge heights being recorded at the various stations, and current meter observations taken as frequently as practicable. From these, curves of discharge for any height on gauge are compiled, and the volumes of discharge worked out.

By direction of the Commission a Conference of Gauging Officers has been sitting for some time past, under the Chairmanship of Mr. H. Shute, L.S., with the object of ensuring uniformity in gauging methods, and also to deal with matters generally affecting the measurement of streams, and diversions, etc.

This report has recently been completed, but not yet dealt with by the Commission.

UPPER MURRAY STORAGE.

At Bringenbrong, some 90 miles by road above Albury, the main stream of the Murray is formed by the junction of the Swampy Plains River, rising in N.S.W., and the Indi River, which rises in the Snowy Mountains in Victoria. Between Bringenbrong and Jingellic it is joined by the Tooma River, rising in New South Wales, and between Jingellic and Albury by the Mitta Mitta and Kiewa Rivers, rising in Victoria.

Cumberoona Site.—The 1902 Royal Commission, after investigating several sites, fixed upon that at Cumberoona, 20 miles by river above the junction of the Mitta Mitta River, as the most suitable. It was then estimated that a dam 8,000 feet long and 70 feet high would be suitable, with a storage of 582,000 acre feet. Later investigation, however, with a diamond drill, showed that the original hand-drill borings were unreliable, and the depth to rock at this site was found in places to be over 230 feet.

Investigation of Sites.—Following upon the Interstate Engineers' Report, extensive investigations were made with diamond drills of a number of dam sites on the Murray River from Albury to above Jingellic. This investigation, which occupied several years, was under the joint charge of Mr. F. M. Smith, Assoc.M.Inst.C.E., representing New South Wales, and Mr. E. Checchi, representing Victoria. In the lower portion of this section of the Murray Valley, the formation is grey granite, changing in the vicinity of Jingellic to silicified slate.

Two diamond drill plants, supplemented by a hand-boring plant, were used, and 25 sites in all were tested. At every site, except that finally chosen, the depth to bedrock at some portion of the cross-section of the Valley was found to be so great, from 125 to over 230 feet, as to make the cost of foundation work prohibitive.

Sites on Head Waters.—When it became known that the only practicable site was that selected, immediately below the junction of the Mitta Mitta River, considerable opposition was shown by residents on the Victorian side, by reason of the fact that the flats along the Mitta Mitta, below Tallangatta, will be submerged, and requests were made that the question of constructing smaller storages on the headwaters should be further investigated. These storages would comprise the following:—Indi River at Tom Groggin, Swampy Plains River at Geehi, and Tooma River at Black Jack. The total catchment area above these dam sites is small, approximately 634 square miles, and even with the addition of storages on the Upper Mitta and Snowy Creek, it was estimated that the regulated flow to be obtained from the combined storages would be less than one-half of the 240,000 acre feet per month referred to in the 1913 Interstate Engineers' Report.

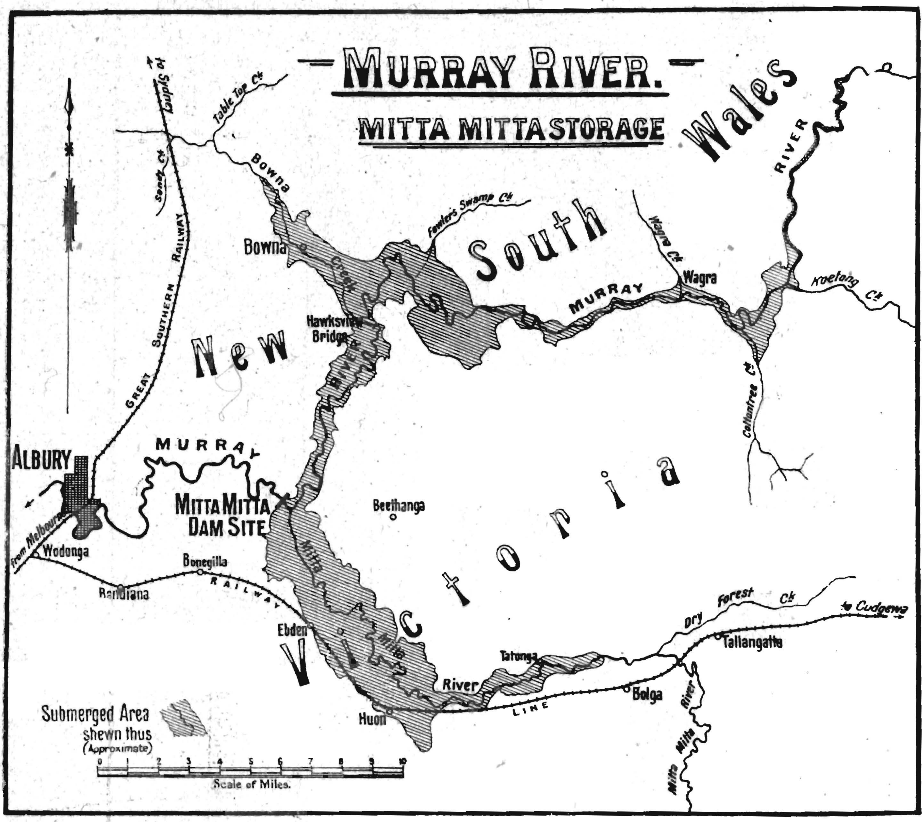
Selected Site.—The site finally selected is about half a mile below the confluence of the Mitta Mitta and Murray Rivers, and it is estimated that a storage of 1,000,000 acre feet will be provided by a dam about 3,600 feet long, with a full supply level of about 73 feet in depth over the flats on the Victorian side, increased to 94 feet in depth in the river channel.

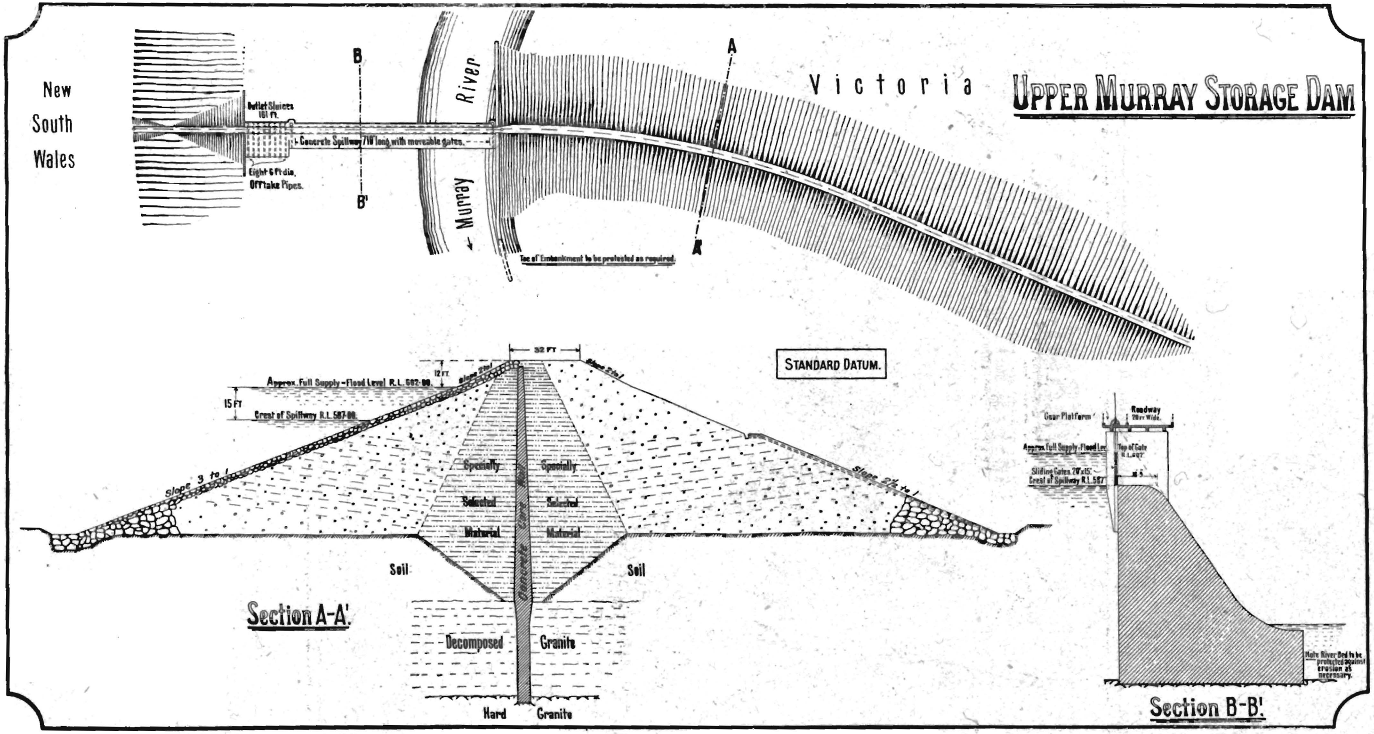
Such a storage will rank among the greatest in the world, and the following particulars are given for purposes of comparison:—

Upper Murray Dam Compared with Other Great Dams.

Elephant Butte	Capacity,	2,600,000	Acre Ft.
Assouan	,, . .	1,865,000	,,
Roosevelt	,, . .	1,279,362	,,
Upper Murray	,, . .	1,000,00	,,
Burrinjuck	,, . .	771,641	,,

Mass Curve.—A mass curve diagram of flow at the dam site has been prepared for the period from the 1st January, 1900, to 31st December, 1917. Assuming that the reservoir commenced to fill on the former date, the accumulated flow of the river above the site is shown by the full line for the above years. Upon the assumption made in the Interstate Engineers' Report, viz., that a regulated flow of 240,000 acre feet per month would be supplied at Albury from August to April inclusive, a reduction would be made in the capacity of the


MURRAY RIVER.
MITTA MITTA STORAGE
New South Wales
Victoria
ALBURY
MITTA MITTA DAM SITE
Wodonga
Bonegilla
Bandiana
Ebden
Huon
Beethanga
Hawksview Bridge
Bowna
Wagra
Tatonga
Bolga
Tallangatta
MURRAY
RIVER
GREAT SOUTHERN RAILWAY
to Sydney
Table Top Ck
Sandy Ck
Fowlers Swamp Ck
Koetong Ck
Cottontree Ck
Dry Forest Ck
to Cudgewa
From Melbourne
RAILWAY
LINE
Mitta Mitta River
Submerged Area shewn thus (Approximate)
0 1 2 3 4 5 6 7 8 9 10
Scale of Miles.



UPPER MURRAY STORAGE DAM
New South Wales
Victoria
River Murray
Outlet Sluices 161 Ft.
Concrete Spillway 710' long with moveable gates.
Eight 6 Ft dia. Offtake Pipes.
Toe of Embankment to be protected as required.
STANDARD DATUM.
32 FT
12 FT
15 FT
Approx. Full Supply-Flood Level R.L. 602·00.
Crest of Spillway R.L. 587·00.
Slope 3 to 1
Slope 2½ to 1
Specially Selected Material
Soil
Decomposed Granite
Hard Granite
Section A-A'.
Roadway
Gear Platform
Top of Gate
Sliding Gates 20' x 15'
Crest of Spillway R.L. 587
Note River Bed to be protected against erosion as necessary.
Section B-B'.

dam, as shown by the hatched line, after making due allowance for the unregulated flow of the Kiewa River. From this it will be seen that in periods of exceptional drought, such as 1902-03 and 1914-15, a supply at the above rate could not be provided, and in such seasons the amount of water available for irrigation purposes must be reduced. Provision for such a contingency is made in the River Murray Waters Act, whereby the Commission is given authority to make proportional reductions of the amounts to which the respective States are entitled under the Agreement.

Design.—The total length of 3,600 feet will be made up of earthen embankment 2,700 feet, and concrete spillway and outlet works 900 feet. The embankment, 32 feet wide on top, with crest at 12 feet above F.S.L., will extend across the alluvial flats on the Victorian side, where the granite occurs, at an average depth of about 34 feet below the surface. The slopes proposed are 3 to 1 upstream, and $2\frac{1}{2}$ to 1 downstream, from natural surface, to F.S.L., and 2 to 1 in either case from F.S.L. to crest. The upstream slope will be protected against wave action. The embankment will be constructed with a concrete core wall, carried down into the granite, the material on either side of the core wall being specially selected and consolidated.

The design of the spillway section has required careful consideration by the Engineers responsible, Messrs. de Burgh and Dethridge, in order to avoid undue submergence of adjacent lands by a high flood coming down on top of a full reservoir. Fortunately, before the work was undertaken, Mr. Hydrographer French obtained at Corowa a record of the highest flood in the Murray River, of which reliable records are in existence. This was in October, 1917, when the discharge, as gauged with current meter, was estimated by Mr. French at 125,240 cubic feet per second. The catchment area above Corowa is about 7,260 square miles, so that the flood rate was approximately 17 cusecs per square mile of catchment. The catchment area above the dam site is about 6,000 square miles, and after deducting the volume of the Kiewa River, which joins the Murray below the dam site, it has been estimated that the spillway should be capable of discharging a flood of 100,000 cubic feet per second. The spillway will be of the same general design as that of the well-known dam on the Goulburn River in Victoria, and will comprise a concrete dam of granite section suitably shaped for discharging the flood water, 710 feet long, with movable gates. Piers carrying the roadway will rise above the concrete, and will act as supports for 31 gates, each 20 feet wide in the clear, 15 feet high above the crest. In flood time these will be lowered behind the up-

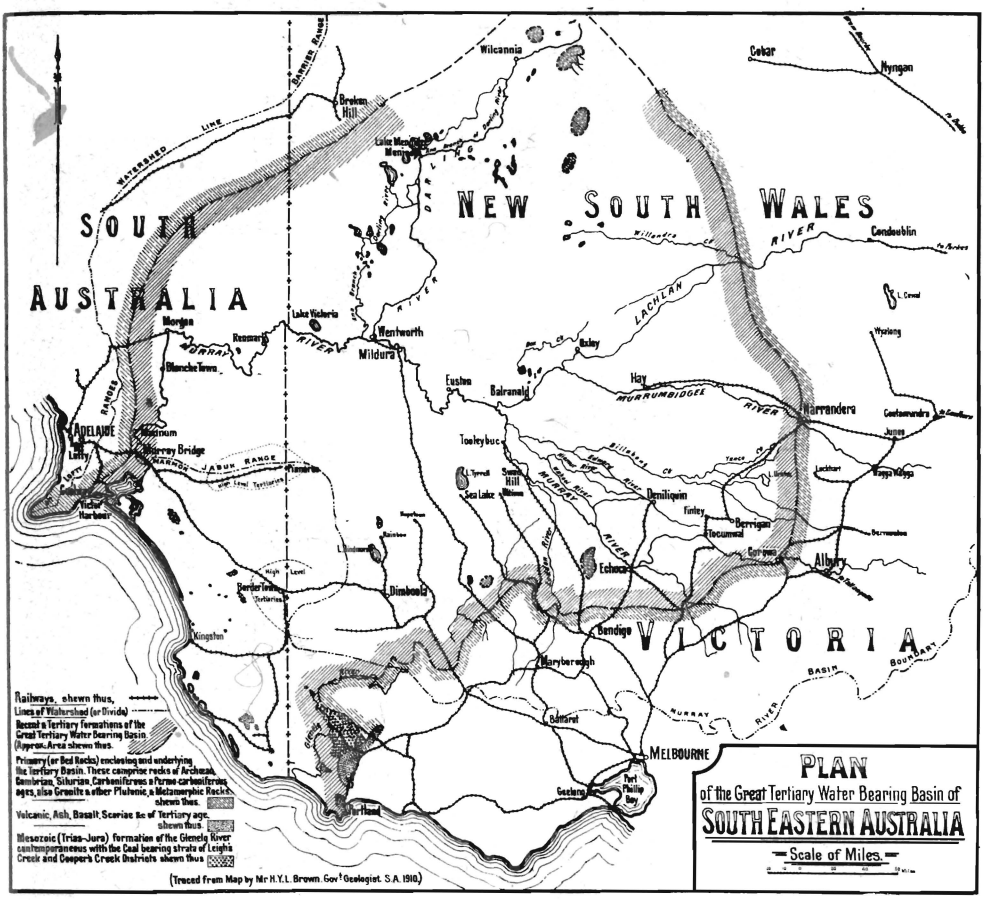
stream face by suitable gearing, operated by turbines situated in a chamber within the dam. It is estimated that a surcharge of 15 feet over the concrete wall will suffice to discharge the maximum flood. For ordinary regulated flow discharge eight outlet pipes, 6 feet diameter, will be provided, situated on the New South Wales bank, and provided with suitable controlling valves. Including the cost of resuming the land which will be submerged, some 30,000 acres, and certain railway and road diversions, which will be required, a tentative estimate of £1,600,000 has been submitted for the whole cost of the work, but this is subject to revision upon completion of the surveys for the land to be resumed.

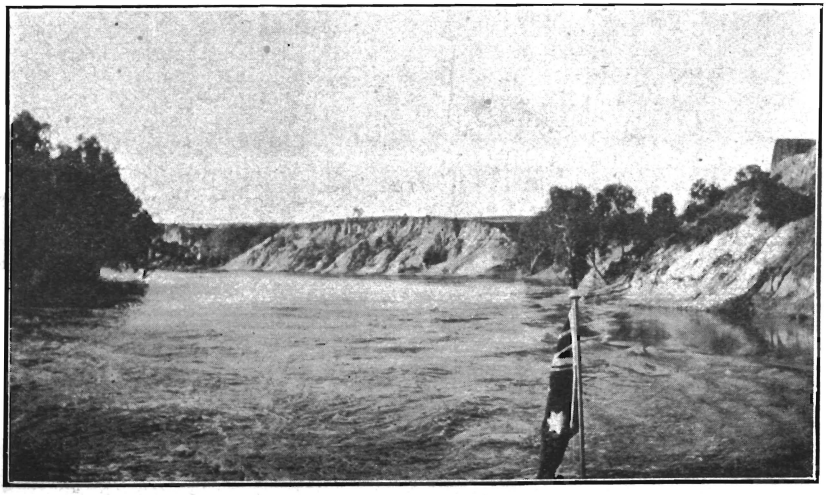
The general design has been approved by the River Murray Commission, and preliminary operations at site have been commenced.

GEOLOGY OF MURRAY VALLEY BELOW ECHUCA.

For the better understanding of the foundation problems to be dealt with in connection with the construction of locks and weirs, the following extract is given from the 1910 Victorian Royal Commission's Report regarding the geological history of the Murray basin:—

"Excluding that portion of the Darling watershed north of Menindie, the plains of the Murray basin have been the result of the silting up of a large arm of the sea which had its opening to the ocean in the neighbourhood of the present mouth of the Murray, and which extended into Australia as far north as Menindie, as far east as Tocumwal, and as far south as Echuca and Dimboola. The whole of this area is surrounded by old rocks, with the exception of the coastline about the lakes at the mouth of the river. Borings put down all over this area have disclosed that the materials filling up this huge basin consist of river and lake deposits to a depth of over 1,000 feet from the present surface. . . . The siltation of this basin, and the river valleys leading into it, extended over long periods of time, and is still going on. The initial cause of this action was probably the uprising of the floor of this inland sea in South Australia, along the coast and near the mouth of the river. This fact is evidenced by the occurrence of seashells and limestone in the high cliffs through which the river has cut its way in its lower reaches in South Australia. The lake so formed was filled by the sands and silts carried into it by the rivers denuding the surrounding highlands, which have now only a fraction of the elevation they previously attained. The last series of deposits laid down as deltaic formation in this original lake, and which now forms the surface of the plains, consists of the rich alluvial soils of the mallee, Riverina, and





1.—High Cliffs on Murray River in South Australia.

south-west New South Wales. Deposition is still going on in the Murrumbidgee and Murray east of the junction of these rivers, but to the west of this point the rivers flow through a valley in places some 10 miles wide and 100 feet below the general surface level. This valley has been cut out by the meanderings of the Murray, and places such as the red and white cliffs, which frequently occur along the river, indicate where this really is still in process of formation. The upper strata forming the filling of the Murray basin is seen at these cliffs."

At no site of the many tested in South Australia has any rock-bar been found at a sufficiently high elevation to admit of founding any lock and weir entirely thereon, and piling must be resorted to for carrying either the whole or the greater part of the concrete work.

An examination was made by Mr. Assistant-Engineer Bailey of the whole length of the upper section of the river bed, from Echuca to Wentworth, during the phenomenally dry summer of 1914-15, when the river had practically ceased to flow, with a view to determining whether there are any bars suitable for foundations. Mr. Bailey reported as follows:—

"From Echuca to Swan Hill, 193 miles by river, the bars or reefs are nearly all of a clayey formation; in a few instances very soft sandstone or indurated sand is found. There is practically no sand on this portion of the river.

"From Swan Hill to the junction of the Wakool River, 75 miles, the bars are almost all of a clayey material, very similar to those above Swan Hill; but more sand is found, increasing in quantity towards the Wakool River Junction. It might be stated, as showing the state of the Murray, that between January and 16th May last no water flowed between Tooleybuc and the Wakool Junction, a distance of 22 miles, and the residents were depending upon the water in the holes between the dry bars. Between the Wakool Junction and the Murrumbidgee Junction, 28 miles, there are some outcrops of soft sandstone and considerable lengths of sandy reaches with little or no clay.

"From the Murrumbidgee River Junction to the junction of the Darling River at Wentworth, 254 miles, there are a great number of sandstone outcrops, generally only on one side of the river, and not likely to be of any use as sites, the remainder of the river bed being practically all sand, varying from very fine to very coarse.

"Although I have submitted sections of a number of sandstone reefs, I am doubtful if any of them will prove useful for foundations; the stone is generally rotten and crumbly, and in my opinion does not extend much below the river bed."

At the Curlwaa Pumping Station there is a pronounced outcrop of ferruginous sandstone extending nearly across the river, but upon being tested recently by Mr. G. H. Tolley, District Engineer, it was found to be merely a cap overlying sand which contained water under pressure, which rose in one shaft to a height about 4 feet above the level of the water in the river.

It is clear, therefore, that on the upper section of the river also no satisfactory rock bars exist for foundation purposes, while the absence of stone suitable for concrete will also increase the cost of the work.

NAVIGATION.

Major (then Captain) E. N. Johnston, Corps of Engineers, U.S. Army, in his valuable report in 1912 to the South Australian Government on the "General Scheme for the improvement of the River Murray," stated that: "The navigation of the River Murray is carried on by steamboats and barges. Most of the steamboats used are of the side-wheel type, and the barges are shaped with pointed bow and stern, provided with a single rudder at the stern. These barges are towed either singly or in file by the steamboats. The steamers draw when loaded from 2½ feet to 7½ feet, the latter draft being exceptional, and very few being of greater draft than 6 feet. The barges carry from 110 tons to 500 tons on drafts of from 3 feet to 7 feet 6 inches. The largest steamer on the river appears to be the 'Gem,' which is 133.6 feet x 20.7 feet x 6.6 feet, with a beam across the paddleboxes of 35.6 feet. The largest barge is the 'Crowie,' which is 151 feet x 30 feet x 8 feet."

The minimum depth to be provided in the locked river is discussed by Captain Johnston at considerable length, his final conclusion being that, "with a lock and weir system designed to afford in the pools at least channel depth of 6½ feet, it will, therefore, be practicable to use boats and barges drawing from 5½ feet to 6 feet, without undue retardation of their movements." It may be pointed out that the minimum depth of 6½ feet will only occur at the head of each lock pool. For the balance of the pool the depth will be much greater, e.g., from 6½ feet to 16½ feet at the lower end, in cases where the lift is 10 feet above the lower pool.

LOCKED RIVERS.

The total length of the river to be locked, from Echuca to Blanchetown, is 900 miles, the distances from Echuca to some of the principal towns on the river being as under:—