THE UNIVERSITY OF NEW SOUTH WALES

WATER RESEARCH LABORATORY

REPORT No. 12

Dissipator Wangi Power Station Ashpond

by

E. M. Laurenson

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The University of New South Wales

WATER RESEARCH LABORATORY

HYDRAULIC MODEL INVESTIGATION
of
ASHPOND OUTLET STRUCTURE
WANGI POWER STATION, N.S.W.

by

E.M. Laurenson

Project No. E.C. 1.4

Final Report to

The Electricity Commission of New South Wales

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February, 1960.

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PREFACE

This study forms part of a series of hydraulic investigations undertaken by the Water Research Laboratory of the University of New South Wales at the request of the Electricity Commission of New South Wales. The study was commenced on 12th May 1959 and completed on 17th August 1959.

Throughout the course of the study, close liaison was maintained with the Electricity Commission through an engineer on the staff of the Commission's Project Development Section, Mr. B.H. Keogh, whose friendly co-operation in the supply of all necessary data is gratefully acknowledged. Internal progress reports of test results were made available to the Commission as data became available.

The study was carried out at the Water Research Laboratory, Manly Vale, N.S.W. by Mr. E.M. Laurenson. The Electricity Commission programme is under the direct supervision of Mr. D.N. Foster of the Laboratory Research staff.

H.R. Vallentine

Associate Professor of Civil Engineering
Officer in Charge of the Water
Research Laboratory.

22nd September, 1959.

CONTENTS

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SUMMARY

Proposed outlet works for the Ash Pond dam of Wangi Power Station comprise two 6 ft diameter pipes discharging into a concrete energy dissipator and thence into an open channel with an unlined bed and rip rap banks. Model tests of the original outlet design for the maximum design flow of 600 cfs indicated the likelihood of unsatisfactory asymmetrical flow in the discharge channel, with excessive scour of the bed and undercutting of the left bank near the outlet and also near the bend at the downstream end of this bank.

Design modifications tested in the model in an attempt to overcome the scour problem included the addition of sills of various shapes, dimensions and locations to the flat apron of the energy dissipator. Satisfactory results were achieved with an arrangement featuring two sills, one located near the outlet from the pipes and the other at the end of the apron, the downstream sill being surmounted by low blocks against each wing wall. Other modifications to the original design incorporated in the final recommendation are an increase in the height of the wing walls of the energy dissipator, a change in the shape of the rip rap blanket immediately downstream of the energy dissipator, and a modification to the rip rap banks at the extreme downstream end of the discharge channel.

1. INTRODUCTION

1.1 The Prototype

Ash from the Electricity Commission of New South Wales Wangi Power Station on Lake Macquarie is transported in suspension in water through a pipeline to a disposal area on Crooked Creek near the head of Pantaloon Bay, Lake Macquarie. An earth dam approximately 60 feet high is to be constructed across Crooked Creek to retain this ash. The proposed outlet works for the discharge of flood waters from this dam comprise a hollow tower type intake structure with a variable height crest, discharging into a closed conduit, which terminates in two 6 ft diameter pipes about 440 ft long. At the downstream end, these pipes have a 45° bend followed by 12 ft of straight pipe before discharging into a concrete-lined energy dissipator 25 ft long. This structure forms a transition into an open channel with an unlined bed 30 ft wide and rip rap banks at a batter of 1:1. The open channel has a length of about 150 ft and discharges into Crooked Creek about 1,500 ft from the outlet of this creek into The Lagoon, off Pantaloon Bay. Figure 1.1 shows the general arrangement of the outlet works.

The energy dissipator as originally designed is shown in Figure 1.2. This structure is 25 ft long, 14 ft 8 in. wide at the upstream end and 30 ft wide at the downstream end. The apron has a plane surface falling from R.L.98.00 at the upstream end to R.L. 97.75 at the downstream end. Protection for the toe of this apron is provided by a cut-off wall 2 ft 6 in deep, and by rock rip-rap 3 ft deep extending 20 ft from the toe of the apron. The vertical wing walls have a height of 7 ft at the upstream end, decreasing to 2 ft over a distance of 23 ft measured along the centre line of the structure and falling away to zero over the final two feet of the structure.

Although the bed level of the open channel from the energy dissipator to Crooked Creek is at R.L.97.75, the natural bed of the creek is in some places at about R.L. 101, though the general level of the bed in the vicinity of the outlet works is about R.L. 99. The average lake level is R.L. 100, and the tidal fluctuation is very small. Thus, at times of no flow, the open channel and energy dissipator will be submerged to a depth of approximately 3 ft. The material in which the channel is to be excavated is a sandy loam.

In the vicinity of the outlet works, the natural stream channel is about 15 ft wide and 2 ft deep. This section increases to about 40 ft wide and 4 ft deep near the mouth of the creek where it discharges into the Lagoon. Throughout this length the bed is badly snagged and the banks are covered with thick scrub and medium timber. An approximate average cross-section of the creek just downstream of the outlet works is shown in Figure 1.3.

A design flood discharge of 600 cfs was specified and, as the pond storage will provide a very great routing effect, storage area at F.S.L. being about one-third of the catchment area, the design outflow of 600 cfs can be assumed to remain approximately steady for at least 12 hours.

During the testing programme, further flood studies, spillway model studies, ash movement studies and consideration of the question of whether to operate the ash pond with a full storage or an empty storage, led to consideration of an overflow type spillway instead of the tower type described above, and a possible amendment downwards of the design flood discharge. At the time of writing, a final decision on these matters has not been made.

1.2 Purpose of Model Studies

Stability of the reinforced concrete energy dissipator and the rip-rap banks of the open channel will depend upon any scour in the unlined bed of the open channel being of negligible proportions, particularly at the end of the apron and the toes of the banks. In order to minimize this scour, as much as possible of the energy of the high velocity flow issuing from the 6 ft diameter pipes must be dissipated on the concrete apron. Further, the 45° bend just upstream of the end of the pipes, and the bend in the open channel itself will tend to produce asymmetrical flow distribution in the channel, and the resulting high velocities may cause excessive scour. The model test programme was therefore planned to assess the scour effects in the channel with the original design and to modify this design in such a way as to obtain maximum energy dissipation on the apron, uniform distribution of flow across the channel and negligible scour at the toes of the energy dissipator apron and the rip-rap banks.

2. THE MODEL

2.1 Description

In order to study the above effects, and to simulate natural flow conditions in the areas concerned, the outlet works were modelled from a point about 80 ft upstream of the pipe outlets to a point in the natural stream about 50 ft downstream from the ends of the rip-rap banks.

The two 6 ft diameter concrete pipes were represented by 3 in. nominal diameter galvanised sheet metal pipes and the reinforced concrete energy dissipator was modelled in plywood. Although the rip-rap banks in the prototype will be flexible, the banks in the model have been fixed in position for convenience, and the stability or otherwise of these banks was inferred from the degree of scour occurring at the toe. Three-quarter inch blue metal fixed to the banks by cement mortar was used to represent the rip-rap. Scour effects were obtained by providing a channel bed of Botany sand and the natural country in the vicinity of the end of the channel was also modelled in sand. Provision was made to model sections on both sides of the channel if it became necessary to study the effects of overbank flow. The rip-rap blanket immediately downstream of the energy dissipator was represented by three-quarter inch blue metal, in this case not fixed in position.

2.2 Scale Ratios

Considerations of scale effects, accuracy required, available pipes, cost and available space led to the adoption of a natural linear scale of 1:23, so that the two 6 ft. diameter outlet pipes were represented by 3 inch nominal diameter sheet metal pipes, and the 30 ft wide bed of the open channel had a model dimension of 15-5/8 inches. The overall size of the model was approximately 15 ft x 6 ft.

As gravity is the predominant force controlling fluid motion in both the model and the prototype, other model scales are fixed by the Froudian relationship as follows:-

Linear dimensions	-	1:23
Area	-	1:529
Volume	-	1:12, 167
Velocity	-	1:~~48~~ 4.8
Discharge	-	1:2,537

3. TESTS AND RESULTS

3.1 Test Procedure

Eleven tests have been run at the design discharge of 600 cfs (model discharge 0.236 cfs) with the original and various modified designs. After achieving a satisfactory design for the maximum discharge, a series of tests were run at discharges of 100, 200, 300, 400 and 500 cfs. to check that no undesirable effects occurred at these lower flows. In all tests, steady flow was maintained until the movable bed had virtually reached equilibrium, the test duration generally being of the order of one to two hours. Flow to the model was supplied in a 3-inch pipe in which a 2-inch orifice meter was inserted.

Mapping of the scoured bed was carried out by scaling below a datum on a grid system, and subsequently plotting the scour contours. Scour depths in this report are quoted in prototype dimensions, but it is not to be inferred that these results are quantitatively accurate since the use of a sand bed in the model does not truly reproduce resistance to scour in the prototype. Scour patterns, however, will be accurately reproduced and the relative depths of scour for different designs are a true indication of the efficiencies of these designs in minimizing scour.

3.2 Test Results

Tests Nos. 1 to 11 were all carried out at the design discharge of 600 cfs. Test No.1 was carried out with the original design of the energy dissipator and channel. This resulted in a very high concentration of flow near the left bank of the channel with a reverse flow upstream along the right bank over a length of 50 ft from the end of the apron. Large eddies were formed against each bank at the end of the apron and there was considerable turbulence and wave action against the rip-rap banks above the concrete wing walls of the energy dissipator.

Very severe erosion occurred in the bed along the left bank, particularly for about 50 feet downstream of the rip-rap blanket and about 30 feet upstream from the end of the bank. A contour map of the scoured bed is shown in Figure 3.1 and photograph 3.13 shows the scour pictorially. It was considered that the first problem to be overcome was to obtain a more uniform distribution of flow across the channel so as to reduce the high velocities along the left bank.

Accordingly, for Test No.2, the energy dissipator was modified by the addition of a sloping sill located at the downstream end of the apron. This sill was of triangular cross section with a vertical downstream face, a height varying from 5 ft at the left bank to 2 ft at the right bank, and a base width 1.75 times the height, as shown in Figure 3.2. This sloping sill had the effect of throwing the main body of flow over to the right bank of the channel and resulted in severe erosion along this bank equally as bad as the erosion along the left bank with the original design (see Figure 3.2). Also, a low hydrauloc jump formed on the rip-rap just downstream of the sill. It appeared that a sloping sill could usefully be employed to obtain an even flow distribution but that the slope used in this test was too great. Also, it was clear that the dimensions of the sill used in this test were disproportionately great, and further, it seemed advisable to locate the sill further up on the apron so that the hydraulic jump would form on the apron and not on the rip-rap.

The modifications to the sloping sill indicated by Test No.2 were made in Test No.5, but, before these were made, the effects of two different uniform section sills were determined. Each of these sills was of triangular cross section with a vertical downstream face and each was located in turn at the end of the apron. However, in Test No.3 the height and base width were both 2 ft 1 in., whilst in Test No.4 the height was 2 ft and the base width 3 ft 9 in. In both of these tests, the flow was reasonably uniformly distributed across the channel but severe erosion occurred against both banks just downstream of the rip-rap blanket. Erosion was particularly severe in Test No.3, which was run overnight for 17-1/4 hrs. Sill arrangement and test results are shown in Figures 3.3 and 3.4. In both of these tests, a hydraulic jump was formed on the rip-rap about 10 to 12 feet downstream of the end of the apron.

In Test No.5 a sloping sill modified as suggested by the results of Test No. 2 was used. This was a triangular cross-section sill with a vertical downstream face located 9 ft from the end of the apron. The height varied from 3 ft at the left wing wall to 2 ft at the right so that the transverse slope was less than in Test No.2, and the base width varied from 5 ft to 3 ft 6 in. Figure 3.5 shows the arrangement of this sill and the scour pattern produced. A uniform distribution of flow over the cross-section was obtained with this sill, but the hydraulic jump formed over the end of the apron and scour holes were again formed against each bank and at the centre of the channel immediately downstream of the rip-rap blanket, as shown in Figure 3.5.

With a view to forming the hydraulic jump further up on the apron and eliminating the three scour holes mentioned above, two sills were introduced in Test No.6. The sloping sill was moved further upstream so that its vertical face was 12 ft from the end of the apron, and a second sill was placed at the end of the apron. This second sill was rectangular in cross-section, 2 ft wide and 9 in. high, and was surmounted by three blocks 9 in. high, one adjacent to each of the wing walls and one in the centre. The arrangement is shown diagrammatically in Figure 3.6. This figure also shows the scour pattern for this test. The hydraulic jump was formed just upstream of the end of the apron in this test and it appeared that the sloping sill could effectively be brought still further upstream.

Scouring effects were not materially improved by the arrangement in Test No.6, as holes 2 ft deep on the right bank, 1 ft deep on the left bank, and about 1 ft 6 in. deep in the centre of the channel were again formed immediately downstream of the rip-rap. It appeared from flow patterns that if the rip-rap downstream of the apron was arranged in the form of a "U" along both banks and across the end of the apron, fine material from within this "U" might be deposited against the toes of the banks in the positions where scour had been occurring. It was considered that a limited amount of scour in the central part of the channel within the "U" would have no deleterious effect.

In accordance with the above observations, the arrangement for Test No.7 was a sloping triangular section sill located 14 ft from the downstream end of the apron, a rectangular sill surmounted by three blocks as in Test 6 located at the end of the apron, and a "U" shaped rip-rap blanket, 6 ft wide along both banks and across the end of the apron and extending 20 ft along each bank. (See Fig. 3.7). Shifting the sloping sill further upstream again had the effect of bringing the hydraulic jump further up onto the apron. With regard to scour at the toes of the rip-rap banks, a distinct improvement was obtained in this test. As will be seen from Figure 3.7, no scour occurred in this position on the left bank, only 1 ft of scour occurred on the right bank and a small amount of material was carried back to the toe of the apron in the centre of the channel. It will be seen also that the scour within the "U" occurs close to the rip-rap, and it was considered desirable to try to limit the extent of this scour more to the centre of the channel. Further, it was thought that the stability of the concrete apron could be further ensured by increasing the height of the rectangular end sill so as to induce a more effective gound roller to carry material back against this sill.

An attempt to achieve the above two results was made in Test No. 8 by increasing the height of the rectangular sill to 1 ft 3 in. and replacing the three surmounting blocks by two, each 9 inches high, 9 ft long and located adjacent to the wing walls, thus leaving the centre portion of the sill clear. In addition, the sloping sill was moved still further upstream so that its vertical downstream face was located 15 ft from the end of the apron. This resulted in a further improvement with regard to scour. Within the "U" shaped blanket of rip-rap, the scour hole, with a maximum depth of just over 2 ft was confined to the centre of the channel with only small amounts of scour at the edge of the rip-rap. A considerable amount of sand was carried back to the toe of the apron in the central section. No scour occurred at the toe of the left bank, but at the right bank a hole of limited extent, and 1 ft. deep again formed. Results are shown graphically in Figure 3.8. The location of the hydraulic jump in this test was on the concrete apron between the two sills.

At this stage of the testing it was considered that the problem of scour in the vicinity of the energy dissipator had been substantially overcome and in Test No.9, the same arrangement of sills was used as in Test No.8 but three further modifications were made with a view to effecting minor improvements. These consisted of making the wing walls of the energy dissipator higher to eliminate the rip-rap banks above these walls, extending the rip-rap blanket a further 10 ft. along each bank, and smoothing the rip-rap banks at the extreme downstream end of the channel into the natural contour instead of finishing them off abruptly at a slope of 1:1. Modification of the wing walls was considered necessary because of the turbulence and wave action against the banks above these walls noted earlier in this section. Accordingly, the tops of the walls were carried out horizontally at R.L. 105 for a centre line distance of 19 ft and then brought down to the top of the blocks surmounting the sill at the end of the apron, a height of 2 ft above the apron. The object of extending the rip-rap along each bank was to attempt to eliminate the small amount of scour that was occurring against the right bank, while the modification to the downstream ends of the rip-rap banks was designed to stabilize these ends, where the 45° sand banks had collapsed in all previous tests.

Figure 3.9 shows the results of Test No.9. It will be seen that the depths and positions of the scour holes are similar to those of Test No.8 with similar deposition of material at the toe of the apron. Observation of the turbulence in the energy dissipator indicated that the tops of the wing walls could usefully be extended horizontally by a further foot, while the modifications at the extreme downstream ends of the banks had the desired effect of stabilizing these banks.

In order to check that the upstream sill in the energy dissipator was serving a useful purpose, Test No.10 was carried out with the same arrangement as in Test No.9 except that the upstream sloping sill was omitted. Results, illustrated in Figure 3.10, indicated a maximum depth of scour of 4 ft and this led to undue disturbance of the rip-rap protection along the toe of the right bank. It was concluded that the upstream sill on the apron does serve a useful purpose in preventing excessive scour.

Test No.11 was designed to compare the efficiency of an upstream sill with a transverse slope as used in previous tests with that of a uniform section sill in the same position. The sill used was of uniform triangular cross-section 2 ft high, with a base length of 2 ft and a vertical downstream face located 18 ft from the end of the apron. All other features were as in Test No.9. Although less material was carried back to the toe of the apron in this test, the scour hole at the toe of the right bank just downstream of the rip-rap blanket was completely eliminated and in the corresponding position on the left bank scour was negligible. These results are shown in Figure 3.11. Because of this improvement, and the simpler construction of the uniform section sill, this arrangement is considered preferable to the sloping sill. During this test the hydraulic jump formed on the apron and with the extension of the wing walls by one foot, the banks above the energy dissipator were adequately protected against turbulence and wave action.

It will be noted from the scour pattern in Figure 3.11, that the deep scour which occurred with the original design against the left bank just downstream of the concrete apron and at the toe of the downstream end of the rip-rap, has been eliminated.

The results of Test No.11 indicated that a satisfactory solution to the problem of scour at the design discharge of 600 cfs had been obtained. A series of tests was therefore run with the modified design, and discharges of 100, 200, 300, 400 and 500 cfs to check that no undesirable effects occurred at low flows. For discharges of 100 and 200 cfs, no scour occurred. At 300 cfs, perceptible sand movement occurred with a small amount of sand carried back onto the rip-rap at the toe of the apron, but no significant scour occurred. For discharges of 400 and 500 cfs, two scour holes 1 ft. deep were formed near the centre of the channel about 15 ft. downstream from the end of the apron and a considerable amount of material was carried back to the toe of the apron, but no undesirable effects were noted.

Scour immediately downstream of the concrete apron for the design discharge of 600 cfs and using the modification described in Test No.11 above is shown in photograph 3.12.

4. CONCLUSIONS AND RECOMMENDATIONS

Testing of the original design at the maximum design flood of 600 cfs revealed the likelihood of unsatisfactory asymmetrical flow in the discharge channel with excessive scour of the bed and undercutting of the rip-rap on the left bank near the outlet and also at the downstream end of this bank. Subsequent tests of a number of modifications to the original design have indicated that excessive scour at the toes of the banks can be eliminated, with only moderate scour near the centre of the channel by the following design modifications, which are illustrated in fig. 4.1:-

(a) Construction on the energy dissipator apron of a uniform sill of triangular cross section 2 feet high with a base length of 2 feet having a vertical downstream face located 18 ft. from the end of the apron.

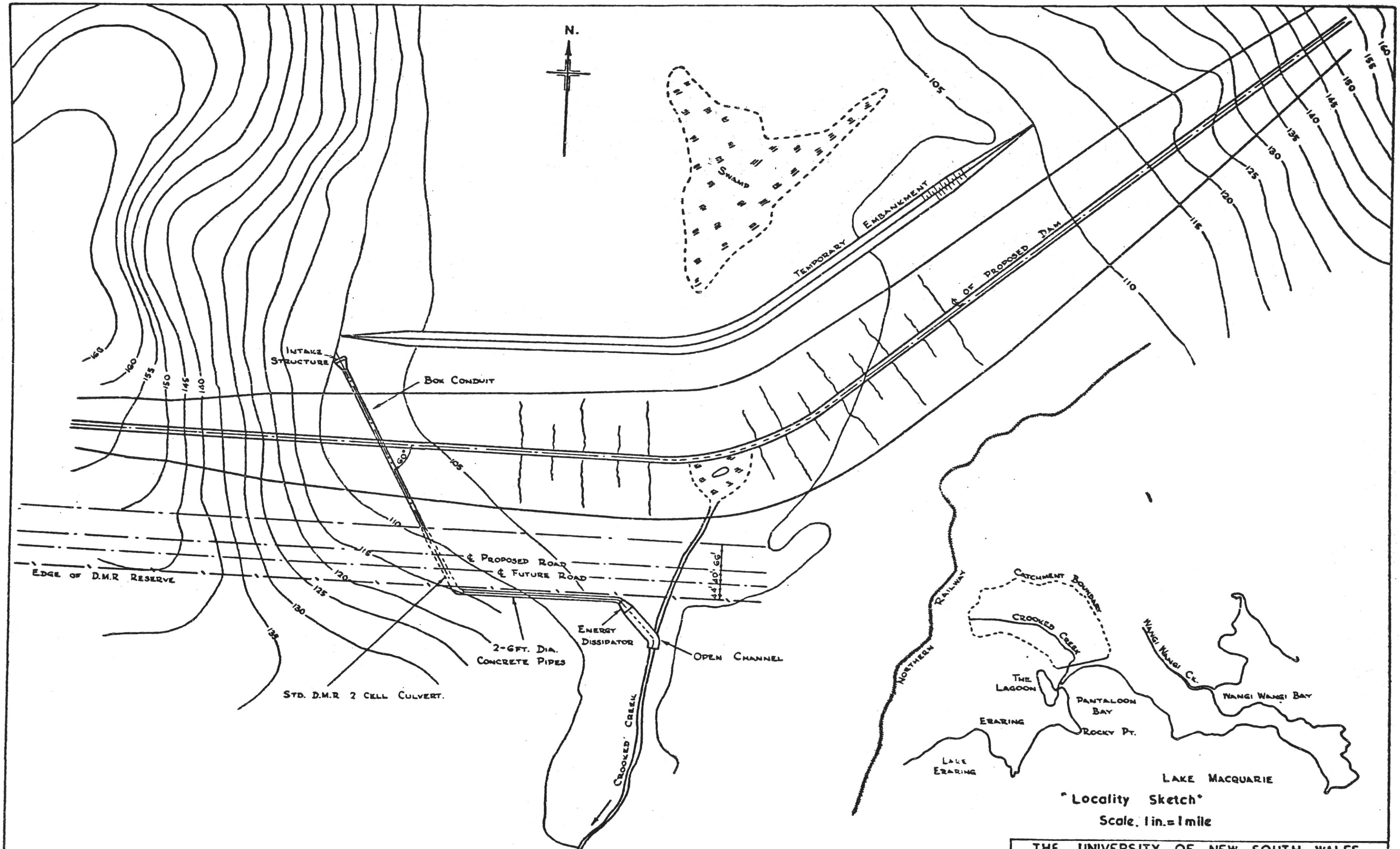
(b) Construction of a rectangular cross-section sill 1 ft 3 in. high and 2 ft wide surmounted by blocks 9 in. high extending 9 ft. from either bank at the end of the apron.

(c) Changing the shape of the rip-rap blanket downstream of the apron to form a 'U' 6 ft wide across the end of the apron and along each bank, and extending 30 ft along each bank.

(d) Smoothing the extreme downstream ends of the rip-rap banks into the natural contour before the rip-rap is finished off.

(c) Increasing the height of the wing walls of the energy dissipator by carrying them forward at a level of R.L. 105 for a centre line distance of 20 feet followed by a uniform decrease to a height of 2 ft at the end of the apron.

It is recommended that the above modifications be incorporated in the design. The tests indicate that they will produce satisfactory results at the design discharge, and create no undesirable effects at lower discharges.



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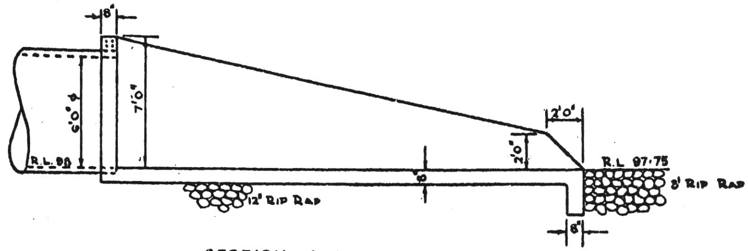
WANGI ASH POND OUTLET WORKS
GENERAL ARRANGEMENT

Electricity Commission of N.S.W. Project 1·4

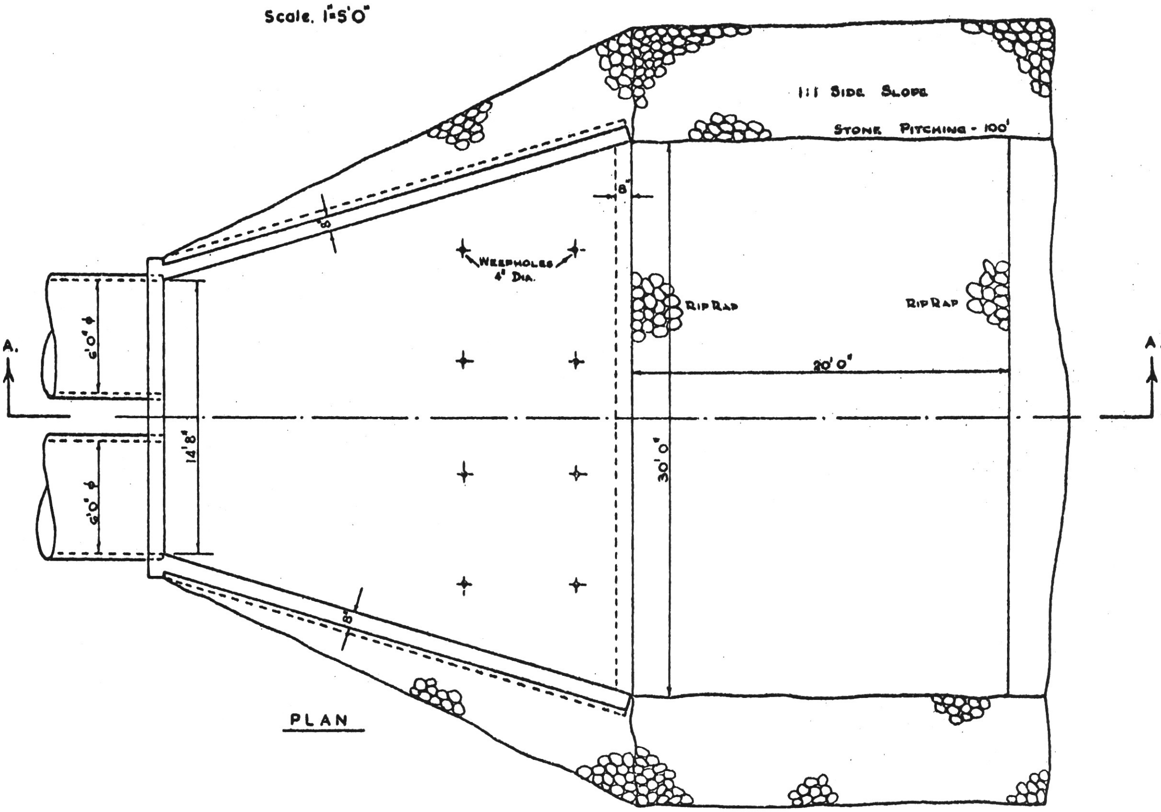
Drawn:	G. R.	CE - D - 626
Checked:	E. L.	

FIG. 1·1

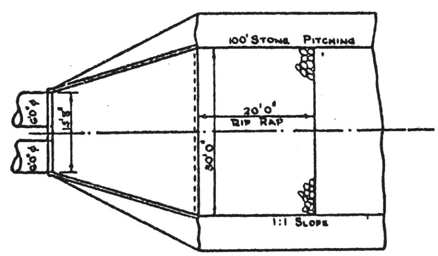


SECTION A-A

Scale. 1"=5'0"



PLAN



GENERAL PLAN

Scale. 1/16"=1'0"

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WANGI ASH POND OUTLET WORKS ORIGINAL DESIGN Electricity Commission of N.S.W. Project 1·4	
Drawn: G.R. Checked: E.L.	CE-D-625

FIG. 1·2

CROOKED CREEK
Approximate Cross Section Below Ash Pond
Looking Downstream

SCALE: HORIZ. - 10 ft. to 1 in.
VERT. - 5 ft. to 1 in.

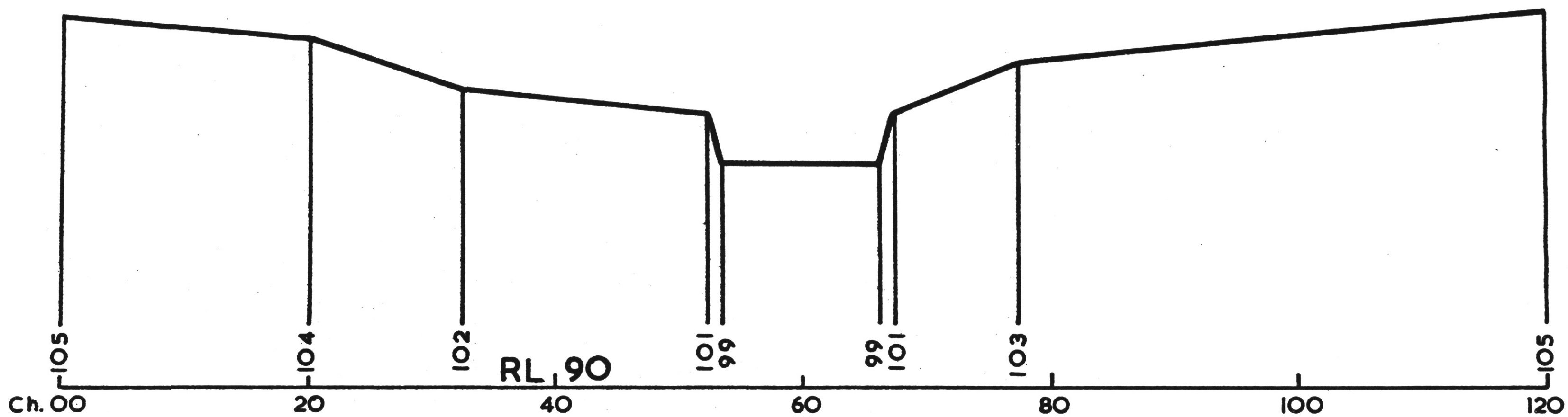


FIG. 1·3

FIG. 1·3.

WANGI ASH POND OUTLET MODEL

TEST RESULTS

Contours show scour depths in feet

FIG.3·1.

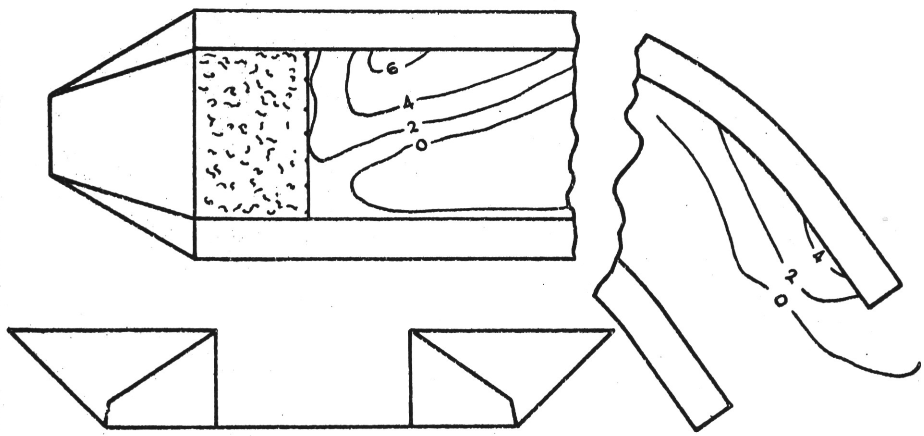
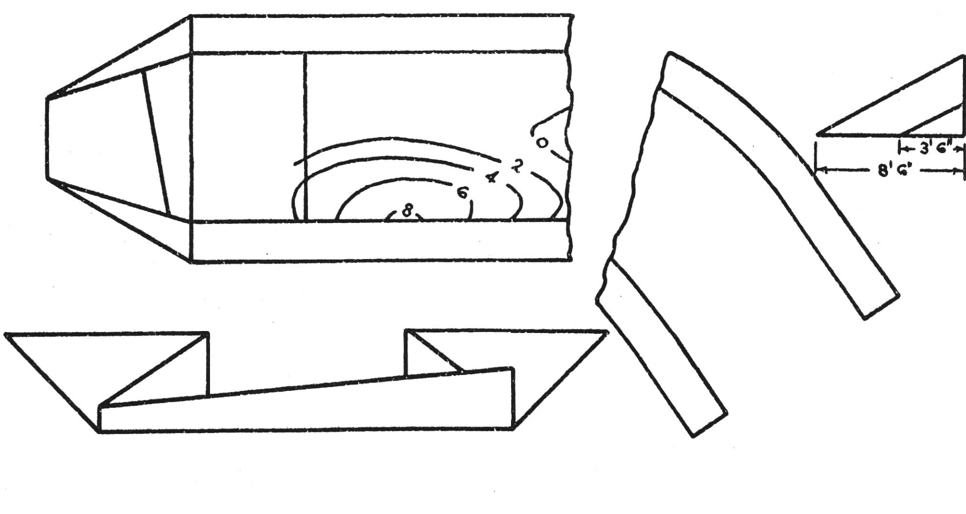


FIG.3·2.



WANGI ASH POND OUTLET MODEL

TEST RESULTS

Contours show scour depths in feet

FIG. 3·3.

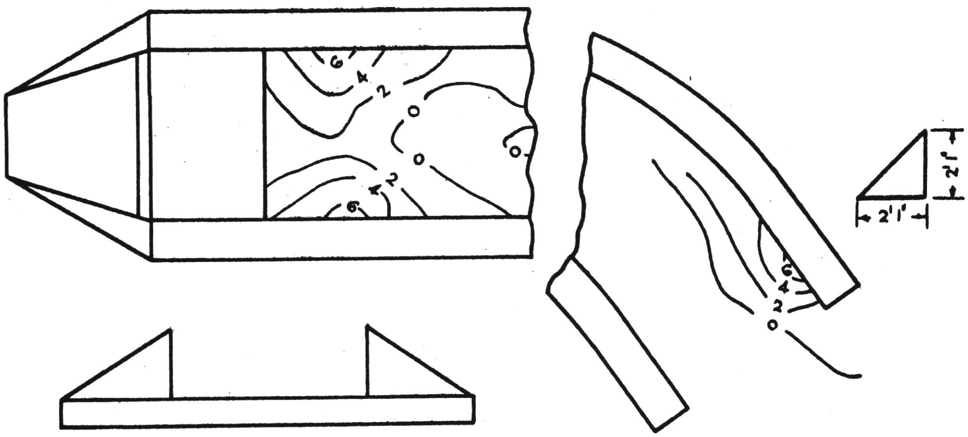
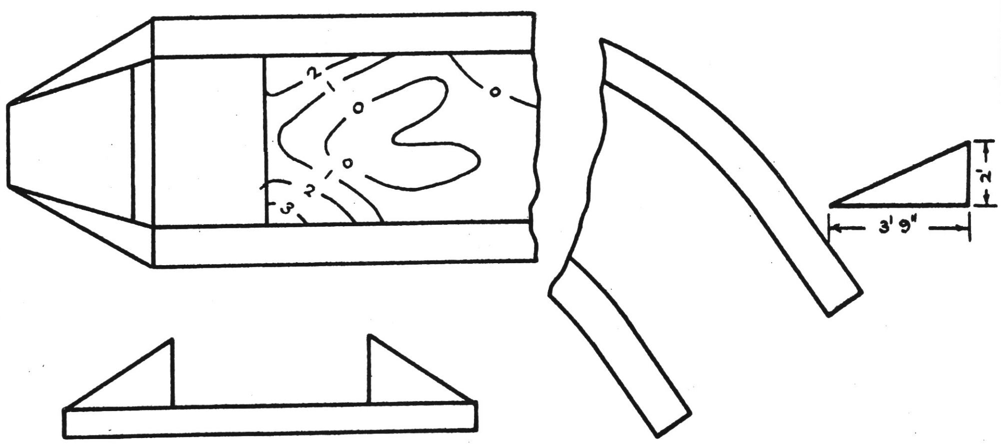


FIG 3·4.



WANGI ASH POND OUTLET MODEL

TEST RESULTS

Contours show scour depths in feet.

FIG 3·5.

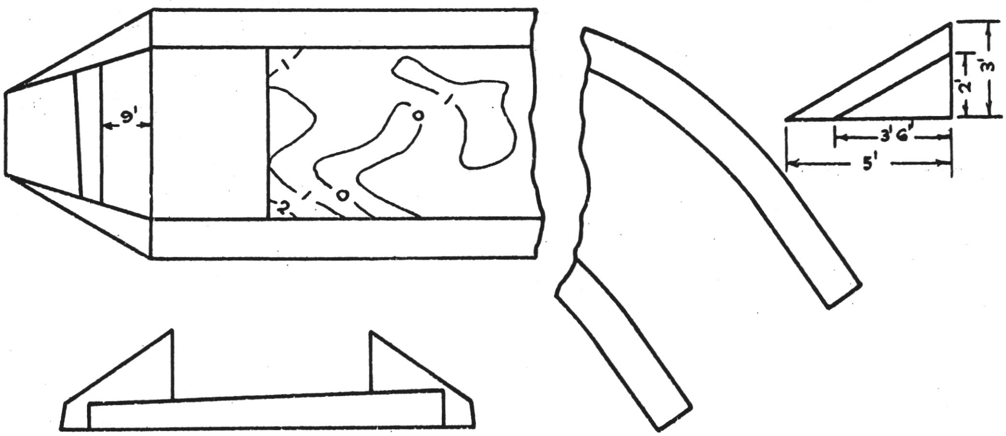
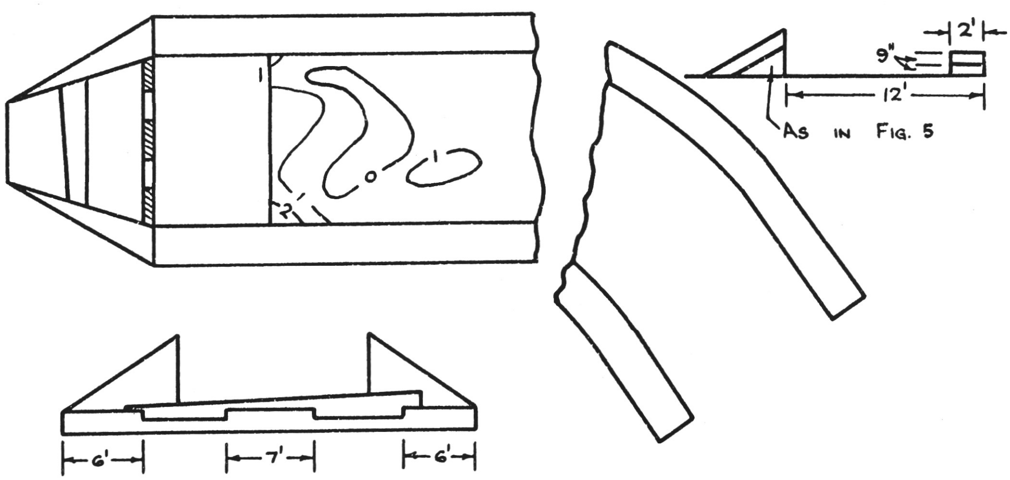


FIG.3·6.



FIGS. 3·5 & 3·6

WANGI ASH POND OUTLET MODEL

TEST RESULTS

Contours show scour depths in feet

FIG.3·7.

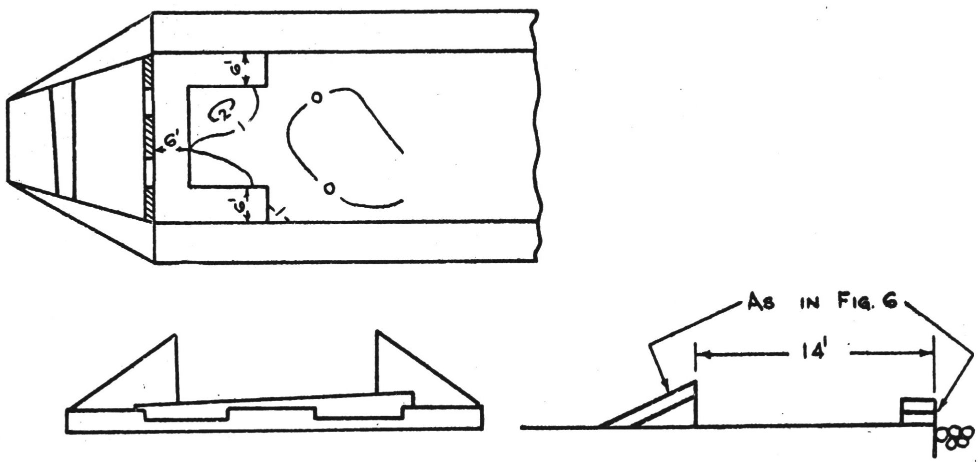
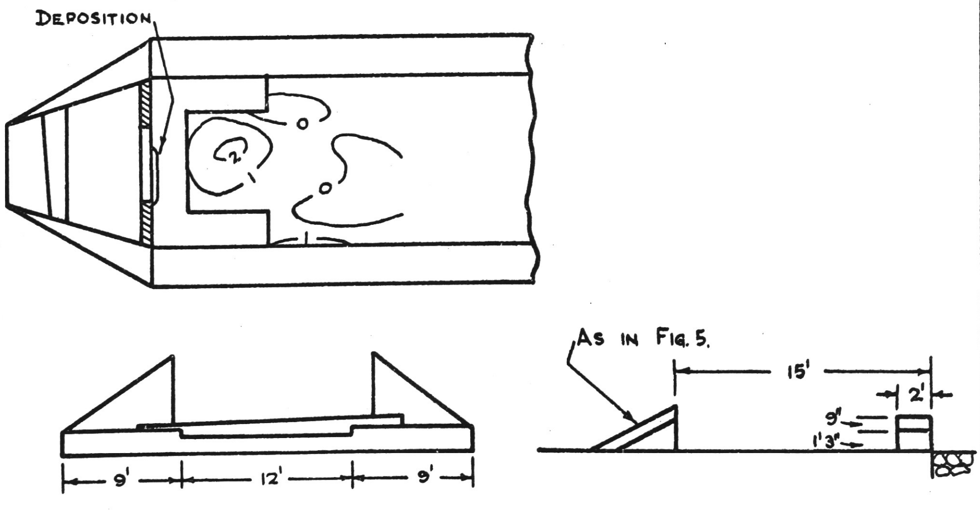


FIG.3·8.



WANGI ASH POND OUTLET MODEL

TEST RESULTS

Contours show scour depths in feet

FIG 3·9.

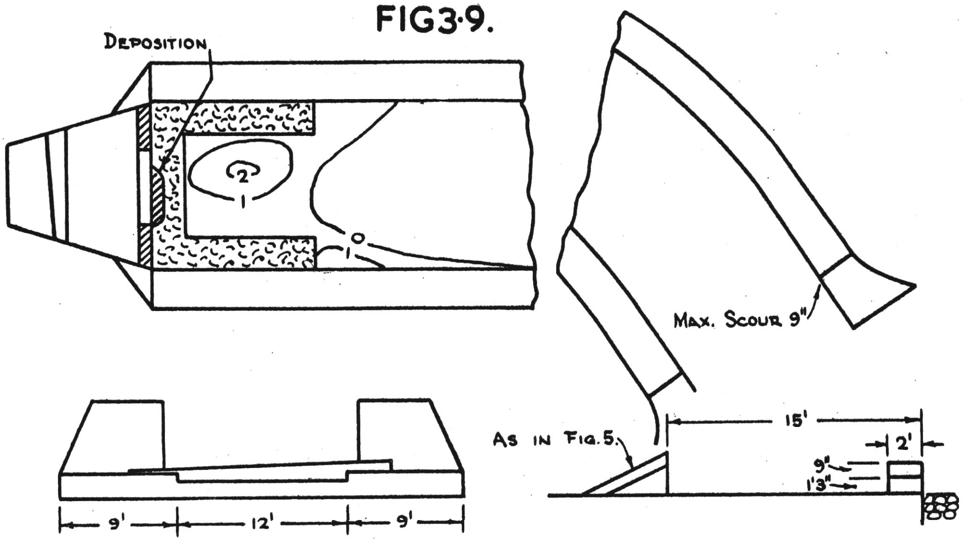
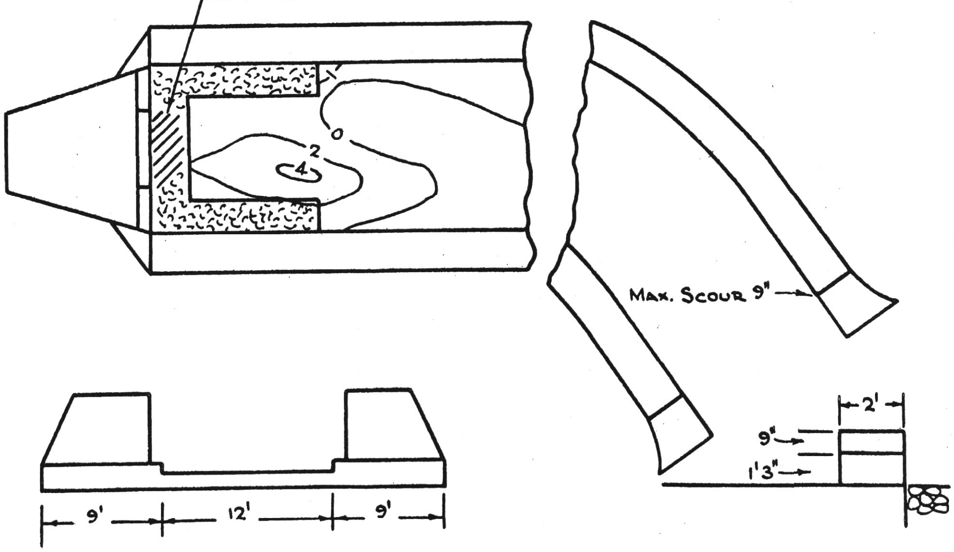


FIG. 3·10.



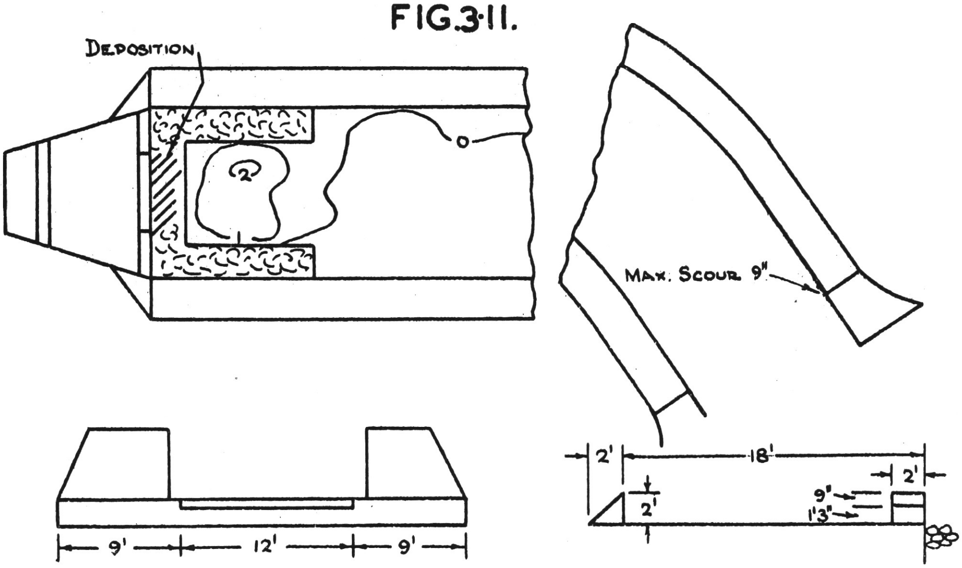
FIGS. 3·9 & 3·10

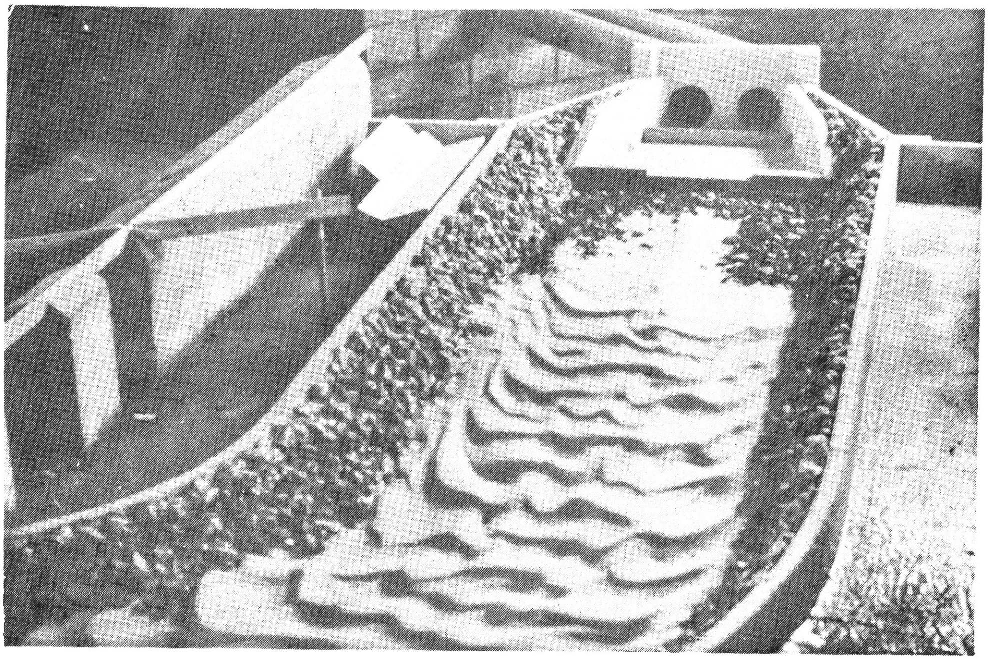
WANGI ASH POND OUTLET MODEL

TEST RESULTS

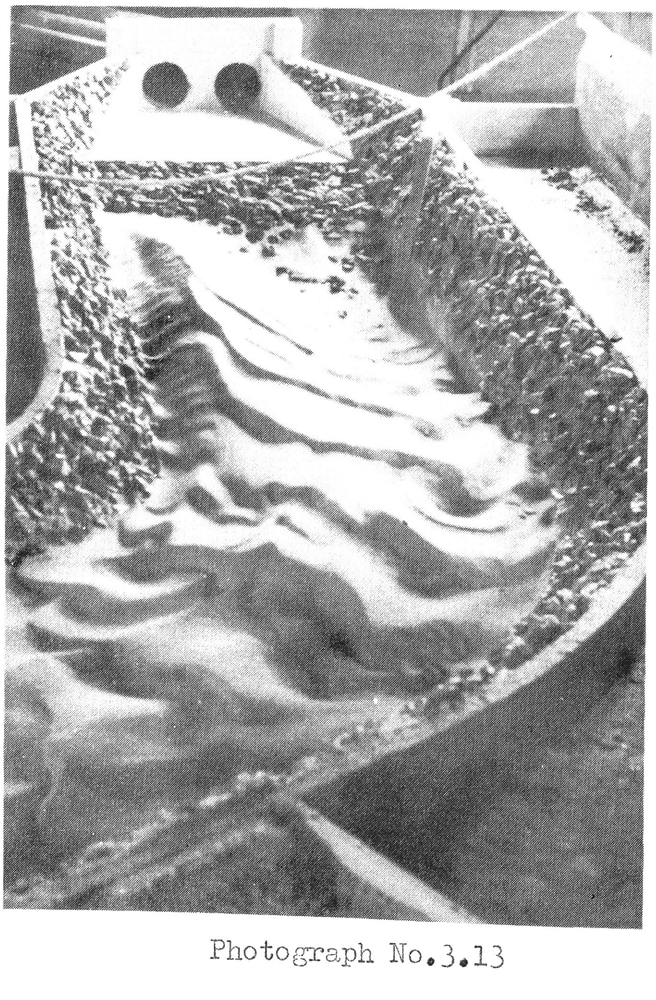
Contours show scour depths in feet

FIG.3·11.



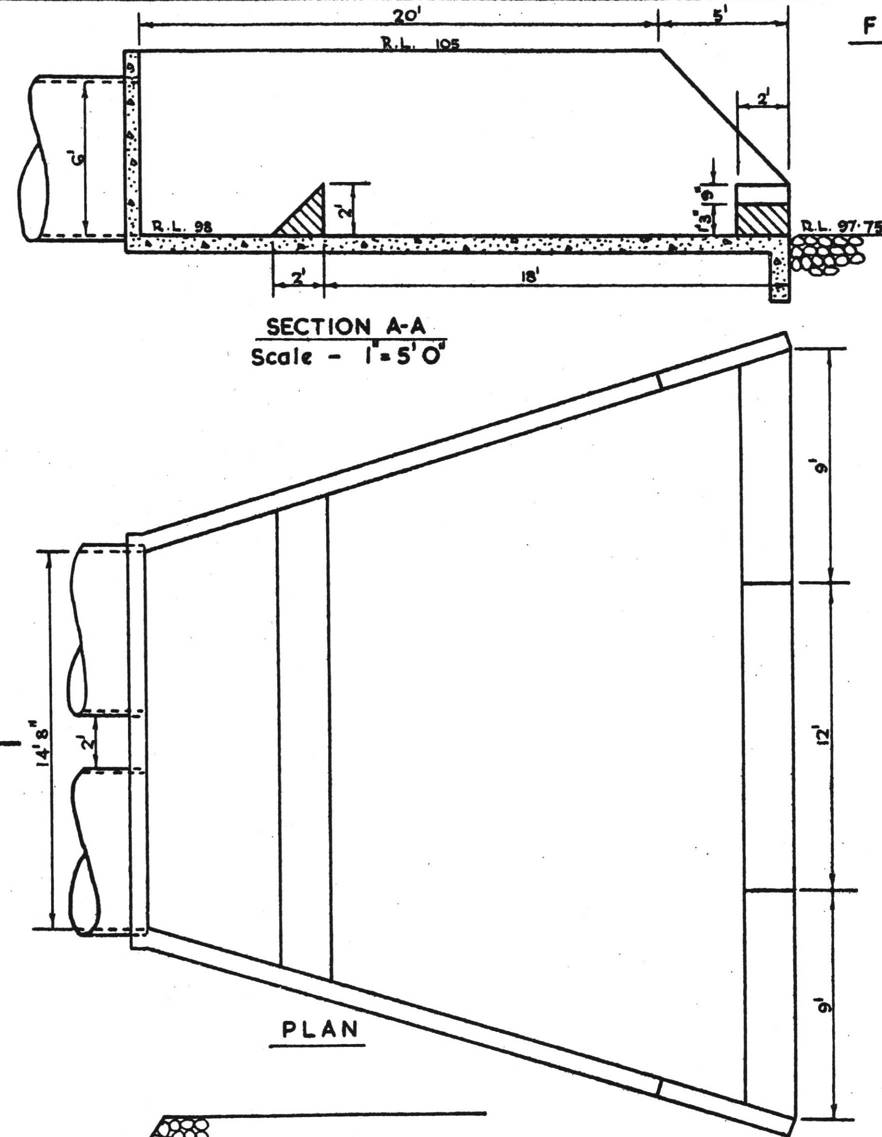


Photograph No. 3.12



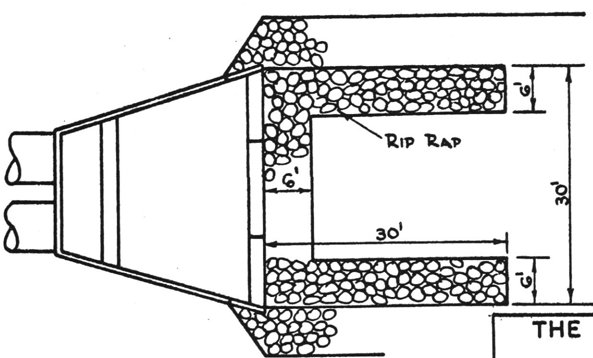
Photograph No.3.13

FIG. 12



SECTION A-A
Scale - 1" = 5' 0"

PLAN



GENERAL PLAN
Scale - 1/16" = 1' 0"

THE UNIVERSITY OF NEW SOUTH WALES Water Research Laboratory	
WANGI ASH POND OUTLET WORKS RECOMMENDED DESIGN MODIFICATIONS	
Electricity Commission of N.S.W. Project 1·4	
Drawn: E. Laurenson	CE-E-623
Checked:	

FIG. 4·1