THE UNIVERSITY OF NEW SOUTH WALES

water research laboratory

Manly Vale, N.S.W., Australia

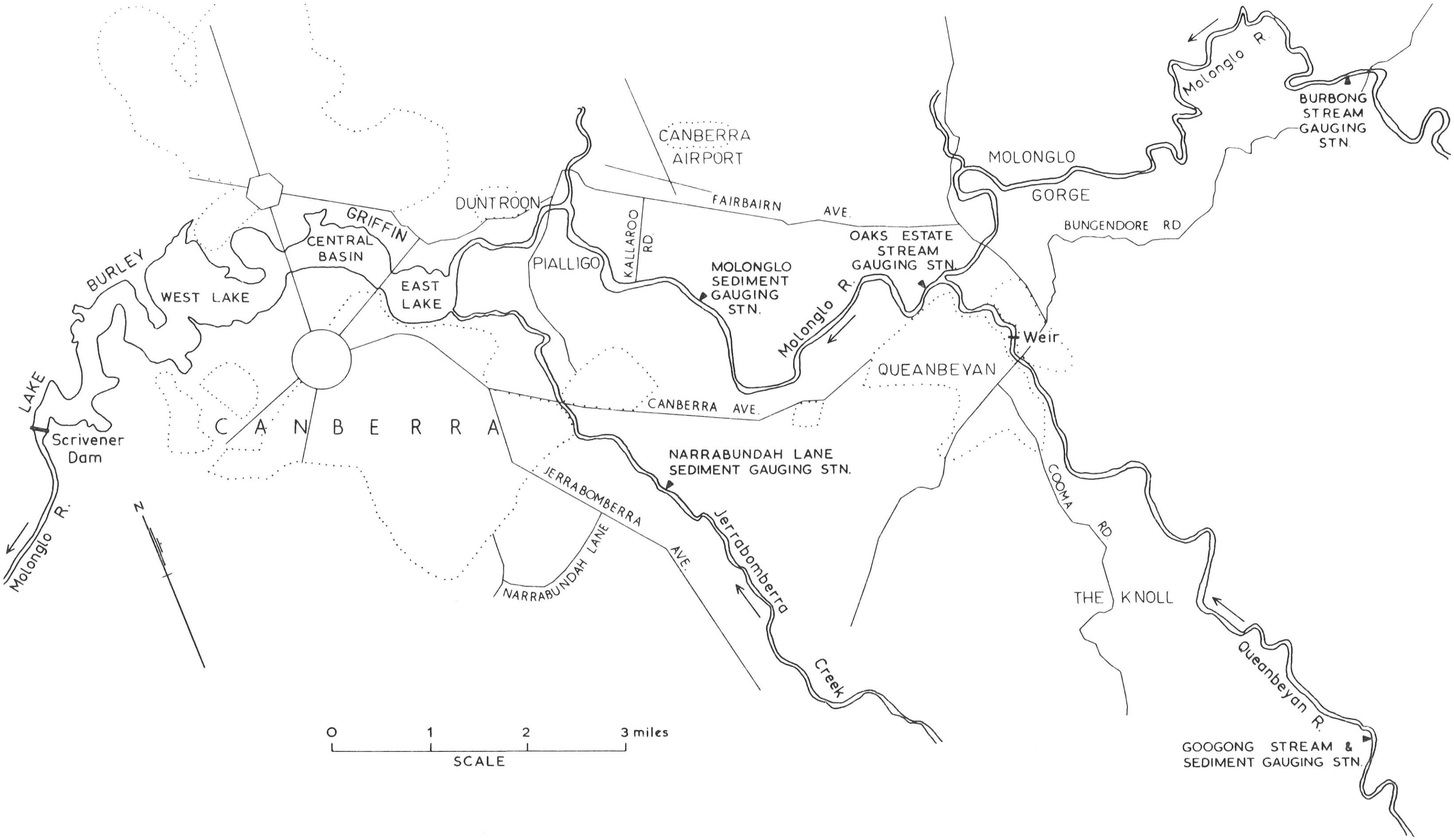
Report No. 97

SEDIMENT DEPOSITION IN LAKE BURLEY GRIFFIN, A.C.T

by

C.H. Munro and R.T. Hattersley

June, 1969



LOCALITY PLAN – LAKE BURLEY GRIFFIN & TRIBUTARY STREAMS

CE-D-7585

University of New South Wales
WATER RESEARCH LABORATORY.

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https://doi.org/10.4225/53/579819db839f1

Preface

Lake Burley Griffin was created by the raising of Scrivener Dam near Yarralumla on the Molonglo River. It constitutes a central feature in the planning of Canberra. The lake is fed by the Molonglo River, and its tributary streams, which are extremely variable in flood flow. They are capable of carrying large quantities of sediment. Data on the character of the sediment loads and the deposition zones are necessary for future planning of the environs of the lake.

This report was originally submitted to Maunsell and Partners, Consulting Engineers to the National Capital Development Commission, A.C.T. Publication of the report for issue to bona fide research workers is by kind permission of the Commission.

Summary

The sediment deposited in Lake Burley Griffin has been found to be silt ranging in size below 50 microns to material of the order of one or two microns. The material is carried by the Molonglo River in suspension and deposited in the lake, but in the East Basin, the amount of deposit is insignificant. In general terms, the material has spread throughout the whole of the bottom area of the lake initially. There are indications that the material tends to gravitate finally, through the agency of sub surface density currents and/ or liquid mud flows, to the deeper sections of the former channel of the Molonglo River. The greatest depth of deposition has been observed in the immediate vicinity of Scrivener Dam.

The percentage of water borne sediment carried by the river to the lake and actually deposited in the lake itself varies with the concentration of sediment in the inflowing river and the discharge-time characteristics of the flood flow. Existing flood data are limited to that obtained from small freshes in the river and one flood with a peak of about 21, 500 cusecs which occurred in November, 1966. Calculations based on data of the November flood showed that the proportion of river borne sediment settling in the lake in the flood was 82 percent. For smaller floods peaking at approximately 3000 cubic feet per second, the percentage is likely to increase to about 96 per cent.

It is concluded that, if over the next half century or more, the flood behaviour is similar to that of the past 50 years of record, then no serious reduction in depth of water at the dam, requiring dredging or other restorative action, will occur. In the shallow portions of the lake along the foreshores, only normal routine maintenance will be necessary.

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1. Introduction

Relative to the planning, improvement and maintenance of Lake Burley Griffin at Canberra, A. C. T. data are required on the nature of the sediment, the rate of inflow, and deposition patterns of the sediment which is brought to the lake by the Molonglo River and its tributaries.

Messrs. Maunsell and Partners of Melbourne and Canberra, Consulting Engineers to the National Capital Development Commission, by arrangement with Unisearch Ltd. (a Company associated with the University of New South Wales) have requested an investigation of all available data, and by both field examination and laboratory research, to extend the information contained in the data and to draw such conclusions as are possible to assist in formulating the engineering design works for improvement and maintenance in the lake. The lake, which was artificially formed by the raising of Scrivener Dam near Yarralumla, A. C. T., has been in existence insufficient time since it was initially filled in April 1964, for reliable measurements to be made of the depth of sediment deposition in various parts of the lake. Consequently, it is necessary to proceed by using information pertaining to the natural state of the river and records from a series of minor floods which occurred in 1964 and 1966. In November, 1966, in the week during which a survey of the bottom material was being conducted for this investigation a flood of 21, 500 cusecs peak approximately occurred which exceeded all others since the date of the initial filling of the dam. This flood, however, falls far short of the maximum design flood which is given as 200, 000 cubic feet per second.

In order to make up for the deficiency in flood-siltation data, it has been necessary to examine the history of the river which is contained in numerous earlier reports listed in the attached bibliography to this report supplied by courtesy of the National Capital Development Commission and the Commonwealth Department of Works. In addition, much data collected from gauging stations, turbidity and temperature measurements made in the lake by the Department of Works since it was filled and also earlier, have been utilised.

2. Collateral Investigation

This report is confined to matters of the actual sedimentation within the lake's boundaries which extend from the outlet of the

Molonglo River in the East Basin to Scrivener Dam at Yarralamula. Highly relevant to siltation in the lake is the question of bed load sediment carried to the lake through the river system but this has been considered separately in Part I of this report. The two parts are intended to be read jointly and for this reason reference to sedimentation in the river system is excluded in all its detail from this part.

3. Reference to Previous Investigators

Various investigators (Ref. 1 and 2) have attempted to determine by empirical processes the percentage of river borne sediment which would be deposited in dams and similar large artificial stilling basins. An expression of the percentage of the total amount of silt deposited in a reservoir or lake compared to the total quantity transported by the river system to the lake in a given period has been described as the trap efficiency.

Except where reservoirs are of simple geometry and inflows and sediment loadings are known in character and quantity reasonably well, the determination of a single figure for trap efficiency requires considerable qualification. Moreover the expression 'trap efficiency' does not give any indication as to where the deposited sediment would lie within the reservoir unless more is known concerning the properties of the sediment itself and the flow factors related to its transport.

The variables which are known to have significant influence on sediment trapping in reservoirs are summarised as follows:-

(1) The ratio of storage volume to inflow or the equivalent expression, average detention period.

(2) The sizes of sediment particles and proportion of sediment particle sizes present.

(3) The behaviour of the finer fractions such as agglomeration, flocculation etc.

(4) Reservoir geometry which includes such salient features as depth to width ratio, existence of old river channels and flood plains, bays and backwaters.

(5) Temperature differences.

(6) Reservoir release works, sluice ways and spillway designs.

(7) Upstream natural or artificial retention trap storages.

(8) Variations in contributions from tributary streams.

(9) Storage level or release procedures.

Of the variables listed above, numbers 1 to 4 inclusive have been found significant in respect of Lake Burley Griffin. Items 5 to 9 have only minor significance.

4. Description of the General Conditions Applicable to Lake Burley Griffin

The inflow of sediment to Lake Burley Griffin is predominantly suspended sediment which is transported from the upland areas of the catchments of the Queanbeyan and Molonglo Rivers. As yet, no significant amount of sand, which normally moves as bed load, has reached the lake although the Queanbeyan River contains large amounts of relatively coarse sand. The procedures adopted in examination of the factors affecting sedimentation in the lake are therefore patterned on the fact that the sediment deposited to date is very fine in grain size and is readily transported by the water flowing into the lake. Varying factors such as lake geometry, fineness of sediment and wide variation in stream flows make it virtually impossible to determine precisely an overall trap efficiency for Lake Burley Griffin without regard to the nature of the flows and purely local factors. Moreover because the problem relates to the question of the possibility of dredging in future years, it is highly relevant to determine for the lake those areas which are likely to receive the highest rates of deposition.

Taking into account the above factors, the form of investigation into suspended sediment has taken two distinct phases:

<u>Phase 1:</u> Investigation of the nature and distribution of the material already deposited on the bottom of the lake since it was first filled with particular reference to the size grading and nature of the material and the locality in which it was found.

<u>Phase 2:</u> Consequent upon the incidence of flood during the period 9th November to 2/3rd December 1966, additional data were obtained which enabled the investigation to be extended to the question of

response of the reservoir to inflow of sediment. Some measurements were obtained by the Commonwealth Department of Works of suspended sediment concentrations and flows at closely spaced intervals of time. This information was of a kind distinct from previously collected information and has enabled valuable inferences to be drawn as to the average detention period of the lake under flood conditions. Unfortunately, the same limitation applies to these data as to previous data on sediment concentrations and streamflow, namely, they are relevant to a flood of moderate size. Extrapolation of these data to floods approximating the maximum design flood remains speculative.

5. Procedures adopted under Phase 1:

5.1 Objective

The objective under this phase is to obtain samples of the material from the bottom of the lake, to identify the origin of this material and as far as possible estimate significant deposition in the several areas of the lake.

5.2 Technique of Sampling

For this purpose three types of sampling apparatus were used. The details of two of these are illustrated in Appendix 2 to this report. The first type of apparatus was known as a "torpedo" sampler and was used where possible to penetrate the bottom. Upon penetration of the bottom a sample of the material is retained within the tube capsule attached to the head of the torpedo. The capsule is returned to the laboratory where the sample is extracted. The samples obtained in this way extend from an inch or two up to 5 inches according to the bottom conditions. When extracted in the laboratory, tube samples under favourable conditions show a stratification of the bottom layers to the extent of penetration of the instrument and for this reason the samples might be called "undisturbed" bottom samples. In this report, tube samples are designated by numbers commencing 2 upwards. Where zero appears in the report, attempts were made to secure a sample but were unsuccessful after several attempts because the bottom was too hard to alternatively it was covered with "liquid" mud not capable of retention in the capsule.

Also, grab samples were obtained with an automatic closing clam type of grab capable of retaining a pound or two of deposit after penetration of a depth of about 2". The samples obtained were of sufficient size to set up test mixtures with water for standard limit hydrometer size analysis. Samples obtained by grab are illustrated in this report under reference commencing A proceeding through the alphabet to AA, FF etc.

A limited number of bottled suspended sediment samples were obtained by using a small electric pump and siphon tubing. Details of the tube samples are contained in Appendix I in which the results of microscopic examination of the samples are also tabulated. Results of the sampling programme with the grab sampler are shown in Appendix III.

The positions of the sampling points within the lake are shown on Drawing No. C-E-6858 attached to Appendix I.

5.3 Echo Soundings

This report also contains the results of echo sounding traverses taken in the lake at selected sections before and during the flood which occurred in the week ending 12th November 1966. Echo sounding equipment was used primarily to determine the sampling points on the bed of the lake during the survey. Where feasible, traverses were made for comparison with previous surveys which included echo soundings taken by the Commonwealth Department of Works in 1964 and more recently in February 1966. The accuracy of the echo sounder is of the order of 6" in depth but the horizontal traverse is subject to errors arising from the difficulty of navigating a small boat bearing the sounding apparatus, the speed of which relative to the bottom is affected by wind and current. Echo soundings are not deemed to be conclusive but are to be considered together with the evidence obtained from sediment samples. The accuracy of echo sounding apparatus was checked in the field at appropriate intervals by lead line soundings. During the incidence of the flood when much soft mud covered the bottom of parts of the lake lead line soundings were found in error due to the very soft nature of the deposited mud in which the lead sounding plates sank and due to the effect of the strong current on the lead line. In such cases, for example, soundings taken under Commonwealth Avenue Bridge during the flood, the echo soundings are more reliable.

6. Results of Bottom Sampling

6.1 Tube Samples

The bottom of the lake is comparatively irregular and the holes and banks of the original bottom have not yet been blanketed by silt deposition. Examination of the tube samples showed that prior to the flood in November 1966, there was little evidence of marked deposition of silt in Lake Burley Griffin except in the vicinity of Scrivener Dam where depths of deposition up to 2 feet were measurable by echo sounder. A slight overlay of very fine silt showed in torpedo samples taken elsewhere in the lake varying from a thin film to 1 or 2 inches. Those torpedo samples taken on the former flood plain of the Molonglo in the East Basin between the Molonglo River outlet and Kings Avenue Bridge showed very slight accretion, if any, of silt and gave more often than not the original earth bottom where blades of grass and other significant elements showed in the samples. Consistently, samples of chocolate silt were found in the former river channel of the Molonglo beneath the lake waters. It is of interest to note that this channel forms the lowest portion of the lake floor. The silt which is in liquid suspension during the deposition phase tends to gravitate as a density current to the lower channel depths. Because freshly deposited silt is chocolate brown in colour, it is distinguished readily from original bed material which is mostly light brown, frequently occurring with granules of decomposed rock. Examination of silt samples by macroscopic examination, touch and microscopic examination, confirmed the nature, composition and origin of the sampled materials. The results of these examinations are given in Appendix I. The distribution of chocolate silt which consistently occurred along the deeper section of the river channel showed on analysis to be predominantly material finer than 50 microns, much of it less than 20 microns. An explanation for the tendency of such material to collect in the lowest point of the lake is thereby found because it has been shown (Ref. 3) that density currents will readily persist with particles in suspension up to 20 microns.

6.2 Hydrometer Analysis of Bottom Sediment

Results of the hydrometer analysis of the bottom sediment are shown in Appendix III. In the table the size shown of the maximum particle is obtained from a cut of the maximum size distribution on the 100 pc. line. Consequently this is an extreme value statistic with such a particle (not necessarily existing in the sample). Sample size analyses are arranged in Appendix 3, generally in order of progression from the upstream end of Lake Burley Griffin to the downstream end of Scrivener Dam. The positions of the sampling points are shown in Appendix II, Figure A. All samples show zero percentage for particles greater than 1000 microns, practically none for particles of 500 microns and the majority of samples show greatest percentage for particles below 50 microns. Those samples which have coarser particles on examination, will be found to be either of the original soil forming the banks of the lake e.g. at R, V, H, F, G, W. Also sample FF was taken at the confluence of the East Basin and the Molonglo River during the recession of the flood on 12th November. This sample which unfortunately was an isolated one, showed some particles of the order of 300 microns but a general absence of particles coarser than this is significant since coarser particles are the characteristic constituents of bed load.

Silt samples taken from the old river channel marked with an asterisk in the table of Appendix 3 show only minor variations in particle composition. A point noteworthy is the increase in grit content of samples X, Y and Z at the bottom of the channel of Scrivener Dam. It is thought that the presence of grit in these samples is rather the result of wash from the adjacent river banks which are of decomposed granitic material and relatively steep, rather than material which has been carried through the length of the lake. Sample V which was taken upstream just inside the boom remote from the steep banks does not contain as much grit as X, Y or Z.

6.3 Suspended Sediment at Outflow

Suspended sediment samples taken by the University staff at Scrivener Dam and separated by use of "Millipore" filters in the laboratory were microscopically examined and found to contain no particles coarser than about 10 microns, although particles of 20 microns were found in the lower suspended samples taken at Scrivener Dam prior to the flood. Microscopic examination of filtered sediment samples taken in the East Basin between Kings Avenue Bridge and Commonwealth Avenue Bridge showed that the maximum particle sizes to be about 20 microns for samples taken near the bottom ranging to 10 microns for samples taken within 10 feet of the surface. These samples were taken during the recession of the flood and the particle sizes present were confirmed by data supplied by the Commonwealth Department of Works.

6.4 Results of Echo Soundings

Results of echo soundings are given in Drawings Nos. CE-E-6893, 6894, 6895, 6896, 6874, 6875, 6897, 6898, 6901. In the case of Section 9 which is to be compared with previous survey cross section and an echo sounding completed by the Department of Works in 1964 and bearing in mind the obviously irregular nature of the bottom of the East Basin, as shown in the profiles, there is no conclusive evidence that accretion has occurred in this region. A further comparison of the cross sections at Kings Avenue Bridge (Drawings CE-D-6895 and CE-D-6894) shows what appears to be substantial accretion of silt beneath the bridge spans. This was proved by lead line soundings and was found to be soft mud as were also deposits sounded at Commonwealth Avenue Bridge shown on cross sections Drawing Numbers 6874 and 6875 attached to this report. The cross sections at Commonwealth Avenue Bridge were subsequently re-sounded by the Commonwealth Department of Works and it was found that except for a slight accretion near the northern bank (chainage 282) most of the deposition recorded in the flood recession has dispersed. Depositions amounting to about 2 feet were noted to have occurred at sections 19, 20, 21 at Scrivener Dam prior to the flood. Most of the silt appears to deposit on the lake bottom downstream of Commonwealth Avenue Bridge.

6.5 General Observations of Bottom Survey

The programme of bottom sampling has clearly shown that the predominant elements of the deposited silt in the lake are particles or brown silt generally finer than 50 microns, the greater part being finer than 20 microns. This material is spread thinly but extensively through the whole of the lake but predominantly in the lower sections of the old river channel. At Scrivener Dam a depth of the general order of 1'0" with a maximum depth of 2'0" in some places was measured. This fine material falls within the classification which others have observed to form stable density currents and it is most likely that such material will readily gravitate as a density current during the active stages of flood flow in the lake. During quiescent stages when the river flow is reduced, this material will tend to settle on the bottom of the lake, deliquefy, and in the sections deeper than 10 ft. where it is not subject to wave action, it will consolidate. Even if the highest of expected floods occurred e.g. 200,000 cusecs, model results (Ref. 5) by the Department of Works, would indicate that velocities on the lake bottom during flood are unlikely to reach high enough values to scour this silt once deposited except in the narrowest sections. In the more shallow sections of the lake, particularly in the vicinity of exposed shorelines, wave action, under the influence of strong breezes, will result in resuspension of the fine material causing redistribution from the shore lines to the deeper sections of the channel. In more sheltered regions, some of the material is likely to remain as mud deposit.

7. Sedimentation During the Flood of 9th November - 12th November and Comparison with Past Records

During the flood, measurements were made by the Commonwealth Department of Works of suspended sediment concentrations at various parts of the lake and these have been considered in conjunction with suspended sediment concentrations measured in previous years commencing 1964.

Information about the suspended sediment capacity of the Molonglo River measured principally at Corkshill's Weir and other gauging stations in the Molonglo and Queanbeyan system has been presented by the Commonwealth Department of Works in a report to the National Capital Development Commission dated May 1961, and Figure 5 attached hereto is reproduced from the Appendix to that report. It will be noted that no data exist for flows exceeding about 20,000 cusecs. The calculated suspended load estimated from the November 1966 flood has been added to the C.D.W. graph in Fig. 5, and it will be observed that these provide four points, corresponding approximately to 4.2×10^4 tons per day of suspended sediment, which is 50 pc. less than shown by the line of the graph. This does not mean that the line is in error, because the number of points available to trace the line is very sparse. For example, reference to the paper by Leopold and Maddock (Ref. 7) shows a similar plot for the Powder River, U.S.A. (reproduced in Fig. 6) which is based on a very large number of samples. These points show a very wide scatter. Nevertheless, the straight line relationship appears to be established on a double logarithmic plot. The possible reason for the wide scatter on such a plot as the Powder River plot or the Molonglo River plot is the absence of indications as to whether the suspended sediment load ratings are determined on a rising or a receding flood, and also the condition of the catchment prior to storm rainfalls.

7.1 Trap Efficiency

The curves for sediment rating of the river can only be applied to calculate deposition if the sediment trapping efficiency of the lake is known. The data obtained in the flood of November 1966 has enabled valuable information to be derived for the actual deposition of sediment during the flood and the trap efficiency corresponding thereto. The method of calculating this is described hereunder.

7. 2 Behaviour of Suspended Sediment in the Lake

The evidence given in the previous section of this report and the additional evidence of suspended sediment samples taken by the Works Department show that in general the flow in Canberra Lakes during flood is fairly well mixed although there is evidence of mud movement as described in Section 6. 4 under "Echo Soundings". Turbidity samples taken in depth both at Scrivener Dam and higher up the lake show no evidence of distinct stratification and this may be in part the result of the general geometry of the lake bottom and side boundaries at the point where the river flows over the lake bottom to enter the East Basin. At this point it is spread to the surface by a submerged bank formed at the end of the old river channel. Here the continuous flow of bottom density current tends to be broken up. This may be the reason for the non-appearance of a density current of the form noted by Bell (Ref. 2). In the absence of subsurface density flow under definable conditions of stratification, the location of the sediment as despatched through the lake must be inferred from the bottom samples and surface samples as described in Section 5. The total amount of sediment dropped in the lake may be inferred by measurement of turbidity at the inlet to the lake and at the outlet of the lake close to the sluices or the overfall. If the readings are spaced in time so that one is able to identify a change in sediment content of the water between inflow and outflow, a 'lag time' or detention period can be defined. Adopting such a method as this, it is possible to calculate the trap efficiency for various stages of a flood, during the time of which the necessary measurements have been taken. The information obtained from the November 1966 flood is suitable for an estimate to be made of trap efficiency. The theory of the process of estimating the response time of the lake for an input of sediment in the East Basin to appear at the exit of Scrivener Dam is given in Appendix IV. For the November flood, the time lag between the arrival of the peak sediment concentration at the East Basin or near the point of measurement has been estimated with respect to the arrival of similar peak concentration of sediment in the vicinity of Scrivener Dam (See Fig. 1).

In the case of Lake Burley Griffin, the level of the water at the spillway is controlled more or less on a fixed value of RL. 1825.0 and for a flood of the order of 20,000 cusecs peak the rise in the backwater surface produces negligible increase in channel depth throughout the length of the reservoir. The reservoir therefore becomes a channel of irregular cross section but not of cross section varying with flood discharge. A computation is possible to show that for such a reservoir, neglecting minor variations in velocity distributions, a constant volume of water which passes from the entrance to the exit of the lake in a time which might be given the attribute of a detention time. The details of this method are set out in symbolic form in Appendix IV.

7.3 Trap Efficiency and Deposition in Flood of 9th November 1967.

From the hydrograph of the flood of November 1966, a mass curve has been drawn (Fig. 2). This enables a graphical comparison to be made of the lag times for sediment transfer associated with various stages of the flood. By considering the sediment concentrations at inflow and sediment concentration at a later time equal to the lag time from the date of sediment inflow, the trap efficiency relating to the average flow over the detention period can be computed. Trap efficiency is then shown as a function of time as shown in Fig. 3. Integration of trap efficiency, sediment concentration, discharge, with increments of time gives an estimate of sediment deposited in the reservoir during the flood. This may be compared with the suspended load of the river entering the lake during the same period.

This process was applied to the first nine days of the November flood, the period over which effective records were kept of turbidity.

The calculations resulted in an average trap efficiency of 82 pc. with an average inflow of 4606 cubic feet per second. These values agree reasonably with a curve for trap efficiency calculated by Maunsell and Partners using Camp's Theory (Ref. 4).

The daily inflow of sediment to the lake was 4755 tons which plots close to the sediment rating line (Figure 5). The average daily deposition of sediment was calculated to be 3910 tons and the total for nine days, 35,200 tons.

For floods of smaller average discharge trap efficiency is expected to rise to a maximum of 96 pc. corresponding to an average discharge of about 2,000 cu. ft. per second.

A plot of trap efficiencies for successive days of the flood in Nov. 1966 is shown in Fig. 3. It is to be noted that trap efficiencies are related to average discharges and in the plot of Fig. 3 above the average discharges are determined from the lag period which corresponds to the "control volume" defined in Appendix IV. The trap efficiencies calculated in this way are not directly applicable to the inflows to the lake as recorded at the gauging stations. A more extensive study of the available stream flow records and a study of the correlation of the existing sediment concentration readings with stream flows is required to extend the relationship with trap efficiency to gauged flood discharge generally.

7. 4 Recommended Scheme for Data Collection in Future

Much of the suspended sediment data collected since the lake was filled has been gathered more or less at fixed intervals of time, generally speaking at about weekly intervals. The method of measuring the turbidities has been by turbidimeter (Jackson Candle), although some of the readings as in the recent flood in November were obtained by weighing.

For the purpose of deriving sediment deposition in the lake much of the collected data are unusable. Because of the poor correlation between Jackson Candle Units and parts per million by weight above about 300 parts per million, the Jackson Candle equipment gives unusable readings in the range of above 300 ppm to 2000 ppm, the range in which most of the deposition occurs in the lake.

Readings taken weekly are not suitable for computing deposition because the intervals of time are too great to trace turbidity variation continuously with time.

Data which are collected for evaluating deposition in the lake needs to be collected at the time of occurrence of a flood at sufficiently small intervals of time to enable the variations of water inflow and outflow to the lake to be plotted as a continuous line. Readings of turbidity at inflow and outflow should also be obtained at similar close intervals of time.

The recommended time intervals are set down below in tabular form.

Data Collection for Sediment Deposition

Item of Data	Period	Time of Cessation of Readings	Remarks
Stream flow at inflow viz. Oaks Estate gauging station.	Hourly during flood, daily in developed recession.	When flow at inflow drops to 100 cusecs.	
Streamflow at outlet Scrivener Dam	Hourly during flood, daily in recession. Record of sluice and overfall recorded separately.	When flow at outlet drops to 100 cusecs.	
Turbidity at Oaks Estate Gauging Station.	Four hourly in rise and fall of flood. Daily in recession.	When flow at gauge drops to 100 cfs or if a fresh occurs in the river.	
Turbidity at King's Ave. Bridge.	Eight hourly in rise and fall of flood. Daily in recession.	When flow at inlet = 100 cfs or if a fresh occurs in the river.	
Turbidity at Scrivener Dam.	Four hourly in rise and fall of flood. Daily in recession.	Continue till turbidity falls to approx. 20 ppm.	Turbidity read at depths 1'0" and 10' and 50' from surface.

It is anticipated that data collected in the above pattern would enable programmed computation to yield the tonnage of silt deposited in future floods.

It is emphasised that the pattern outlined above is not intended to supersede regular readings collected for other purposes. To calculate deposition of sediment brought down by floods, the above pattern of data collection or its equivalent is necessary. A record of deposition and flood flows properly established will enable engineering works required for the maintenance of the lake to be planned well in advance of the need to execute them.

8. Conclusions

8.1 Percentage of Sediment Deposited - Lake Burley Griffin

The percentage of the total load of suspended sediment brought to Lake Burley Griffin by the Molonglo River and its tributaries is found to be 82 pc. for the flood of November 1966 which reached an estimated peak of 21,500 cubic feet per second. For smaller floods the percentage is estimated to rise as high as 96 percent.

For floods in excess of 21,500 cfs peak, the percentage of deposited sediment will be less but insufficient data exist to predict the percentage of deposition for large floods of the order of magnitude of the design flood 200,000 cfs.

For normal flows of up to 500 cusecs, which is the long period condition of the river, practically no sediment is deposited.

8.2 Quantity of Sediment Deposited in Flood of November 1966.

The quantity of sediment deposited by the flood of November 1966 was approximately 35,000 tons of fine silt, in a period of nine days.

8.3 Distribution of Deposited Sediment in the Lake

Sediment deposits in the lake since the time of filling are spread throughout the length of the lake. Depth of deposition in shallow areas of the lake is negligible. Concentrations of deposited sediment appear in deep water at the bottom of the former Molonglo River channel giving rise to the suggestion that by the action of density currents and wave action the deep sections of the lake will form the reception points for most of the deposited silt.

The lake is deepest at Scrivener Dam where depositions up to 2 feet have occurred in the tapering narrow submerged valley since the lake was filled in April 1964. The effect of an extremely large flood of say 200,000 cfs is unknown. Undoubtedly the percentage of the total sediment carried by the river and deposited in the lake will be less than in the flood of November 1966, but the weight of sediment deposited depends also on the duration of such a flood which is unknown. Allowing for an increasing width of surface deposit as the sediment rises in level in future years, no serious reduction in depth of water at the dam requiring dredging or other restorative action is likely within the next half century or so if floods of average magnitude occur, as recorded in the existing 50 year records.

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Appendix I

Tube Samples - Lake Burley Griffin.

Sample No.	a Length	a Description	b Length	b Description	c Length	c Description
2	3/4"	Coarse gritty silt				
3	1"	Choc. mud and sand	$\frac{1}{2}$"	Hard black soil		
4	2"	Gritty pebbles sand medium with mud				
5	$\frac{1}{2}$"	Liquid choc. mud	2"	Sand clay	3/4"	Clay
6	$2\frac{1}{2}$"	Light brown mud	2"	Choc. mud and sand	1"	Choc. mud gritty sand medium
7	2"	Choc. mud				
8	2"	Brown mud with grit				
9	$2\frac{1}{2}$"	Dark mud with grit				
10	2"	Dark mud				
11	1"	Choc. silt				
12	1"	Firm choc. silt				
13	$1\frac{1}{2}$"	Gritty loam with grass				
14	2"	Silt with organic material. Liquid silt on top.				

Appendix I

Tube Samples - Lake Burley Griffin

Sample No.	a		b		c	
	Length	Description	Length	Description	Length	Description
15	$1\frac{1}{2}$"	Sticky soil with clay				
16	1"	Light brown clay				
17	1"	Red brown clay with gravel				
18	$1\frac{1}{2}$"	Compact silt	$\frac{1}{2}$"	$\frac{1}{2}$" Brown clay		
19	1"	Choc. silt	$\frac{1}{2}$"	Hard clay		
20	$\frac{1}{2}$"	Fine silt				
21	$\frac{1}{2}$"	Fine silt	$1\frac{1}{2}$"	Gritty soil loam with organic material		
22	3/4"	Gritty brown sand, clay (no silt)				
23	1/4"	Dark brown silt				
24	3/4"	Gritty brown sand, clay				
25	$\frac{1}{2}$"	Gravelly sand with silt				

Appendix I.

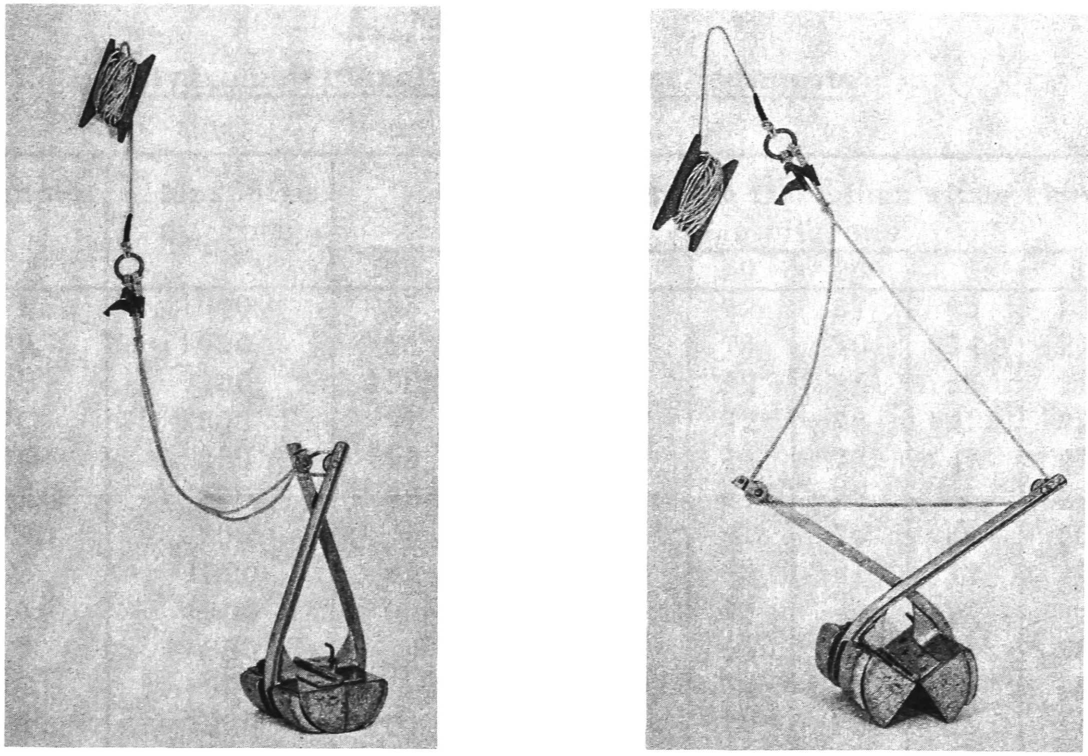
Suspended Sediment Samples - Lake Burley Griffin

Samples 1 to 18 taken 9.11.66 (12 p.m. to 1 p.m.)
Samples 19 to 21 taken 11.11.66 (11 a.m.)

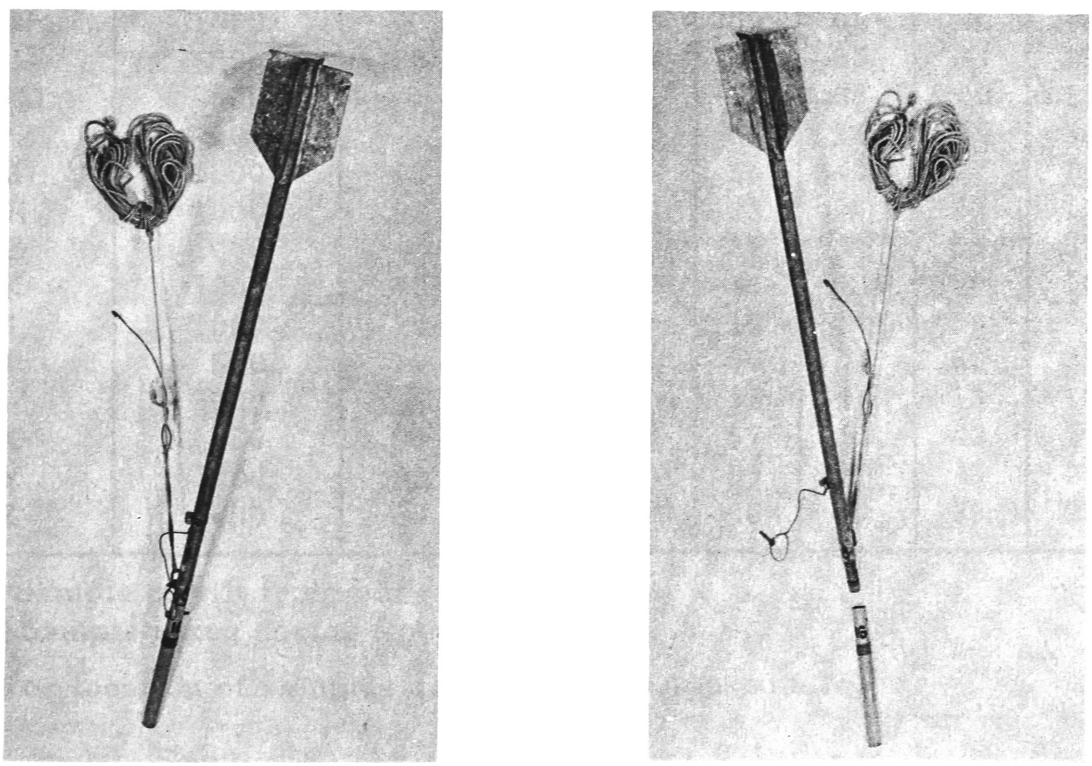
Depth Below Surface	Sample No.	p.p.m.
51'6"	S1	41
50'	S2	21
45'	S3	54
40'	S4	36
35'	S5	29
30	S6	26
25'	S7	18
20'	S8	18
15'	S9	21
10'	S10	22
5'	S11	22
0	S12	26
52'6"	S13	61
50'	S14	29
40'	S15	16
30'	S16	24
20'	S17	32
10'	S18	24
0'	S19	530
24'	S20	715
12'	S21	623

Samples S1 to S12 - Centre Cross Section 21 - Upstream Scrivener Dam.
Samples S13 to S18 at Centre Cross Section 19 - Scrivener Dam.
Samples S19 to S21 - Cross Section 12 - 700' from South Western Shore.

Appendix II.



Grab Sampler



"Torpedo" Sampler

Appendix III.

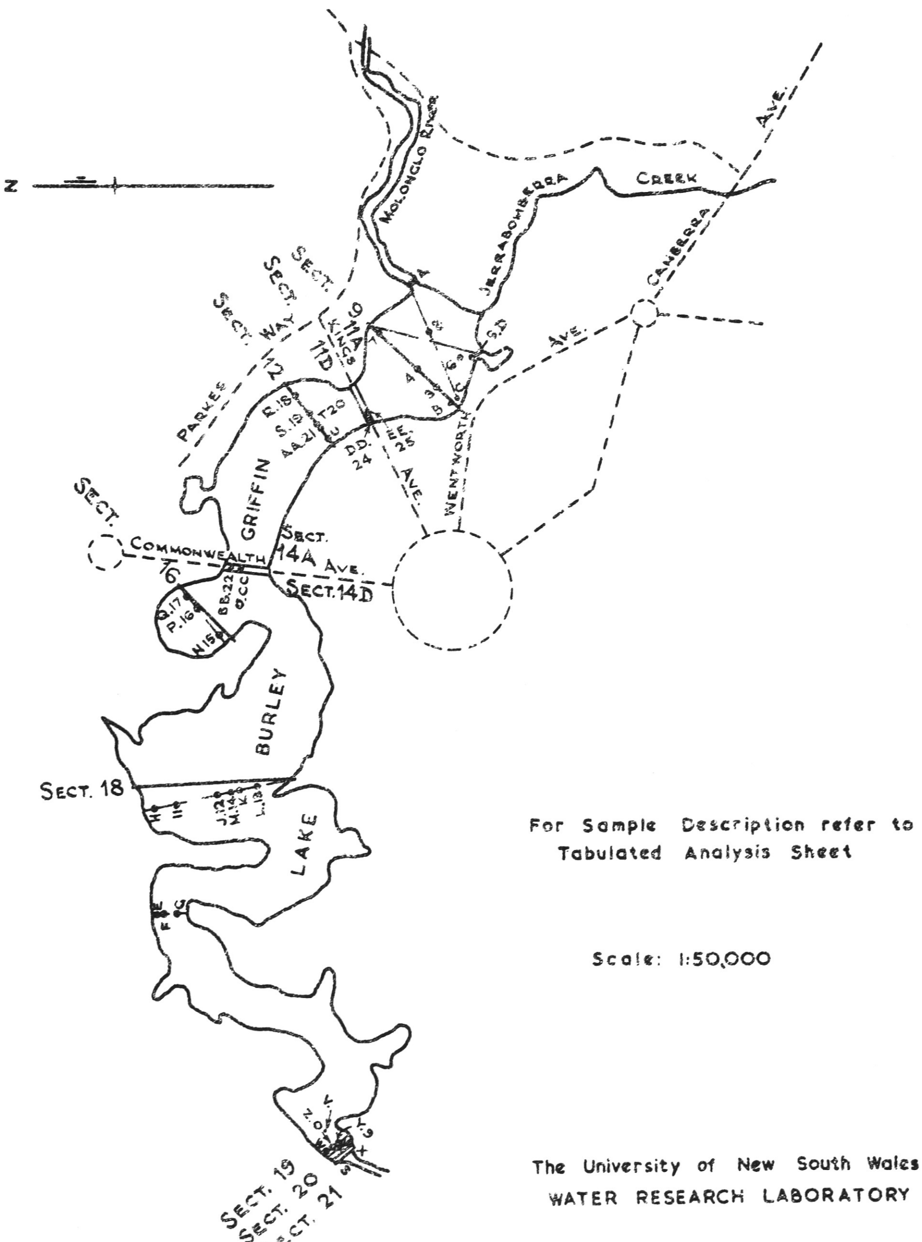
Hydrometer Analyses of Bottom Sediments

Sample	Max. Size microns	Percentage finer than sizes shown in microns						
		300	200	100	50	20	8	3
+*FF	1000	85	82	71	52	37	25	13
*A	1000	96	92	85	75	70	54	23
*B	300	100	99.5	99	92	84	51	21
*C	1000	91	87	82	72	60	41	22
*D	300	100	99.5	99	83	73	47	23
*EE	800	99.5	99.0	97	85	75	55	26
*DD	200	-	100	98	81	70	45	20
+ U	1000	81	75	68	52	41	32	24
+ AA	500	-	99.5	99	83	49	29	8
+ T	800	-	98.0	90	65	45	31	15
+ S	500	-	99.5	95	74	55	33	16
+ R	1000	97	96	93	70	50	31	11
+*BB	1000	96	94	91	73	69	57	30
+*CC	400	99.5	99	96	93	87	72	35
+ Q	1000	93	91	89	79	63	44	23
+ P	1000	98	96	95	91	80	54	28
+ N	1000	-	99	98	80	62	40	18
L	800	95	90	84	66	53	41	29
+*M	500	-	99	98	80	68	50	28
*K	500	-	-	99	81	72	60	36
+J	1000	93	90	86	55	40	27	15
+H	1000	92	86	83	63	49	30	15
*E	1000	-	-	99	87	72	55	31
F	1000	78	72	76	46	31	20	10
G	1000	70	45	30	12	8	4	2
V	500	99	98	97	90	77	62	38
W	1000	52	42	30	22	16	13	10
*X	800	96	95	89	67	52	42	29
*Y	1000	93	87	77	65	58	41	24
*Z	1000	88	85	79	60	51	39	23

*Sample of silt from old river channel
+Sample taken during flood

For location of samples see Figure A, Appendix I.

Appendix III.



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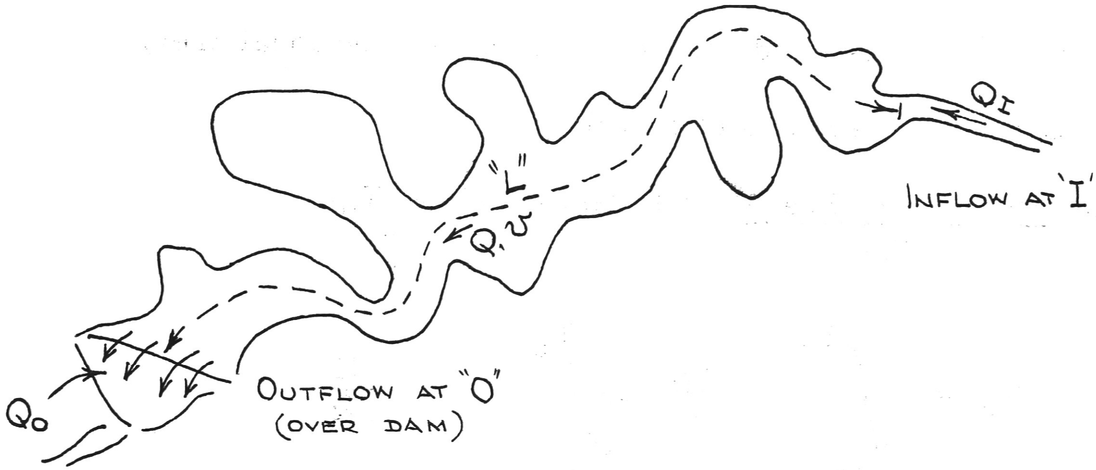
LAKE BURLEY GRIFFIN SAMPLING POINTS FOR BOTTOM SEDIMENTS

CE-E-6858

FIGURE A.

Appendix IV.



Theory

Let Q_I = inflow at 'I' at time T_I

Q_o = outflow at "O" at time T_o later than T_I by a time interval T_d

T_d = effective time of lag between the inflow of an elementary volume of water at the head of Lake Burley Griffin and its outflow at Scrivener Dam.

(i) Time of travel from "I" to "O" is determined for a single event e.g. the peak turbidity or concentration at "I" is lagged by its appearance at "O" by

$$T_d = T_o - T_I$$

(ii) Since water level at Scrivener Dam is held constant by design and backwater effect in the lake is slight, depths are constant. Assuming changes in flow pattern within the main flow channels of the lake are slight as the flood recedes from peak, then cross-section areas (effective) remain constant.

(iii) The equation of continuity applied at successive cross sections gives

$$Q = Av$$

where Q = discharge at the chosen cross section
A = effective cross sectional area
v = average velocity in the cross section

Since "A" is presumed constant (i.e. cross sectional area)

Let L = effective length of travel

Then $\dfrac{\text{Distance of Travel}}{v_m}$ = Detention Time (T_d)

$$T_d = \int_{T_I}^{T_o} \frac{dL}{v} \propto \int_{T_I}^{T_o} \frac{dL}{Q}$$

v_m = average velocity along length "L"

From assumptions in Para. (ii)

$$T_d \propto \frac{1}{Q_m}$$

Q_m = average discharge over time T_d

i.e. $T_d\, Q_m$ = constant = $\forall$

Let this be known as "control volume"

for the given flood = $\forall$

i.e. $\forall = \int_{T_I}^{T_o} Q_I \; dT$ i.e. area of flood hydrograph between time of peak turbidity at "I" and time of peak turbidity at "O".

(iv) Trap Efficiency for given Q_m = C_{TI}

$$C_{TI} = \frac{M_I - M_o}{M_I}$$

where M_I = suspended sediment concentration at inlet

M_o = suspended sediment concentration in vicinity of outlets at time T_o later than T_I by T_d

(v) C_{TI} and M_I are functions of time (plotted Figures 1 and 3 for Lake Burley Griffin).

Sediment inflow for an arbitrary period of flood flow, T_F, is W

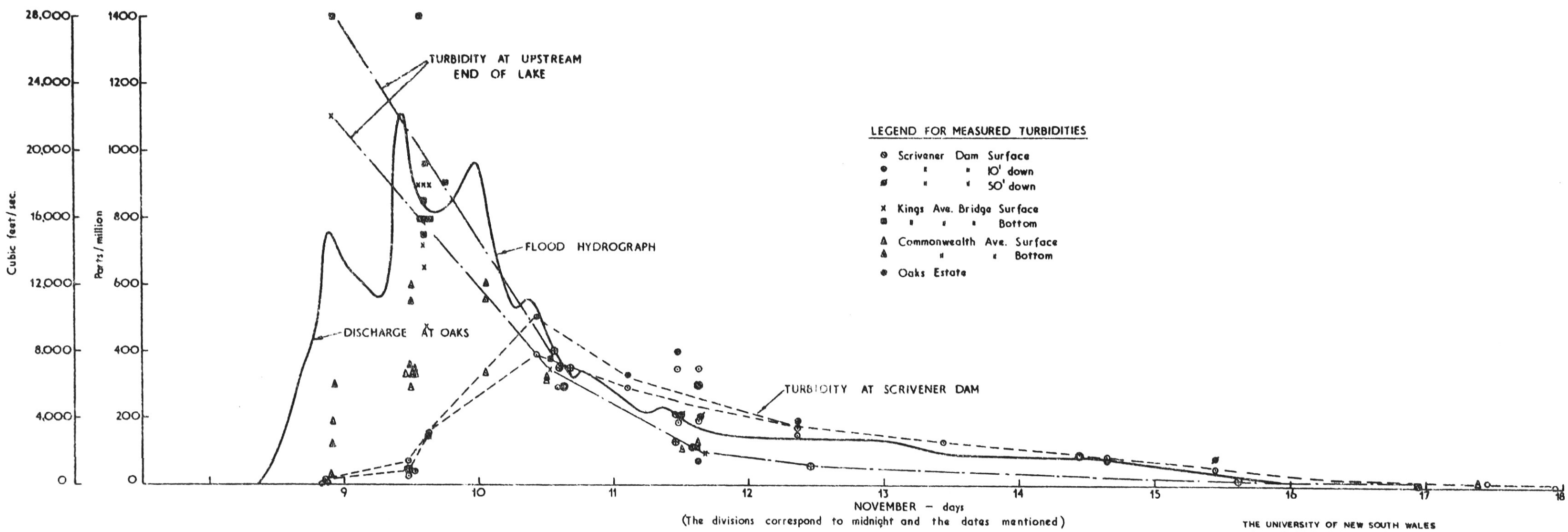
$$W = \sum_{T=0}^{T=T_F} Q_I . M_I . \delta T$$

Sediment deposited in the lake in the arbitrary period of flood, T_F, is W_d

$$W_d = \sum_{T=0}^{T=T_F} Q_I . M_I . C_{TI} . \delta T$$

Average trap efficiency for arbitrary period, T_F, is C_T

$$C_T = \frac{W_d}{W}$$



THE UNIVERSITY OF NEW SOUTH WALES
WATER RESEARCH LABORATORY

Sedimentation Survey of Canberra Lakes

FLOOD DATA - 9th. to 16th. NOV. 1966

CE - D - 6962

FIGURE 1.

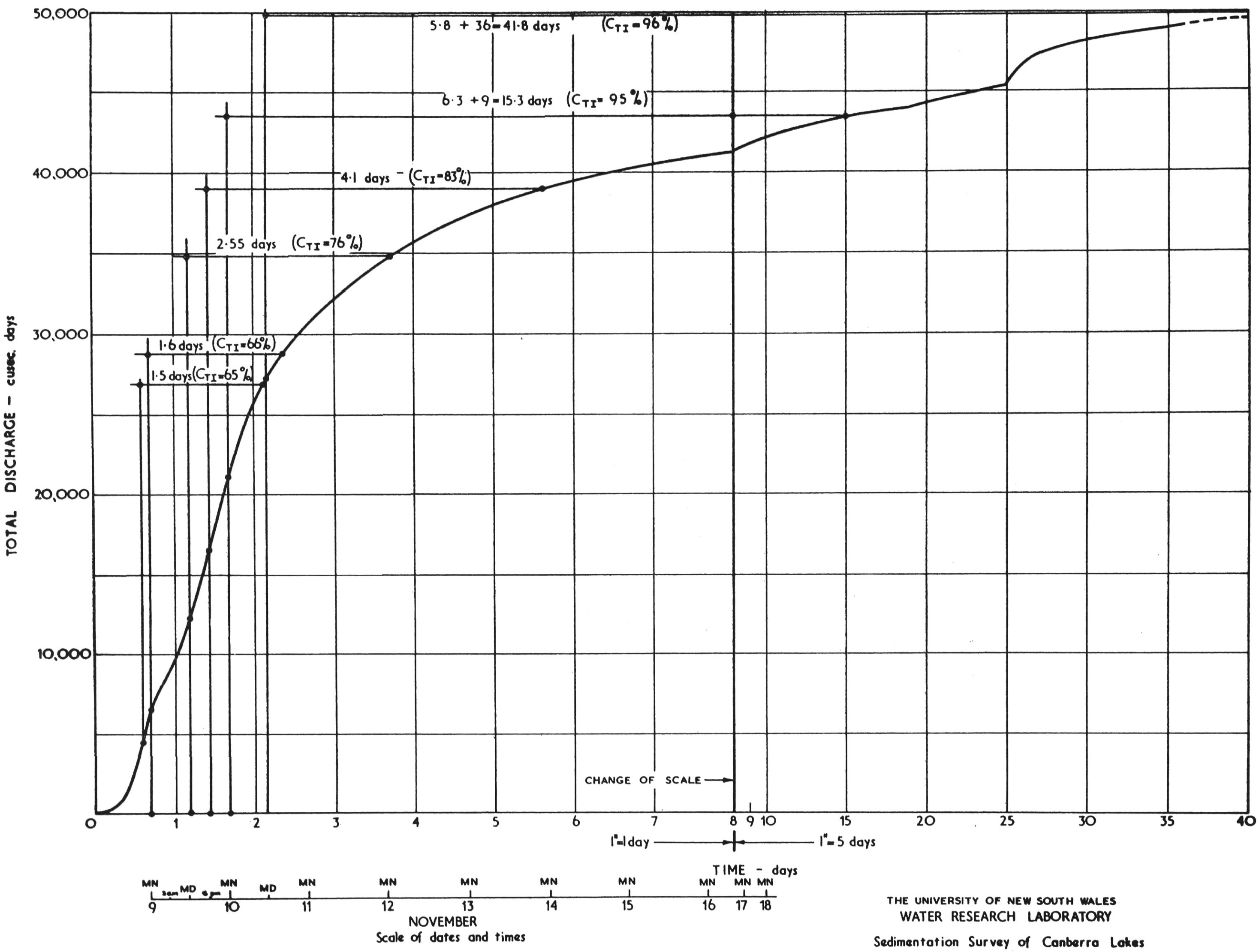


FIGURE 2.

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Sedimentation Survey of Canberra Lakes

MASS CURVE - MOLONGLO RIVER AT THE OAKS GAUGING STATION FOR FLOOD 9.11.66 TO 13.12.66

CE-D-6960

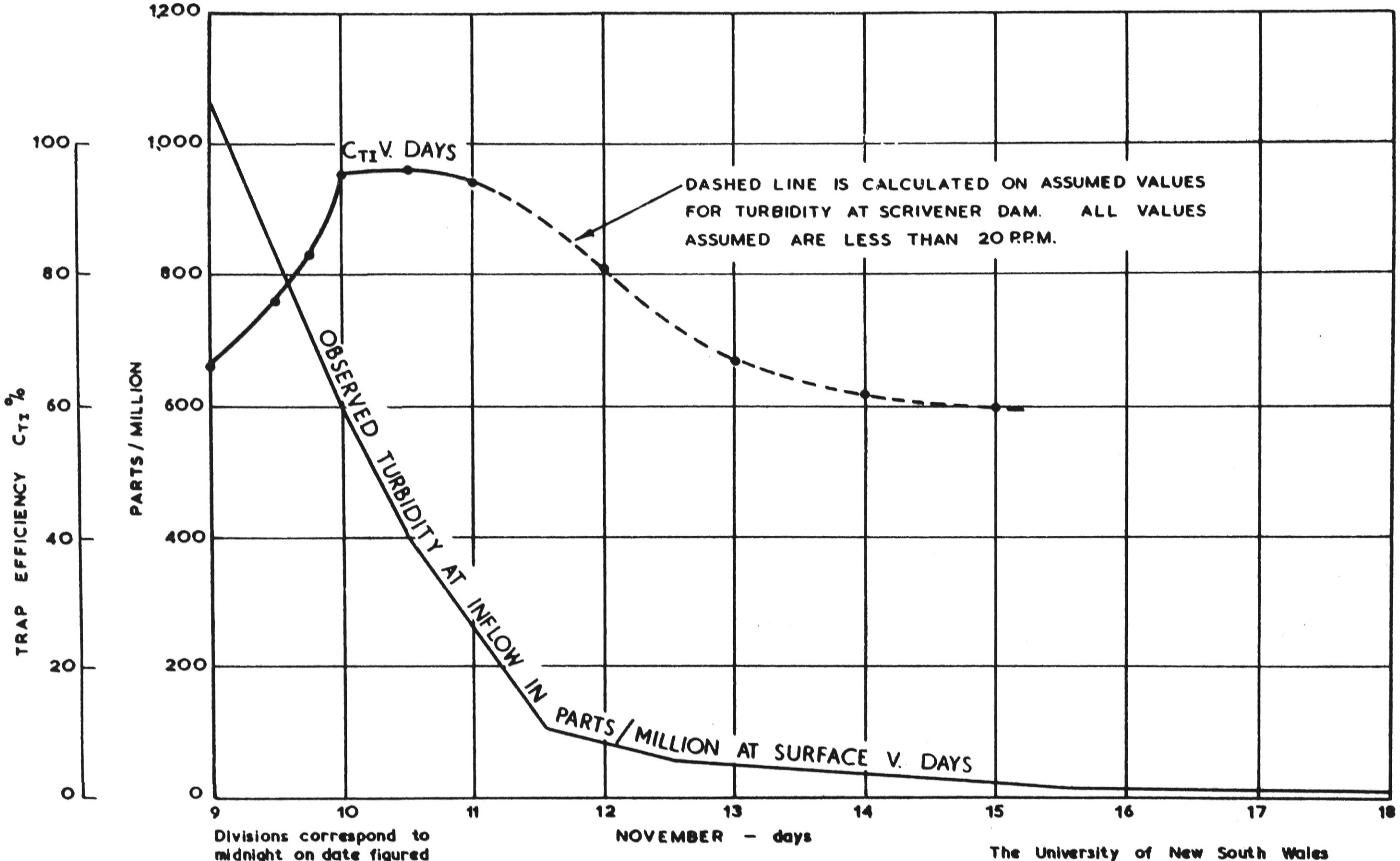

FIGURE 3.

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Estimate of average trap efficiency for flood of Nov., 1966

C_{TI} = Instantaneous trap efficiency = $\frac{M_I - M_O}{M_I}$ at time T_I

Sediment Load at Inflow = $\Sigma Q_I \times M_I \times \delta t$

Sediment Deposition in Lake = $\Sigma Q_I \times M_I \times C_{TI} \times \delta t$

Average Trap Efficiency $(C_T) = \frac{\Sigma Q_I \times M_I \times C_{TI} \times \delta t}{\Sigma Q_I \times M_I \times \delta t}$

(For definition of symbols see Appendix IV)

Sedimentation Survey of Canberra Lakes

FLOOD DATA – 9th to 12th NOV., 1966

CE - E - 6963

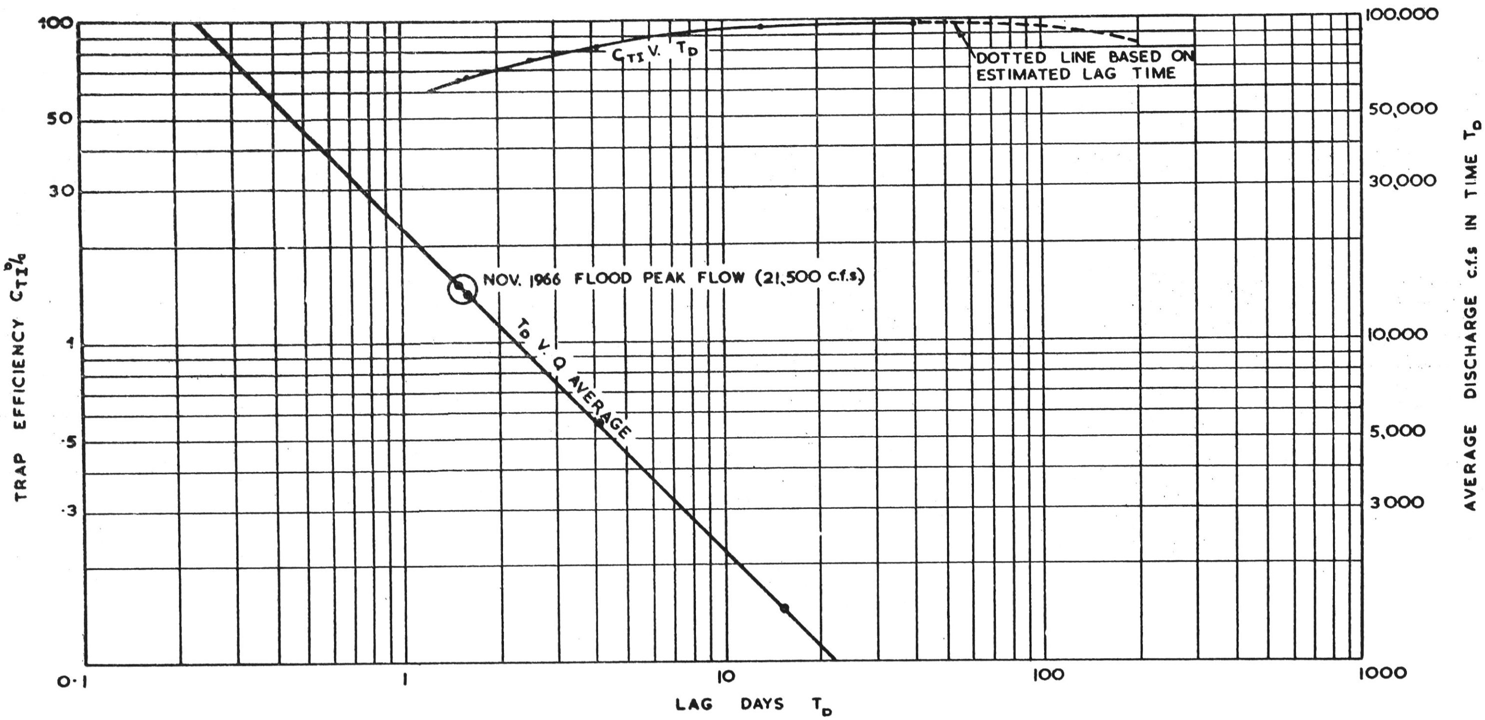

FIGURE 4.

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Sedimentation Survey of Canberra Lakes

INSTANTANEOUS TRAP EFFICIENCY, C_{TI}, IN RELATION TO AVERAGE DISCHARGE Q_A IN LAG TIME T_D. BASED ON CONTROL VOLUME $\forall$ DERIVED FROM NOV. 1966 FLOOD

($\forall$=22,500 cusec days)

CE-E-6982

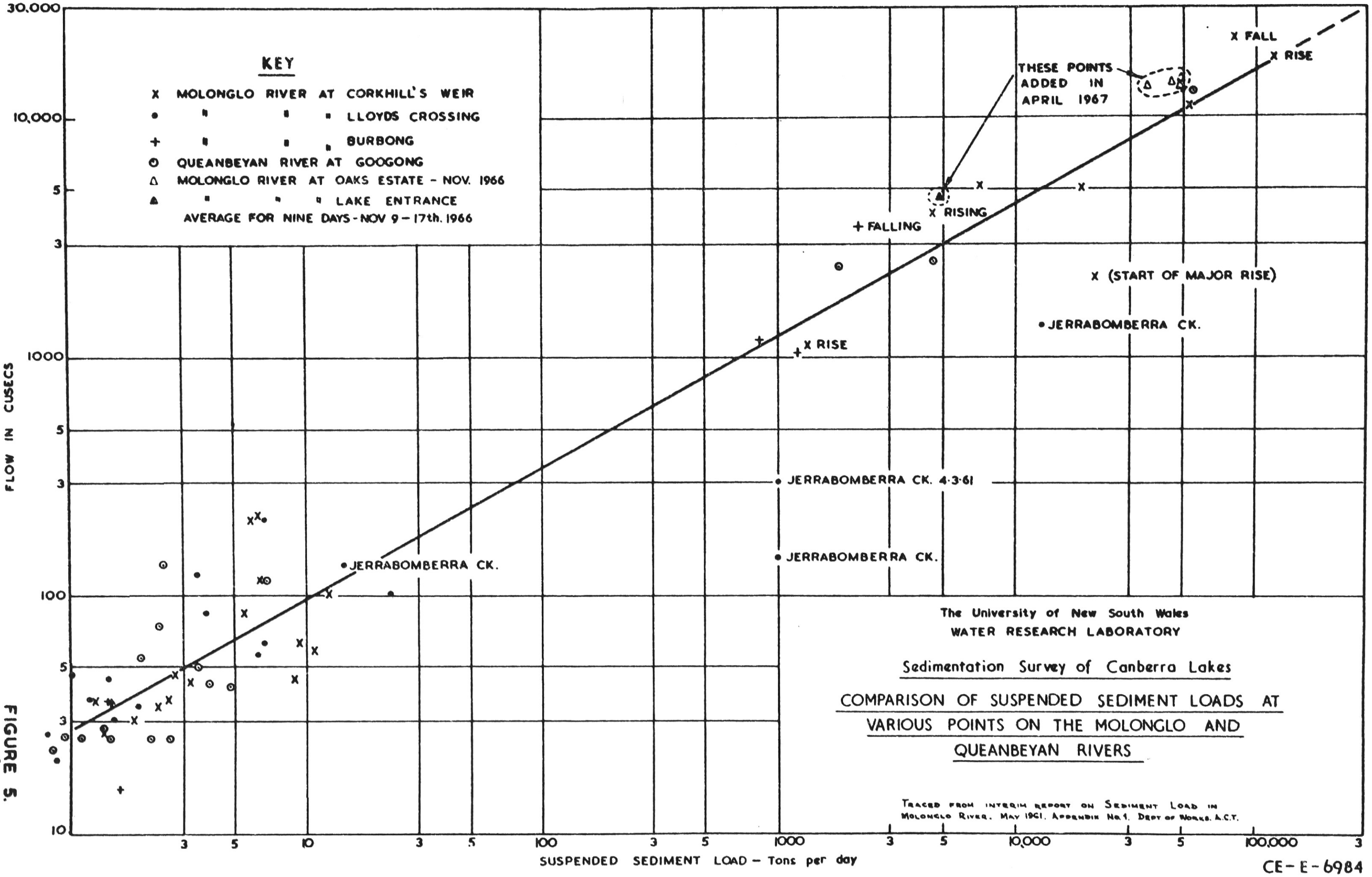

KEY
X MOLONGLO RIVER AT CORKHILL'S WEIR
• " " " LLOYDS CROSSING
+ " " " BURBONG
⊙ QUEANBEYAN RIVER AT GOOGONG
△ MOLONGLO RIVER AT OAKS ESTATE - NOV. 1966
▲ " " " LAKE ENTRANCE
AVERAGE FOR NINE DAYS - NOV 9 - 17th. 1966
THESE POINTS ADDED IN APRIL 1967
X FALL
X RISE
X RISING
+ FALLING
X (START OF MAJOR RISE)
JERRABOMBERRA CK.
X RISE
JERRABOMBERRA CK. 4·3·61
JERRABOMBERRA CK.
JERRABOMBERRA CK.
FLOW IN CUSECS
SUSPENDED SEDIMENT LOAD – Tons per day
30,000
10,000
1000
100
10
10
100
1000
10,000
100,000
The University of New South Wales
WATER RESEARCH LABORATORY
Sedimentation Survey of Canberra Lakes
COMPARISON OF SUSPENDED SEDIMENT LOADS AT VARIOUS POINTS ON THE MOLONGLO AND QUEANBEYAN RIVERS
Traced from interim report on Sediment Load in Molonglo River, May 1961. Appendix No. 1. Dept of Works A.C.T.
CE-E-6984

FIGURE 5.

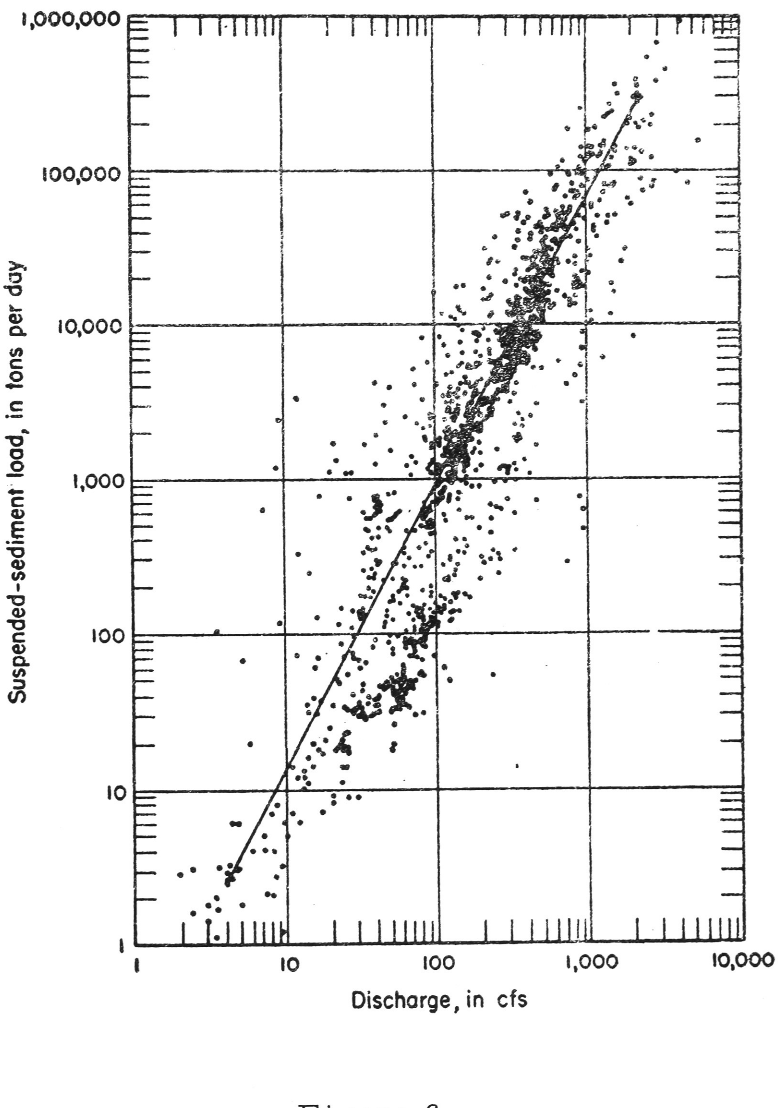
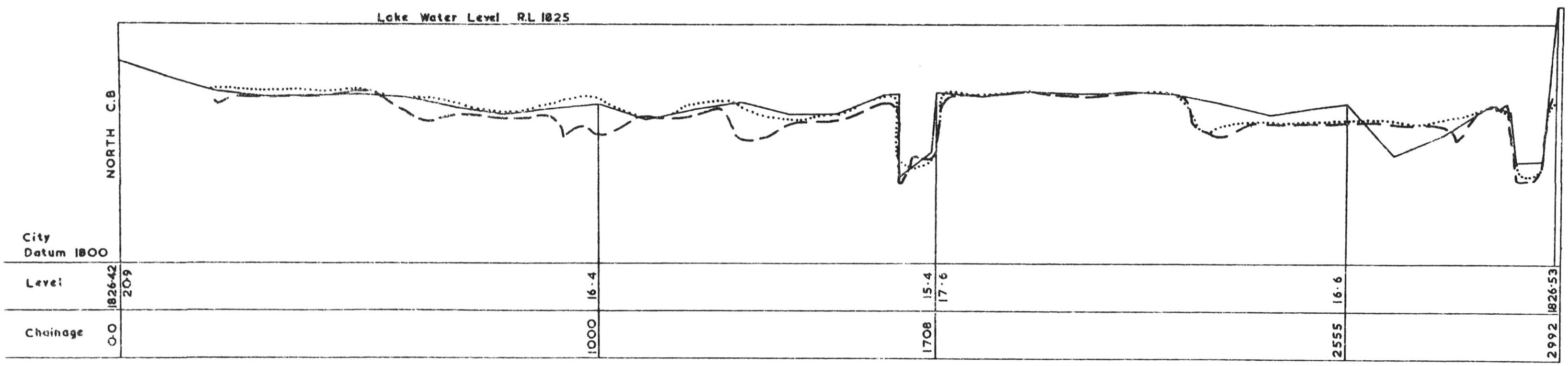


Figure 6.

Relation of Suspended Load to Discharge
Powder River at Arvado Wyo. U. S. A.
(U. S. Geological Survey Prof. Paper 252-1953).

SECTION 9.



KEY:

——— SURVEY - NOV. 1963 (DEPT. OF WORKS)

········ ESTIMATE FROM ECHO SOUNDER - SEPT. 1964 (DEPT. OF WORKS)

— — — ESTIMATE FROM ECHO SOUNDER 8th NOV. 1966 (UNIVERSITY OF N.S.W)

SCALES -

Vertical: 0 10 20

Horizontal: 0 100 200

For positions of Cross Sections in Lake
see Drg. No. CE-E-6858 being Figure A-Appendix I

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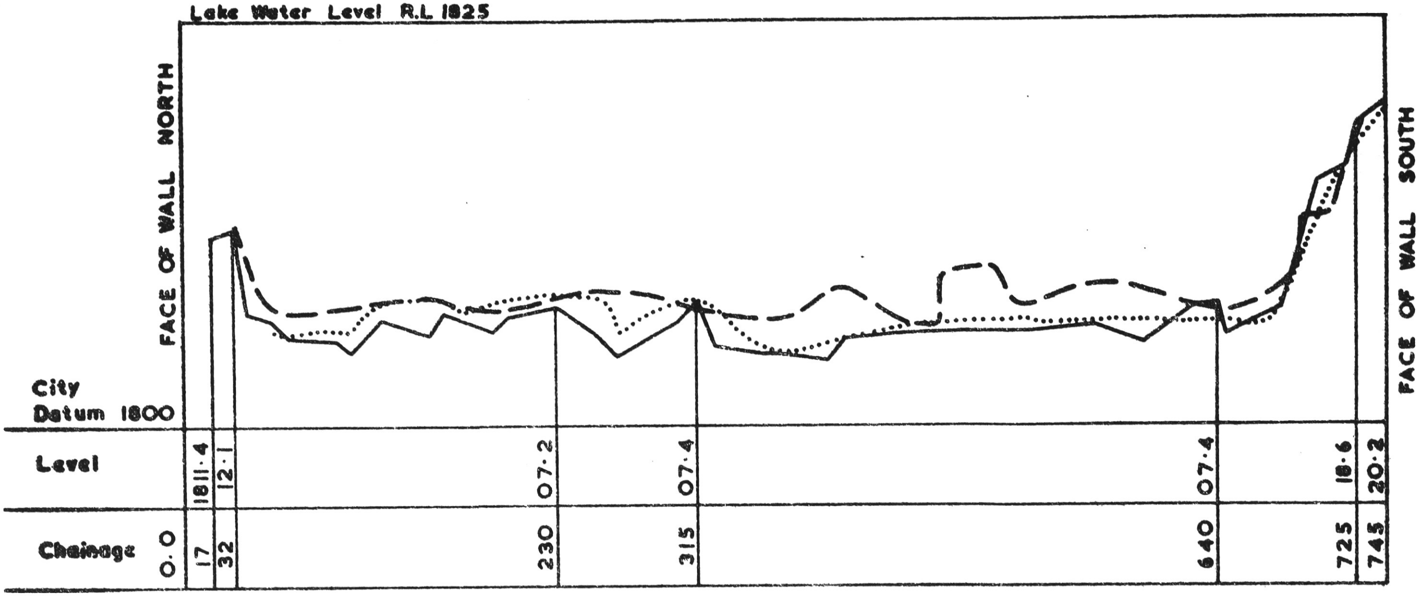
Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE-E-6893

SECTION II A.

King's Avenue Bridge. South Side. U/S.



KEY:

———— SURVEY – NOV. 1963 (DEPT. OF WORKS)

············ ESTIMATE FROM ECHO SOUNDER – SEPT. 1964 (DEPT. OF WORKS)

— — — ESTIMATE FROM ECHO SOUNDER–11th NOV. 1966 (UNIVERSITY OF N.S.W)

For positions of Cross Sections in Lake see Drg. No. CE-E-6858 being Figure A-Appendix I

SCALES–

Vertical: 0 10 20

Horizontal 0 100 200

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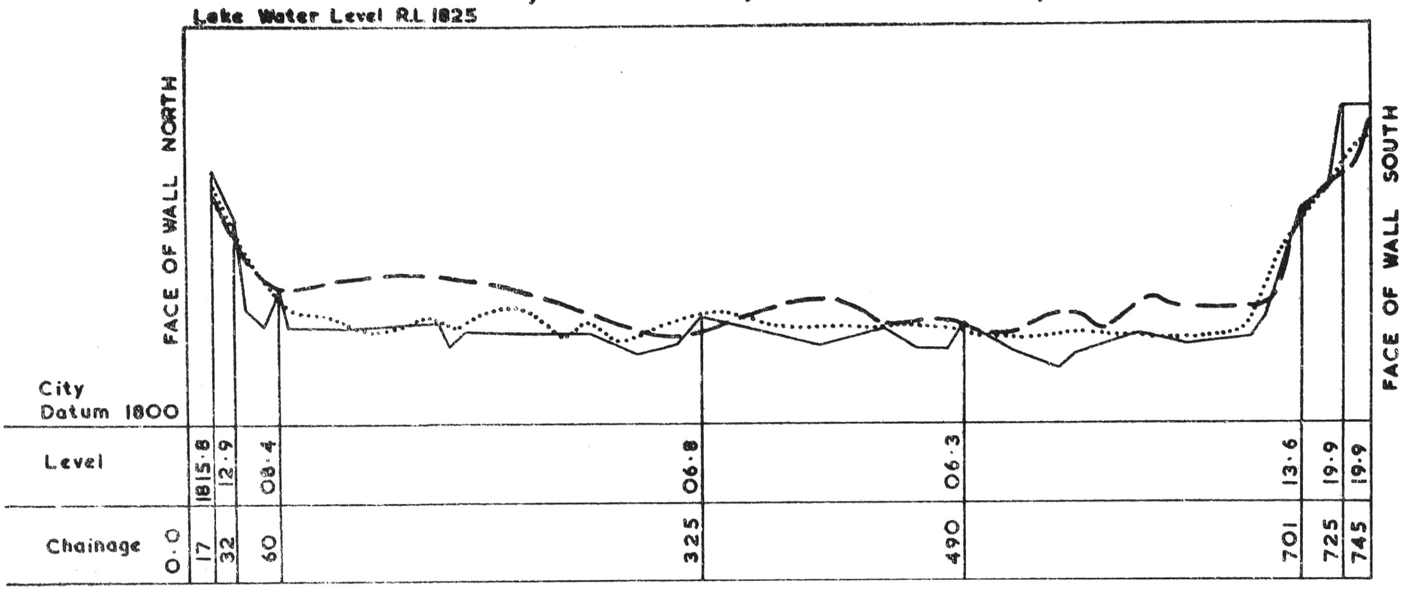
Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE-E-6894

SECTION II D.

Kings Avenue Bridge. North Side. D/S.



KEY:

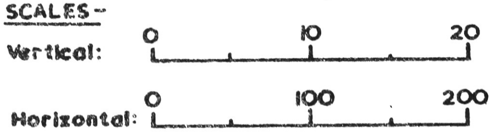
——————— SURVEY – NOV. 1963 (DEPT. OF WORKS)

·············· ESTIMATE FROM ECHO SOUNDER – SEPT. 1964 (DEPT. OF WORKS)

— — — ESTIMATE FROM ECHO SOUNDER 11th NOV. 1966 (UNIVERSITY OF N.S.W)

For positions of Cross Sections in Lake see Drg. No. CE-E-6858 being Figure A-Appendix I

SCALES –



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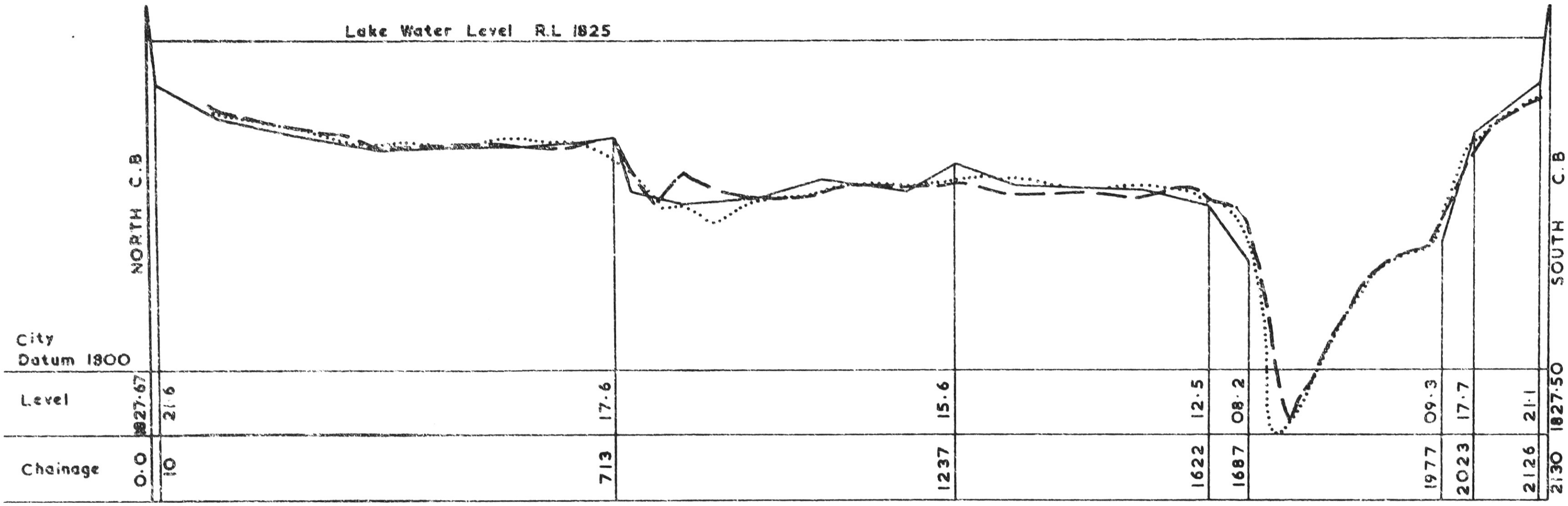
Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE-E-6895

SECTION 12.



KEY:

——— SURVEY - NOV. 1963 (DEPT. OF WORKS)

·········· ESTIMATE FROM ECHO SOUNDER - SEPT. 1964 (DEPT. OF WORKS)

— — — ESTIMATE FROM ECHO SOUNDER ~~11th~~ NOV. 1966 (UNIVERSITY OF N.S.W)

SCALES-

Vertical: 0 10 20

Horizontal: 0 100 200

For positions of Cross Sections in Lake
see Drg. No. CE-E-6858 being Figure A - Appendix I

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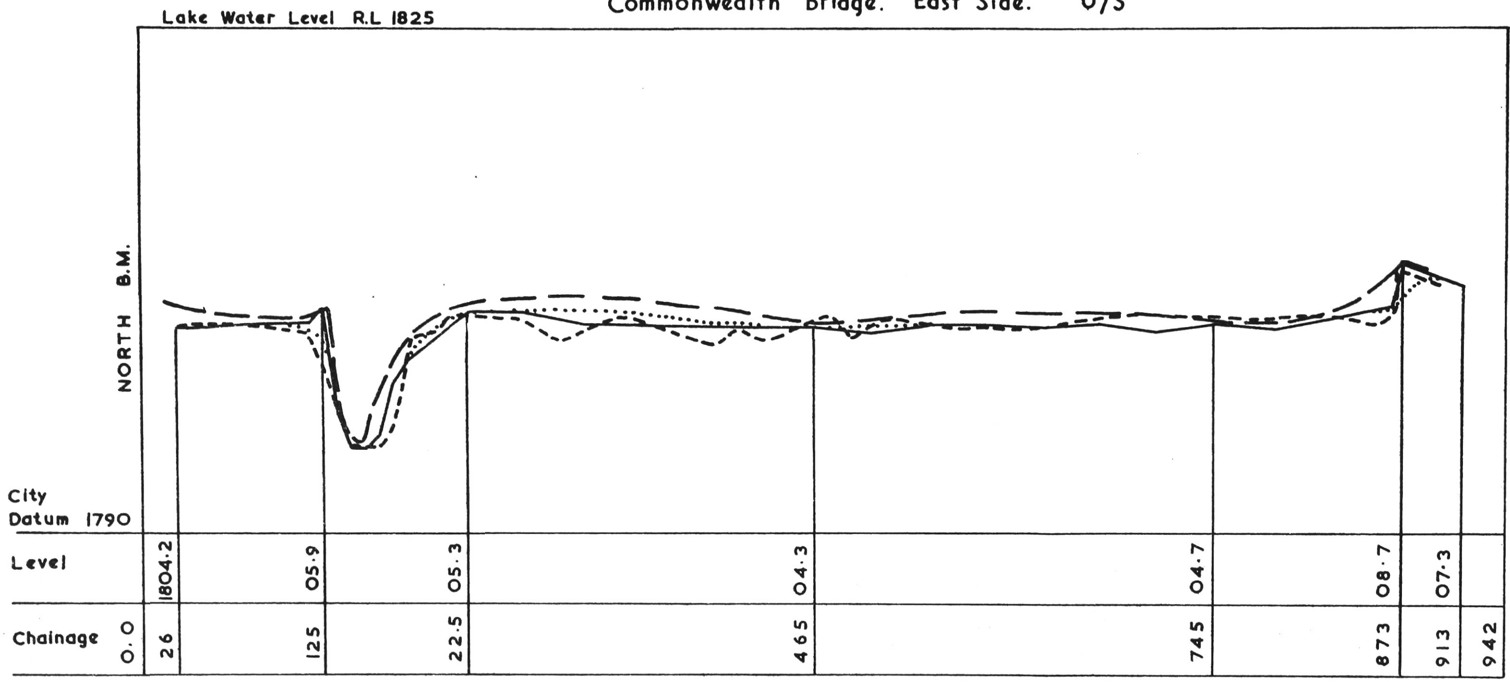
Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE-E-6896

SECTION 14 A.

Commonwealth Bridge. East Side. U/S



KEY:

——— SURVEY – NOV. 1963 (DEPT. OF WORKS)

·········· ESTIMATE FROM ECHO SOUNDER – SEPT. 1964 (DEPT OF WORKS)

— — — ESTIMATE FROM ECHO SOUNDER (FLOOD) – 10th. NOV. 1966. (UNIVERSITY OF N.S.W)

- - - - - - ESTIMATE FROM ECHO SOUNDER – 3rd. MARCH, 1967. (DEPT. OF WORKS)

SCALES –

Vertical: 0 10 20

Horizontal: 0 100 200

For positions of Cross Sections in Lake see Drg. No. CE-E- 6858 being Figure A-Appendix I

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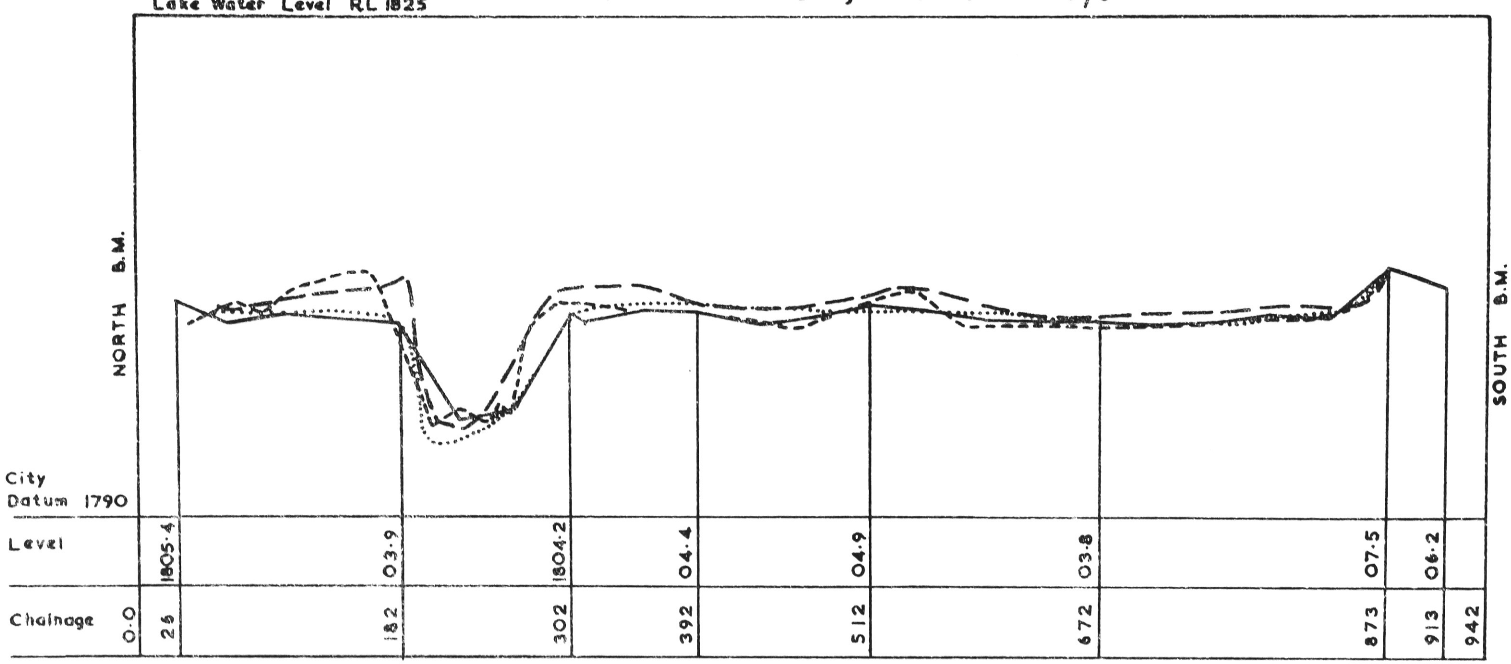
Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE-E-6874

SECTION 14 D.

Commonwealth Bridge. West Side. D/S



KEY:

- ———— SURVEY - NOV. 1963 (DEPT. OF WORKS)
- ·········· ESTIMATE FROM ECHO SOUNDER - SEPT. 1964 (DEPT. OF WORKS)
- — — — ESTIMATE FROM ECHO SOUNDER (FLOOD) - 10th. NOV. 1966 (UNIVERSITY OF N.S.W.)
- - - - - - ESTIMATE FROM ECHO SOUNDER - 3rd. MARCH, 1967 (DEPT. OF WORKS)

SCALES -

Vertical: 0 10 20

Horizontal: 0 100 200

For positions of Cross Sections in Lake see Drg. No. CE-E- 6858 being Figure A-Appendix I

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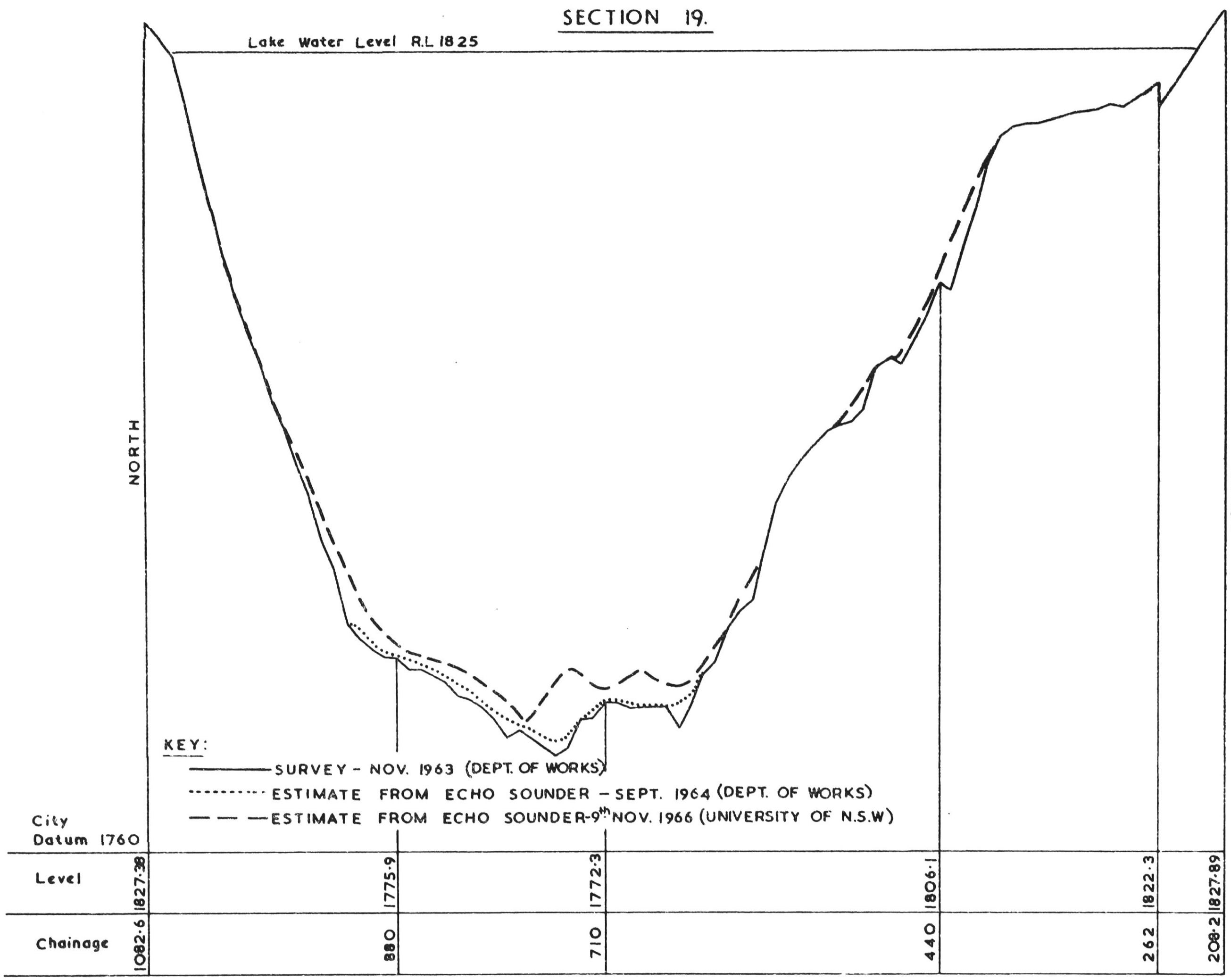
Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE - E - 6875



For positions of Cross Sections in Lake see Drg. No. CE-E-6858 being Figure A-Appendix I

Scale:
Vertical: 1" to 10'
Horizontal: 1" to 100'

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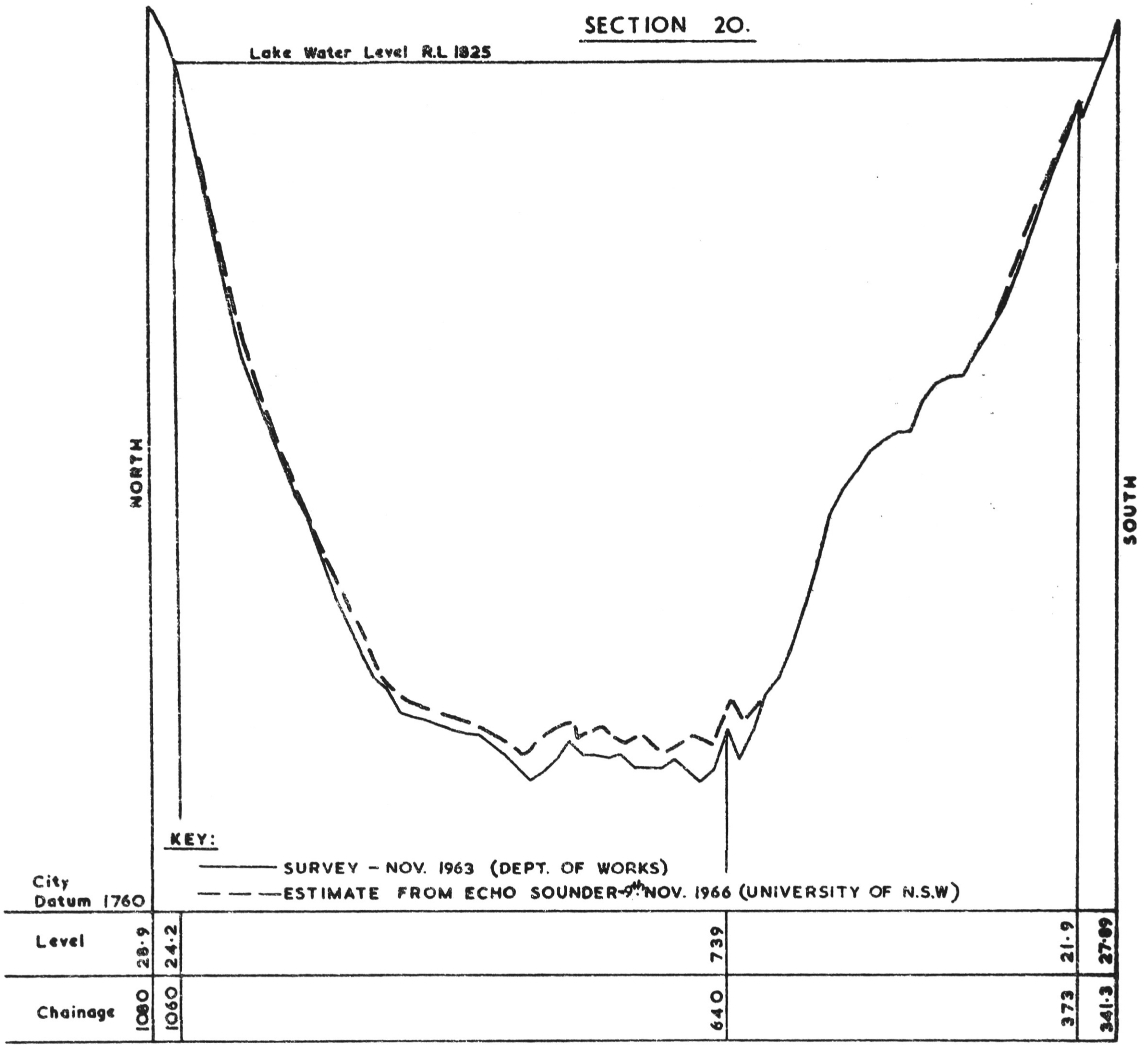
WATER RESEARCH LABORATORY

Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE-E-6901



For positions of Cross Sections in Lake
see Drg. No. CE-E-6858 being Figure A-Appendix I

Scale:
Vertical: 1" to 10'
Horizontal: 1" to 100'

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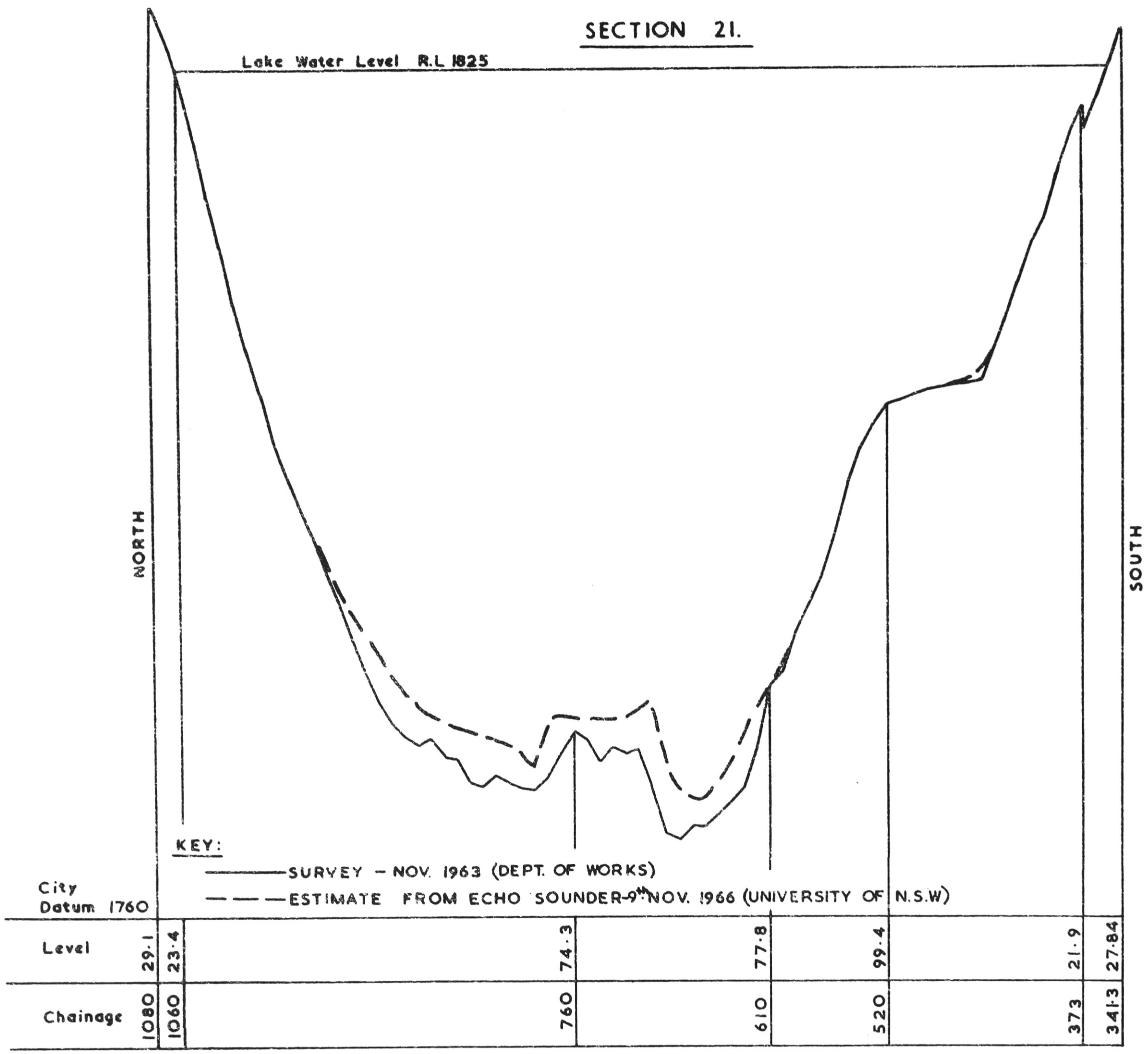
Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE-E-6897



For positions of Cross Sections in Lake see Drg. No. CE-E-6858 being Figure A-Appendix I

Scale:
Vertical: 1" to 10'
Horizontal: 1" to 100'

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Sedimentation Survey of Canberra Lakes

LAKE CROSS SECTIONS

CE - E - 6898