A QUANTATATIVE STUDY

OF THE

GEOMORPHOLOGY

OF THE

WILSON CREEK WATERSHED,

MANITOBA

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SYNOPSIS

This thesis, which fulfills part of the requirements for a degree of M. Sc. at the University of Manitoba, presents the results of a study into some aspects of the geomorphology of the Wilson Creek Experimental Watershed. Data that has been gathered in the watershed over the past decade has been studied to determine rates of erosion in the escarpmental portion of the watershed and rates of deposition in the Wilson Creek Delta.

Studies based on sediment transport data were made to determine the average annual rate of sediment transport over the past ten years which includes the influence of a headwater detention basin. Studies were also made to determine the effect of the headwater reservoir in reducing the average annual sediment discharge.

The annual cost of headwater storage in the Wilson Creek Experimental Watershed was determined and compared to the reduced annual maintenance costs in the artificial drain through the Wilson Creek Delta. It was found that headwater storage cannot be justified on sediment discharge reduction alone. However, evidence indicates that reduction in flood damage accruing to such storage is probably significant and warrants further study.

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CHAPTER I

INTRODUCTION

This thesis presents the results of a preliminary study of the geomorphological processes of streams on the Manitoba Escarpment, in an attempt to explain erosion and sedimentation phenomena of such streams. An estimate has been made of the amount of material that has been eroded from the escarpmental portion of a watershed since deglaciation. Existing topographic and stratigraphic data have been examined in order to determine the quantity of material that has been deposited at the base of the escarpment during this same time. Data gathered with respect to sediment discharge has been examined and an estimate made of the average annual sediment load of the stream. An additional study carried out in the course of this investigation has been an attempt to analyze the effect on the average annual amount of sediment transported by the stream of a flood detention basin located in the head-waters. The reduction in sediment discharge attributed to the detention basin has been related to the reduction in the average annual cost of maintenance of land drainage works at the base of the escarpment in order to partially appraise the economic feasability of detention basins in this particular environment. The benefits of the detention basin considered were limited to the effects of the flood storage reservoir in reducing the sediment infill in the drains, and no attempt was made to evaluate the reduction in flood damage that would result from such reservoirs.

In 1957, the Wilson Creek Watershed was selected for a detailed hydrometeorlogical study to determine if measures in the headwaters of escarpmental streams could be effective in reducing flood and erosion. The watershed was intensively instrumented to measure rainfall, runoff, sediment production and the ground water regime. Geological, soils, and botanical surveys were also carried out. At the same time, a number of works were constructed to determine if such measures as detention dams, stream bed and bank protection works, etc., could be effective in controlling the flooding and erosion problems. The data gathered since 1959 in the Wilson Creek Experimental Watershed were used in this study.

CHAPTER II

THE WILSON CREEK EXPERIMENTAL WATERSHED

General

The Wilson Creek Experimental Watershed is located on the eastern slopes of the Riding Mountain within the Riding Mountain National Park.

The drainage area within the National Park is 5,440 acres. Downstream of the park boundary the stream is confined in an artificial drainage ditch to the point where it enters the Turtle River. The location of the Watershed is shown in Fig. 1.

Topography

The topography in the experimental watershed is typical of watersheds lying on the Manitoba Escarpment. (1) (2). The upper catchment area is located on a relatively flat plateau at about elevation 2,400 feet, and from here the land falls rapidly, dropping about 1,300 feet in four miles. From elevation 1,000, which roughly marks the present limit of the alluvial deposits from the escarpment, the land falls gently toward the northeast to elevation 850 at Lake Dauphin. The middle watershed, between the plateau and the alluvial

(1). G. H. MacKay and C. R. Stanton--Wilson Creek Study Erosion and Sediment Control, Proceedings Fourth Hydrology Symposium, Hydrology Subdivision, N.R.C.--1964.

(2). G. H. MacKay--Wilson Creek Experimental Watershed--unpublished paper presented to the 1966 annual General Meeting, E.I.C., May, 1966.

fan, is deeply insized and cut by a number of draws and coulees tributary to the main water-courses. The main streams are cut into the bedrock shale in deep, V-shaped valleys, four to five hundred feet deep. These topographic details are shown on Fig. 2.

Geology and Soils

A surface mantle of unconsolidated glacial drift of rock materials covers the bedrock formation throughout most of the watershed. Bedrock exposures occur in the deeply insized channels of the main water courses. The rock formations immediately underlying the glacial drift and those outcropping along the water courses are shales of the Upper Cretaceous period. Two phases of the Riding Mountain formation, the Millwood and Odonah, occupy most of the surface contact area. These consist of light grey, hard siliceous shales and soft greenish shale clay. Dark grey shales of the Vermillion River and Favell formations underlie the Riding Mountain shales and contact the surface deposits in the lower portion of the watershed.

Glacial till in the form of end moraines cover the bedrock formations over most of the watershed. A narrow strip of alluvial deposits, composed mainly of shale fragments, occur on terraces in the creek valleys in the lower portion of the watershed. Shallow peat deposits cover the glacial till in enclosed depressions in the upper part of the basin.

A detailed reconnaisance soil survey of the watershed was undertaken in 1958. Ten soils types were identified and mapped during the survey. The soil survey indicated that the watershed may be divided into two segments for consideration of runoff and erosion problems insofar as soils influence these phenomena.

The middle portion, comprising the steep slopes of the escarpment consist of wapus soils and talus slopes. These materials are quite permeable to water and do not contribute materially to surface runoff. However, the shale fragments, which constitute the bulk of these materials are very susceptible to erosion, especially through scour on the banks of the creek channels. It is this portion of the watershed that probably contributes most of the coarse sediments that are found in the stream.

The upper portion, which consists of finer textured, relatively impermeable soils, probably contributes a significant portion of the surface runoff. However, most of these areas are stabilized by vegetation and very little erosion seems to occur. A few recently eroded gullies may be observed on the valley slopes along the south branch of Baldhill Creek, and these, no doubt, contribute some of the finer sediments.

Vegetation

Both broad and detailed studies have been made of the existing vegetative cover in the watershed by Ritchie, 1958. These involved both field studies and air photo interpretation studies.

On the upper plateau, the cover is primarily an open forest of hardwoods and spruces with some areas of shrub. The upper escarpment slopes have a more or less closed cover of mixed forest, made up chiefly of white birch and aspen poplar with local stands of coniferous trees. The middle to lower portion of the catchment is occupied by young stands of deciduous trees dominated by white birch and aspen poplar. The forested part of the lower delta abutting on the escarpment bears a mixed vigorous forest with varied assortment of conifers and hardwoods.

Climate and Runoff

The general climatic conditions prevailing over the area of Manitoba in which the watershed is located, are sub-humid with an average annual precipitation of about 18 inches, and a mean annual temperature of about 35 degrees Fahrenheit. Approximately 14 inches, or about 80% of the annual precipitation falls as rain during April to October, and the remaining four inches as snow during the winter months.

Throughout the general escarpmental region, the summer precipitation often occurs during sharp, intense thunderstorms. These are usually centered over the higher portion of the escarpment and often are extremely local. Rainfall intensities of up to four inches per hour for short periods of time have been measured in the watershed.

Runoff from the watershed occurs as a result of the melting of the winter snow pack, precipitation from; frontal storms in the late spring and early summer, convective storms during the early and middle summer, and mild frontal storm activity in the late summer and fall. The average annual runoff from the watershed during the period 1959 to 1968 has been about four inches, 80% of which occurs during the months of May and June.

CHAPTER III

GEOMORPHOLOGY OF THE WILSON CREEK WATERSHED

General

It is generally accepted that the last of the thick continental ice-sheets that covered the northern part of North America prior to 15,000 years ago melted away from the Riding Mountain area prior to 13,000 years before present (B.P.) (3). The ice mass as it moved over the Manitoba escarpment altered the existing landscape by filling pre-glacial valleys with glacial debris and eroding high areas. It may be visualized that immediately subsequent to deglaciation the escarpment was plastered with a mantle of glacial drift so that the surface of the eastward facing slope would be relatively smooth with only very minor relief. (4).

Glacial Lake Agassiz was formed as a result of the wasting of the continental ice-sheet. As various outlets to Lake Agassiz were formed the lake receded and by 11,000 B.P., the lake had receded in the region of the Riding Mountain, to what may be considered to be the base of the Manitoba escarpment.

(3). Life, Land and Water--Proceedings of the 1966 Conference on Environmental Studies of the Glacial Lake Agassiz region edited by W. J. Mayer-Oakes, 1966.

(4). Personal Communication--Dr. R. Klassen, Geological Survey, Canada.

<u>Wilson Creek Delta</u>

Immediately subsequent to deglaciation, erosion of the slopes of the escarpment commenced. The eroded material was carried down the slopes and deposited in the glacial lake. These lacustrine deposits would have been uniformly washed along the lakeshore and worked by waves and by littoral drift. After the lake receded, to below about elevation 1,100 (11,000 B.P.), the eroded material was deposited in the lagoons and swamps left behind various beach ridges of the glacial lake. These ridges, which may be readily traced on present day aerial photographs, (5), inhibited drainage and the material was deposited in a series of coalescing deltas along the base of the escarpment. An examination of Fig. 2 shows plainly the shape of the Wilson Creek delta by the "bulging" of the contour lines.

From the events described above it may be concluded that two distinct sections of the Wilson Creek delta may be identified. The base of the delta being the bedrock shale surface or the surface of the glacial deposits remaining after the passage of the glacier; immediately on top of the bedrock or till surface one would expect a layer of lacustrine deposits overlain by a layer of alluvial deposits. An examination of the logs of test holes in the delta area, as presented in Appendix 1, confirms this sequence of deposition.

(5). A mosaic of one inch equals one mile aerial photographs was made for this study. Because of reproduction problems, it is not included in this thesis. The mosaic may be examined by request to the author.

It may be visualized that the erosion process on the escarpment during the period that the glacier was wasting immediately to the north of the Riding Mountain region would take place at a rapid rate. The climate adjacent to the cold lake and the cold front of the glacier would be extremely humid, (6) with annual precipitation much greater than today. It has been postulated that during this time weather patterns were such that moist air was circulated from the south west area of North America and was brought into the area immediately south of the front of the glacier. In addition, immediately subsequent to deglaciation the slopes of the escarpment would be bare of any vegetation resulting in the opportunity for rapid erosion. As a result, it might be expected that the lacustrine deposits in the delta would be much thicker than the overlying alluvial deposits. These alluvial deposits occured after the glacier had receded a considerable distance northward so that it would probably not have a significant effect on the local climate in the Riding Mountain area, hence, annual precipitation would be reduced and, in addition, a vegetative cover would have developed on the slope of the escarpment giving some measure of protection to the steep slopes. An examination of the test hole logs shown in Appendix 1 bears out this hypothesis. For example, test hole 69-5 (see Appendix 1) indicates that the lacustrine deposits are thirty-five feet thick, while the alluvial deposit is only about eleven feet thick.

(6). Life, Land and Water--opp. cit.

In order to determine the amount of material deposited during the alluvial phase of the formation of the delta the existing topography as shown on Fig. 2 was examined carefully along with the stratigraphic information presented in Appendix A. As shown in Fig. 2, an approximation of the pre-alluvial phase topography was made. The previously mentioned aerial mosaic was extremely helpful in delineating the periphery of the alluvial phase of the delta. As will be seen on Fig. 2, the pre-alluvial surface was assumed to have a west-east slope similar to the existing slopes adjacent to the delta. This assumption agrees quite well with the stratigraphic data. It will be noted that the depth of the alluvial material as plotted on Fig. 2 agrees generally with the pre-alluvial surface as shown by the dashed contour lines.

In order to determine the volume of the alluvial material, the area between the pre-alluvial surface and the present surface was estimated at thousand foot intervals across the delta. It is interesting to note that a buried beach-ridge of glacial Lake Agassiz was observed on the lower portions of the cross-sections made to determine these areas. From the elevation of the beach it is suggested that the buried beach was formed during the Campbell Phase of Lake Agassiz, 11,000 B.P. (7).

The total volume of alluvial material determined as outlined above amounted to 140 million cubic yards. If it is assumed, based

(7). Life, Land and Water--opp. cit.

on the stratigraphic data presented in Appendix A, that the lacustrine phase of the delta is approximately twice as thick and has about the same aerial extent as the alluvial phase, then it may be estimated that the total volume in the Wilson Creek delta above the post-glacial surface is between 400 million and 500 million cubic yards.

Erosion of the Upper Watershed

Numerous creeks have developed on the upper watershed, particularily in the escarpmental portion and are disecting it by headward erosion. These creeks first downcut into the till, and when enough till is exposed, it slides into the creek (8) and is carried away, but the boulders, being too large to be easily transported, remain in the creek bed. Continuous down-cutting exposes the bedrock and when sufficient bedrock is undermined it too will slide into the valley. In this case, the overlying till and the bedrock slide into the creek as an amorphous mass leaving isolated buttes like Baldhill. The creek soon cuts down through the till and forms a terrace.

The determination of the amount of material eroded from the escarpmental portion of the watershed requires that many assumptions be made. The two primary assumptions used in the estimate made for this study were:

1. The surface subsequent to deglaciation was relatively smooth,
2. Erosion of the rim of the drainage basin has been insignificant.

(8). Pers. Comm.--Dr. P. A. Carr, Geological Survey of Canada.

Cross-sections at 1,000 foot intervals of the existing surface were made from the uppermost portion of the watershed to the Wilson Creek delta utilizing the best available topographic maps of the watershed. These maps were prepared by photogrometric means and are considered to be reliable and accurate. Based on the two above mentioned assumptions the post-glacial surface was superimposed on the cross-sections of the existing surface.

It was noted that the southern rim of the watershed is generally higher than the northern rim. It was postulated when drawing the postglacial surface that a general south to north slope prevailed on the escarpment after deglaciation. The areas between the two surfaces were computed for each cross-section and the volume between the two surfaces was calculated to be 450 million cubic yards. It was therefore concluded that during the period between deglaciation and the present, about 13,000 years, a total volume of 450 million cubic yards of till and shale bedrock has been eroded from the escarpmental portion of the Wilson Creek watershed.

CHAPTER IV

SEDIMENT TRANSPORT

Measurements of the sediment discharge of Wilson Creek were initiated in 1962. At that time a program of suspended sediment measurements were initiated at the main hydrometric station at the boundary of the national park (see Fig. 2).

The sediment load of a river is composed of material that is moved along the bed of the stream, along with finer material that is carried by the stream in suspension as a result of the turbulence of the flow. The suspended load, as measured by accepted methods and using the available instruments, does not include the bedload. Visual observations made of the sediment transported by Wilson Creek indicated that a significant amount of material is transported along the stream bottom as bedload. Instruments have not been developed to measure quantitatedly the bedload transport of a stream and since an indication of the total sediment transport of Wilson Creek was necessary it was decided to adopt a method of estimating the total sediment load. In 1962, a small in-channel weir was constructed a short distance downstream of the hydrometric station at the Park boundary in order to "trap" the sediment carried by the stream. The reduction in stream velocity resulting from the backwater caused by the small dam causes material in suspension and moving as bedload to be deposited. Measurements of the volume of material deposited in the reservoir over a given period of time are made and the volume compared to the amount of sediment measured as suspended load at the hydrometric station for the same time period. When the reservoir behind the "silt trap" is nearly filled, the deposited material is mechanically removed from the reservoir and further measurements of sediment infill are made.

During periods when the Wilson Creek Watershed produces large flows as a result of heavy precipitation, the "silt trap" becomes filled and a portion of the sediment load is transported through the reservoir and over the dam and is deposited somewhere downstream. The volume of sediment deposited during such flood periods is not measured. The following table shows the results of the calculations made of the volume of material deposited in the "silt trap" as compared to the volume of suspended sediment measured at the hydrometric station:

PERIOD	MEASURED SUSPENDED SEDIMENT (TONS)	SHALE DEPOSIT (CU. YDS.)	SHALE DEPOSIT (TONS) (based on a weight of 105 lbs. per cu. ft.)
June 21-Sept. 9 '65	798.35	814.2	1153
Sept. 14-Sept. 20 '65	919.51	1013.1	1440
April 13-May 16 '66	850.26	1066.65	1525.30
May 25-Sept. 12 '66	350.46	765.73	1094.99
June 6-Aug. 20 '68	714.70	581.62	831.71

It may be considered that the volume of sediment deposited in the "silt trap" represents the total sediment load of the stream during the measuring period and the volume of sediment measured as suspended load at the hydrometric station is the suspended load of the stream during the same period. The average of the values shown in the above table indicate that the suspended sediment load as measured at the hydrometric station represents about 55% of the total sediment load of the stream.

Bedload

There are many imperical relationships that have been developed over the years to calculate the amount of sediment moved as bedload by a stream. Most of these relationships are based on the following parameters:

i. the composition of the streambed

ii. the flow conditions near the bed

iii. the slope of the streambed.

Two commonly used formulae were employed to calculate the bedload of the Wilson Creek at the park boundary to compare the results to those obtained by the measurements described above for the "silt trap". These two formulae used were the Schoklitsch Formula and the Shield's Equation. (9) (10) In order to use the

(9). Computation of Total Sediment Discharge Niobrara River near Cody, Nebraska, U.S.G.S. Water Supply Paper No. 1357-1955.

(10). Handbook on the Principles of Hydrology-Editor-in-Chief, D. M. Gray-In Press.

bedload formulas it is necessary to know the particle size distribution and the unit weight of the material in the stream bed at the point where the bedload is to be estimated. Accordingly, bed material samples were obtained and analyzed. The results of the particle analysis are shown in Fig. 3. (11) The Schoklitsch Formula is:

$$G = \left(\frac{86.7}{D_{50}^{1/2}} \right) \left(S_e^{1.5} \right) \left(Q - 0.00532 \times \frac{WD_{50}}{S_e^{4/3}} \right)$$

in which G = discharge of bed material, in lbs. per second

D_{50} = median diameter of bed particles, in inches

S_e = slope of energy gradient (taken as bed slope)

W = width of stream at measuring section, in feet

Q = water discharge, in c.f.s.

The results of the calculation using the Schoklitsch Formula are shown in the following table:

(11). Pers. Comm. Mr. C. R. Miller, U.S.D.A. Sedimentation Laboratory, Oxford, Mississippi, 1964. (deceased)

Q (cfs)	G_i #/sec/ft.	G_i Tons/day
1	.0000120	0.01296
5	.000134	0.144
10	.000326	0.352
50	.00194	2.093
100	.00399	4.312
200	.00805	8.688

Similar values were found using the Shield's Equation. Both of these equations were developed for round quartz particles. The bedload carried by Wilson Creek is primarily shale, with a specific gravity of only about 70% of granite. The shale particles are round, flat thin plates. Observations indicate that because of their shape, these flat shale particles are moved more easily by the moving water than are round particles. It can be observed that the shale plates tend to be set in motion easier and once in motion are carried at a greater distance by saltation. In order to correct the values calculated from the above formulae, a shape correction factor based on the median particle diameter and the ratio of the volume of a sphere compared to the volume of a thin plate was calculated. Applying both the weight correction factor and the shape correction factor, the value of the bedload transport of 16 tons per day for discharge of 100 c.f.s. was determined. This compares with the value of about 80 tons per day calculated from the volume determinations made from the "silt trap" data.

It was found in the Niobrara River study (12), that "at low discharges of sediment the measured and computed tonnages agree fairly well; but at higher sediment discharges the computed tonnages are much lower than the measured tonnages". The calculations outlined above indicate the same type of discrepancy for Wilson Creek. For this study, the results of the measurements made on the silt trap have been used in order to determine total sediment transport.

Average Annual Sediment Transport

It is possible to predict or estimate the probable long term sediment yield of a drainage basin with a fair degree of confidence. The flow duration-sediment rating curve method has proved a reliable means of determining long term sediment yields from watersheds. This procedure involves the plotting of a water-sediment relationship and the developement of a flow duration curve using available stream flow and sediment sampling records. Fig. 4 shows the relationship between sediment discharge and water discharge that was developed for the Wilson Creek Watershed. This relationship was based on all the suspended sediment data that has been accumulated since 1962. The majority of the measurements were made during the period May to October and very few measurements were made during the spring freshettes. The sediment measurements include only the suspended load and were obtained by conventional suspended sediment samplers using the depth intergrating method with a few determinations using

(12). Computation of Total Sediment Discharge, Niobrara River near Cody, Nebraska--opp. cit.

the point intergrating sampler. No bedload estimates are included in the sediment discharge. The following table indicates the relationship that was developed based on a "straight line least squares" determination of the logarithms of the independent and dependent variables, the water discharge in c.f.s. and the sediment discharge in tons per day respectively:

Water-Sediment Relation For Wilson Creek Experimental Watershed

Number of Observations	1136
Dependent Variable	Suspended Sediment-Tons per Day
Independent variable	Mean daily discharges c.f.s.
Intercept	-1.19012
Slope of the line	1.67703
Correlation Coefficient	0.90464
Adjusted Correlation Coefficient	0.90455
Std. Error of Estimate	0.49368
Adjusted Std. Error of Estimate	0.49368

It will be noted that the corrected coefficient of correlation is fairly high being above 0.90. This indicates that a good correlation has been developed. The coefficient of determination is about 0.80 indicating that 80% of the variation in sediment discharge may be explained by variations in water discharge. However, it will be noted that the standard error is fairly large being 0.49368 log units. This indicates that there is a fair degree of scatter of the points.

In order to determine the change in the water sediment relationship from year to year, the daily sediment versus daily discharge were plotted for each year for the period 1962 to 1968 and are shown on Fig's 5 and 6. In each case a "least squares best fit line" of the logarithms of the variables was made. It will be noted that there is a shift from year to year of the relationship between sediment discharge and water discharge. This is probably due to many factors, such as; time of the year of storm producing rainfall, intensity of storm producing rainfall, antecedent moisture conditions on the basin, and many others. However, the indications are that there is not a significant shift in one direction indicating a progressive change in the water sediment discharge relationship.

A flow duration curve using average daily discharges was prepared for the discharge data obtained at the hydrometric station at the Park boundary. The flow duration calculations were made by Mr. M. Sydor of the University of Manitoba, Civil Engineering Staff on the University 360 I.B.M. computer. The computer program and calculations are described in Appendix 2.

The incremental combination of the two curves i.e., the flow duration curve and the water sediment discharge curve produces an estimated long term sediment yield as shown on the tables in Appendix 3. The average annual suspended sediment transport is 4.68 tons per day and this is based on a sampling period for the suspended sediment of seven years, 1962 to 1968 and the sampling of the daily discharges over the period 1959 to 1968. This figure does not include the bedload portion of the total load.

If the figure that was determined from the "silt trap" measurements for the suspended sediment portion of the total load is applied to this figure, a value of 8.51 tons per day is obtained. If it is assumed that the sediment producing period each year is 200 days, then an average annual total sediment transport of 1,700 tons is obtained. Based on a density of the sediment load of 105 lbs. per cubic foot (13) the average annual long term volume of sediment carried by Wilson Creek under existing conditions is 1,200 cubic yards.

Total Sediment Transport during Alluvial Phase of Delta Formation

As outlined previously, the alluvial phase of the Wilson Creek Delta has been in the formation stage since about 11,000 B.P. Based on the above calculated average annual total sediment transport (suspended sediment load plus bedload) and a formation period of 11,000 years, a total amount of material of 13,200,000 cubic yards is obtained.

It will be noted that this figure is considerably less than the amount of material that was estimated previously to be in the alluvial portion of the Wilson Creek Delta. This descrepancy is probably due primarily to changes in climate over the last 11,000 years. As noted above, the figure of 13,200,000 cubic yards is

(13). Pers. Comm. C. R. Miller--opp. cit.

based on a sampling period of only ten years. The climate over the region has varied drastically since the beginning of the formation of the alluvial phase. For example, it is stated in "Life, Land and Water" (14) that since 550 B.C. there have been seven climatic episodes over the region occupied by glacial Lake Agassiz that are readily identifiable. Each of the climatic episodes is characterized by a definite precipitation regime varying from extremely wet to arid. Because of changes in the climatic regime during these periods, there would be vast differences in the rate of annual sediment transport by the creek and therefore the rate deposition would alter from climatic episode to climatic episode. This variation in the rate of deposition may be seen in the photographs accompanying this thesis. Photos 7 and 8 show exposed banks of the creek through the delta area and definite indications of changes in the rate of deposition may be seen by obvious change in particle size and the color bands.

(14). Life, Land and Water--opp. cit.

CHAPTER V

BALDHILL RESERVOIR

Description

In 1960, studies were initiated to determine if it would be feasible to develop storage in the headwaters of Wilson Creek. (15) The studies indicated that careful developement of adequately observed storage reservoirs in the headwater areas would serve a twofold purpose, namely, controlling a potential source of flood producing run-off and furnishing necessary information to clarify conclusions with regard to the physical feasibility of the construction of detention basins in the headwaters of escarpmental streams. A study of aerial photographs and topographical maps of the upper portions of the watershed indicated a number of potential sites for headwater storage developement. These sites were verified by field reconnaissance. They were open boggy meadows located in the upper part of the watershed in the area where forest cover was minimal. The meadows had at some time in the past been flooded by now breached beaver dams. Topographical surveys of the dam site and reservoir were completed and the design of the Baldhill Dam was undertaken.

Construction of the Baldhill Dam and Reservoir was completed in 1961. The drainage basin tributary to the reservoir has an area

(15). G. H. MacKay, G. T. Forsyth, Headwater Storage Proposals, Wilson Creek Watershed, 1960, Unpublished Report, P.F.R.A.

of 584 acres and is divided into north and south sections by a low ridge. The two sections are connected through the ridge by a small channel. The location of the dam and reservoir is shown in Fig. 2. The dam is an homogeneous earthfill with a maximum height of twenty-six feet. The embankment has $3\frac{1}{2}$:1 side slopes on the upstream side and 3:1 side slopes on the downstream side. An uncontrolled twelve inch diameter corregated metal pipe serves as the main outlet for the water stored in the reservoir. The design criteria with regard to rainfall and assumed runoff coefficients indicated that the design flood would reach an elevation twenty-two feet above the bottom of the reservoir, based on the assumption that the reservoir would be empty at the beginning of the flood. An uncontrolled earth spillway is constructed at this elevation to allow for the passage of rare floods through the reservoir without encroaching on the safety of the dam. The storage capacity at the elevation of the emergency spillway is 337 acre feet.

The cost of the Baldhill Dam and Reservoir was approximately \$20,000 exclusive of engineering costs. The operation and maintenance costs since the dam and reservoir were completed have amounted to an average of \$400 a year. Based on an interest rate of 6% and an assumed life for this structure of fifty years, the interest and amartization charges amount to \$1,270 annually. The total annual cost, therefore, for the development of 337 acre feet of storage is approximately \$1,670.

Inflow Hydrographs

In order to determine the inflow hydrograph to the reservoir an automatic stage recorder is incorporated into the dam. This makes it possible to have a continuous record of the change in stage in the reservoir with respect to time. As mentioned above, the outflow during the passage of ordinary floods is through an uncontrolled twelve inch conduit. Measurements have been made of the discharge through this conduit for various reservoir stages and a reservoir level-discharge rating curve has been prepared. By combining the storage-elevation curve and the outflow-elevation curve and by knowing the rate of change of water level in the reservoir it is possible to determine, for a given storm, the shape and size of the inflow hydrograph.

The stage and discharge data that has been obtained on the reservoir since it was completed in 1961, were programmed by Mr. M. Sydor, University of Manitoba, Civil Engineering Department on the I.B.M. 360 computer and all of the storm events were routed through the reservoir and the inflow hydrograph for each storm event determined. (16). The routing program and routing calculation details may be found in Appendix 4.

(16). The individual inflow hydrographs are not included herein. However, they are available upon request to the author.

Calculations of the Effect of Baldhill Reservoir on Flows at the Watershed Outlet

In order to determine the effect of the storage reservoir in the upper portions of the watershed on flows at the watershed outlet, it is necessary to determine the shape of the hydrograph at the outlet if the reservoir had not been in existence. This was accomplished by routing the calculated inflow hydrographs through the stream channel, downstream to the Park boundary. The difference between the resulting inflow hydrograph, as would have been measured at the Park boundary and the actual reservoir outflow hydrograph routed to the outlet, were then added to the recorded discharges at the main hydrometric station. The resulting hydrograph then represents the hydrograph that would have been observed at the main hydrometric station if the reservoir had not been in existence. Fig. 7 shows the hydrographs resulting from the storm of May 17, 1962. The calculated inflow hydrograph to the Baldhill Reservoir is shown along with the calculated inflow to Baldhill Reservoir routed to the Wilson Creek outlet. The resulting theoretical hydrograph at the Wilson Creek outlet is shown on the same figure. It will be noted that the peak discharge at the main hydrometric station which was measured at 56 c.f.s. would have been 73 c.f.s. if the Baldhill Reservoir had not been in existence.

In order to route the inflow hydrograph through the stream channel to the outlet of the watershed several simplifying assumptions were necessary. The most important assumption made in this study was that the hydrograph would be translated, but there would be no attenuation as a result of channel storage. This assumption is thought to be relatively valid since the Wilson Creek is extremely steep and a very slight change in stage corresponds to a large increase in discharge; therefore, it is reasonable to expect that a significant amount of water does not have to go into channel storage in order to pass the flood wave through the system.

The time of travel of the hydrograph through the channel system was based on data obtained during an experiment in the watershed carried out during the summer of 1968. At that time, water stored behind a beaver dam in the upper portions of the watershed was released suddenly by rapid removal of the beaver dam and the resulting flood wave was measured as it moved downstream. The time of travel from the upper part of the watershed to the hydrometric station at the park boundary was approximately two and one-half hours. This figure was used as the time of travel of the hydrograph from the Baldhill Reservoir to the outlet. It may be argued that the experiment conducted in 1968 in the watershed was superimposed on a relatively small flow in the creek and that during larger floods the flood wave would move more rapidly. This may be the case, however, in view of the short travel time compared to the duration of the peak of the hydrograph at the main outlet, it is not considered that the assumption used will significantly effect the results. For each of the 18 storm events for which inflow hydrographs were calculated and routed to the outlet, the effect on the average daily discharge of the Baldhill Reservoir was calculated.

Based on these new average daily discharges, a flow duration curve was prepared (17). Fig. 8 shows the flow duration curves under existing conditions, that is, with the Baldhill Reservoir in operation and, under natural conditions. The difference between the two curves indicates the effect of the reservoir. It will be noted that flows below 4 c.f.s. occur more often with the reservoir than without as a result of the release of flood water from storage. It will also be noted that the higher discharges occur less frequently with the reservoir in operation than they would have under natural conditions.

Effect of Baldhill Reservoir on Average Annual Sediment Transport

Using the relationship between water discharge and sediment discharge as previously developed and as shown in Fig. 4, the average annual sediment discharge based on the flow duration cuve under natural conditions was calculated. The value for the average annual suspended sediment transport under natural conditions is 5.33 tons per day. (See Appendix 3). Based on the assumption that the suspended sediment discharge under natural conditions of flow represents the same proportion of the total sediment discharge as was measured under the control conditions since 1962, the average annual total sediment transport under natural conditions is 9.69 tons per day. Based on a sediment producing period of 200 days per year then the average annual total sediment discharge is 1,938 tons.

(17). The flow-duration curve for natural conditions was calculated by Mr. M. Sydor. (opp. cit.)

Using a unit weight of 105 lbs. per cubic foot, the number of cubic yards of material transported under natural conditions would be 1,365 per year. This compares with a total average annual discharge of 1,200 cubic yards under controlled conditions. The difference, 165 cubic yards per year, is the benefit that may be attributed to the Baldhill Reservoir in the reduction of sediment transported and deposited in the channel downstream of the national park boundary.

CHAPTER VI

MAINTENANCE COSTS FOR THE WILSON CREEK DRAIN

Brief History of Drainage in the Wilson Creek Delta Area

Agricultural developement of the Wilson Creek Delta began in 1908 in a homestead in the S. E. $\frac{1}{4}$ - 31-20-15 W.P.M. In 1908, the Wilson Creek had no formed channel through section 31 and such water as came into this section emptied into peat bogs and marshy areas and any out-flow continued in a general northeasterly direction, likely joining with similar type of flow from McKinnon Creek and thence to the Turtle River. Very shortly after the initial homesteading took place in the area, there was a concentrated effort on providing land drainage in order to lower the water table and to reclaim some land that was in jackpine swamp and in low marshy meadows.

Original plans indicate that the first land drainage in the Wilson Creek Delta was initiated about 1916. (18). The drain intercepted the creek at approximately one-half mile east of the national park boundary and ran north-westerly to the corner of the section and then directly east to the Turtle River.

(18). C. R. Stanton, Wilson Creek Watershed. A report on Background Information. 1958. Unpublished mms.

Maintenance Costs

There was no further work on drainage until about 1929, at which time reconstruction of the original drain was carried out. The total cost of the reconstruction amounted to $10,000. From 1935 to 1957 a periodic maintenance of the drain was carried out, primarily cleaning out sediment which was deposited after every freshette on the creek. During this period a total of $13,500 was spent on the main drainage channel. From 1950 to 1957, which represented a relatively wet period, some $29,600 was spent on periodically cleaning out the drain. As the cleanouts continue, more and more of a problem is encountered in the disposal of material dredged out of the drain. As the spoil bank adjacent to the drain becomes larger it is necessary to purchase more land in order to dispose of the material. Not including the original cost of the drain, a total expenditure of some $43,000 has been spent on maintenance since 1929. Based on these figures an average annual maintenance cost of approximately $1,500 a year is attributable directly to the sediment aspect of the problem caused by the Wilson Creek as it moves through the Wilson Creek Delta.

A comparison of the average annual cost as computed from the drainage records with the cost calculated from the figures for average annual sediment transport reveals a relatively close agreement. As noted above, the average annual sediment transport, under natural conditions, is approximately 1,365 cubic yards. If is is assumed that all of this material is deposited in the drain between the National Park boundary and the Turtle River, then at a unit cost of $1.00 per cubic yard to remove this material, a total annual cost of $1,365 is arrived at. The cost figure of $1.00 per cubic yard is not considered excessive if it includes the cost of right of way purchase, spoil disposal, as well as removal of material from the drain, and other costs that are included in the figure of $43,000 total maintenance costs of the drain.

Based on the same unit costs the value of the Baldhill Reservoir in reducing the sediment discharge of the stream may be calculated. As noted previously, the Baldhill Reservoir reduces the long term average annual transport by 1.81 tons per day. Again, based on a 200 day per year sediment transporting period, an average annual reduction in the sediment deposited in the drain of 165 cubic yards could be attributed to the Baldhill Reservoir. Based on $1.00 per yard, the benefit that could be attributed to the Baldhill Reservoir in reducing the average annual maintenance costs of the Wilson Creek Drain would be $165 per year.

CHAPTER VII

COMPARISON OF RESERVOIR COSTS AND SEDIMENTATION EFFECT BENEFITS

Costs

The average annual costs of the Baldhill Reservoir include interest on the initial investment, amortization of the initial investment and annual operation and maintenance costs. One of the purposes of the Wilson Creek Experimental Watershed Project was to determine the cost of developing and maintaining an experimental watershed, and for this reason an elaborate system of cost accounting was established (19). By reference to the cost figures in the annual reports of the project, the following detailed cost break-down for the Baldhill Reservoir is available:

A. CAPITAL COST

1. Baldhill Dam including foundation preparation, conduit, and compaction of fill material	$12,068.88
2. Fills associated with Baldhill Reservoir	7,970.50
TOTAL CAPITAL COST	$20,039.38
Total maintenance cost of Dam and fills during period 1961-1968	$ 4,150.00
TOTAL COST TO DATE	$24,189.38

(19). See annual reports for period 1959-1968 on the Wilson Creek Watershed prepared by P.F.R.A. and available from the author.

B. ANNUAL COSTS

1. Interest at 6%			\$1,202.36
2. Amortization at 6%-50 years			69.00
3. Average operation and maintenance			518.00
TOTAL ANNUAL COST			\$1,789.36
Average annual cost per acre foot of usable flood control and sediment reduction storage	$\frac{1789.36}{337}$	=	\$ 5.30

Benefits Resulting from Reduced Sediment Load

As outlined previously, the average annual total sediment load under natural conditions, based on a sampling period of seven years, 1962 to 1968 is 1,365 cubic yards. If it is assumed that none of the sediment load moves through the Wilson Creek Delta area, but is all deposited in the Wilson Creek Drain, then the maximum benefit that could be obtained would be to reduce the sediment load carried out of the escarpmental portion of the watershed to zero. If a unit cost of removal of the sediment deposited in the drain of \$1.00 per cubic yard is adopted, then the maximum annual benefit that would be attributable to any type of sediment reduction works would be \$1,365. The unit value of one dollar per cubic yard is considered a reasonable figure based on the actual cost of material removal of \$0.25 per cubic yard, the cost of spreading the removed spoil material of \$0.25 per cubic yard, the cost of obtaining cultivated land on which to dispose the material of \$0.30 per cubic yard and other miscellaneous costs such as cleaning out culverts, vegetation control on spoil banks and contingencies of $0.20 per cubic yard.

The benefit that may be attributed to the Baldhill Reservoir to the reduction in the cost of drain maintenance is the reduction in the average annual amount of material deposited in the drain resulting from the construction of the Baldhill Reservoir. As noted previously, this amounts to 165 cubic yards per year. At a unit value of $1.00 per cubic yard the benefits accruing to the Baldhill Reservoir are then $165 per year.

Comments on Economics of Headwater Storage

It must be emphasized that the only benefits that were considered in this study were those of reduced maintenance resulting from reduced average annual sediment load in the Wilson Creek Drain which carries the Wilson Creek through the Wilson Creek delta. It is obvious if the average annual benefit in this regard is only $165, while the average annual cost as noted previously is $1,800, the Baldhill Reservoir could not be justified on the basis of reduced sediment alone.

It will be very obvious from consideration of reduced flow resulting from the Baldhill Reservoir that the main source of benefits to headwater storage along the escarpment is in the reduction of flood damage. For example, during the flood of 1953, in which thousands of acres of agricultural land were flooded along the base of the escarpment, direct flood damage to agricultural land and to public works, such as roads, bridges, etc., averaged about ten dollars per acre (20). The average annual direct flood damage is estimated to be about $1.00 per acre. Before a conclusion may be reached regarding the economics of the flood detention basins, detailed studies in the reduction in flood damage resulting from such reservoirs are required. An indication of the significant reduction in flood flows that result from headwater storage may be found in the following table:

DATE	INSTANTANEOUS PEAK			AVERAGE DAILY PEAK		
	natural (c.f.s.)	with reservoir (c.f.s.)	reduction (c.f.s.)	natural (c.f.s.)	with reservoir (c.f.s.)	reduction (c.f.s.)
17/5/62	73	56	17	31	27	4
30/5/62	298	237	61	258	218	40
4/6/63	43	31	12	27	21	6
10/6/63	246	202	44	200	165	35
4/5/64	39	18	21	30	15	15
19/6/64	22	11	11	15	8	7
6/5/65	173	126	47	136	98	38
28/6/65	4.5	2.0	2.5	4.0	1.5	2.5
1/7/65	4.8	2.7	2.1	3.5	2.0	1.5
1/8/65	11.0	4.5	6.5	7.5	3.5	4.0
3/9/65	126	111	15	85	46	39
15/5/66	81	56	25	60	47	13
30/6/66	21	18	3	13	9	4
8/8/66	121	114	7	80	76	4

(20). Pers. Comm. C.R. Stanton, Canada Department of Fisheries and Forestry, Ottawa.

A few comments on the cost of headwater storage are worthy of mention. The Baldhill Reservoir was located in a particularily advantageous site. The storage per foot of dam height was very significant because of topography. Additional storage sites in the Wilson Creek Watershed are not nearly as attractive as the Baldhill site and it may therefore be concluded that the cost of storage will be far in excess of the $5.30 per year per acre foot for the Baldhill Reservoir. Other studies (21) indicate that the unit cost of storage will likely approximate $15.00 per acre foot per year in the upper portions of the watershed and far in excess of this figure in the escarpmental portions.

Detailed studies on other escarpmental water sheds have not been made, but it is reasonable to expect that at least one site, similar to the Baldhill site, may be found for each watershed. If it is assumed that the chances of locating a good to excellent storage site are proportional to the size of the plateau portion of the watershed, and that the plateau portion of the watershed is at a relatively constant proportion of the size of the total watershed, then it may be estimated that reservoirs as effective as the Baldhill Reservoir may be constructed along the escarpment at a cost of about $0.60 per year per square mile of drainage area above the base of the escarpment. Each watershed should have a reservoir site which may be developed at this cost that will control 10% to 15% of the watershed.

(21). These studies were made by the author on the cost of storage develeopement in Manitoba as part of another project.

CHAPTER VIII

DISCUSSION

The results of this study may be discussed under two main sections:

1. Geomorphology and
2. Economics of Headwater Storage.

Geomorphology

The estimate made on the amount of material deposited in the Wilson Creek Delta at the base of the Manitoba escarpment above the post glacial surface indicated between 400 million cubic yards and 500 million cubic yards. The majority of this material was deposited in the lacustrine phase of the delta formation, 13,000 B.P. to 11,000 B.P. During these two thousand years it is postulated that extremely wet conditions prevailed, and the steep slopes of the escarpmental portion of the watershed were void of any vegetation and for these reasons erosion was rapid and sustained throughout the whole period.

During the alluvial phase of the formation of the delta, 11,000 B.P. to present, a total of 140 million cubic yards were deposited. This figure is based on volume determinations made between the present surface and the surface assumed to exist at 11,000 B.P. immediately after the drainage of Lake Agassiz. This latter surface was inferred from existing topography, stratigraphic test holes, and an examination of small scale aerial photographs.

During the alluvial phase it is most likely that the area has experienced wet periods of rapid alluvial fan developement interspersed with longer periods of quescence. During an inspection of the delta of Henderson Creek, a short distance to the north, the author observed an artificial cut through the delta in which five complete topsoil profiles interspaced with alluvial shale deposits overlay the glacial surface. This indicated periods of rapid erosion, followed by periods of small erosion during which time soil profiles had a chance to develop.

An attempt was made to estimate the amount of material that has been eroded from the escarpmental portion of the watershed during the period since deglaciation. Based on the assumption that the glacier covered the preglacial topography with a layer of glacial debris and that the remaining surface was relatively smooth and, further, based on the assumption that during the past 13,000 years the northern and southern rims of the watershed have not been eroded, it was estimated that about 430 million cubic yards of material has been eroded from the face of the escarpment within the Wilson Creek watershed.

Calculations were made on the average annual sediment discharge of the Wilson Creek using the data from measurements made on the sediment and water discharge as part of the Wilson Creek Experimental Watershed. Based on the sampling period 1962 to date, it was determined that the average sediment load that is in suspension and moving along the bed as bedload is 8.51 tons per day. With a unit weight of the transported material of 105 lbs. per cubic foot a total amount of sediment transport of 1,200 cubic yards per year was found. This figure includes the effect of the Baldhill Reservoir. The average annual sediment transport under natural conditions was found to be 1,365 cubic yards per year.

On the assumption that the rate under natural conditions was maintained constant over the period of alluvial developement of the fan, 11,000 B.P. to date, a total amount of 15,000,000 cubic yards has been moved by the stream into the delta area. It was found that it is unlikely that the average annual transport calculated on the data gathered during the past decade is equal to the average annual sediment transport over the past 11,000 years.

From the above, it may safely be concluded that the rate of erosion over the past decade is less than during previous times and there is no evidence to indicate that the rate of erosion is increasing with time. On the contrary, every evidence points to a reduction in average annual sediment load of the stream. Indications also are that the erosion and deposition processes being observed are geological processes and works of man have had, or can have, little if any effect on the rate of this process.

Economics of Headwater Storage

This portion of the thesis was limited to the determination of the benefits that can be attributed to the Baldhill Reservoir in reducing the average annual clean-out costs on the artificial waterway carrying Wilson Creek through the Wilson Creek Delta. The effect of the detention basin on average daily flows at the outlet of the watershed were calculated and from this the reduction in average annual sediment transport computed.

It was found that a reduction in average annual total sediment load of 165 cubic yards could be attributed to the Baldhill Reservoir.

The average annual cost of the Baldhill Reservoir was calculated to be approximately $1,800. Based on an annual benefit of $165 and an annual cost of $1,800 it is obvious that the Baldhill Reservoir cannot be justified on the reduction in drain maintenance costs alone.

The incremental cost of storage developement was calculated to be $5.30 per year per acre foot. The maximum benefit that could accrue to reduction in drain maintenance would be $1,365 if the annual cost were reduced to zero. At an annual unit cost of storage of $5.30 not more than 258 acre feet could be developed to achieve this total elimination of maintenance costs if the entire reservoir cost were to be allocated to reduced maintenance of the Wilson Creek Drain.

It should be strongly emphasized that without the data that has been gathered and accumulated as part of the Wilson Creek Experimental Watershed project none of the calculations used in this thesis could have been made.

Further work with regards to the quantitative geomorphology of watersheds that flow across the Manitoba Escarpment should be undertaken. Carbon dating techniques could be employed to better understand the developement of the delta and to appraise the varying rates of deposition. Additional studies on the economics of head-water storage are warranted. It is likely that much larger benefits will accrue to reduction in flood damage than accrue to the reduction in annual costs of drain clean-out. Additional studies on the translation of the flood hydrograph through the escarpmental drainage system should be undertaken as the next step in appraising how headwater storage modifies the flood hydrograph at the outlet of the watershed. Data is available from the information being collected in the Wilson Creek Experimental Watershed to undertake all these studies and the author recommends that immediately competent manpower becomes available such studies should be put under way.

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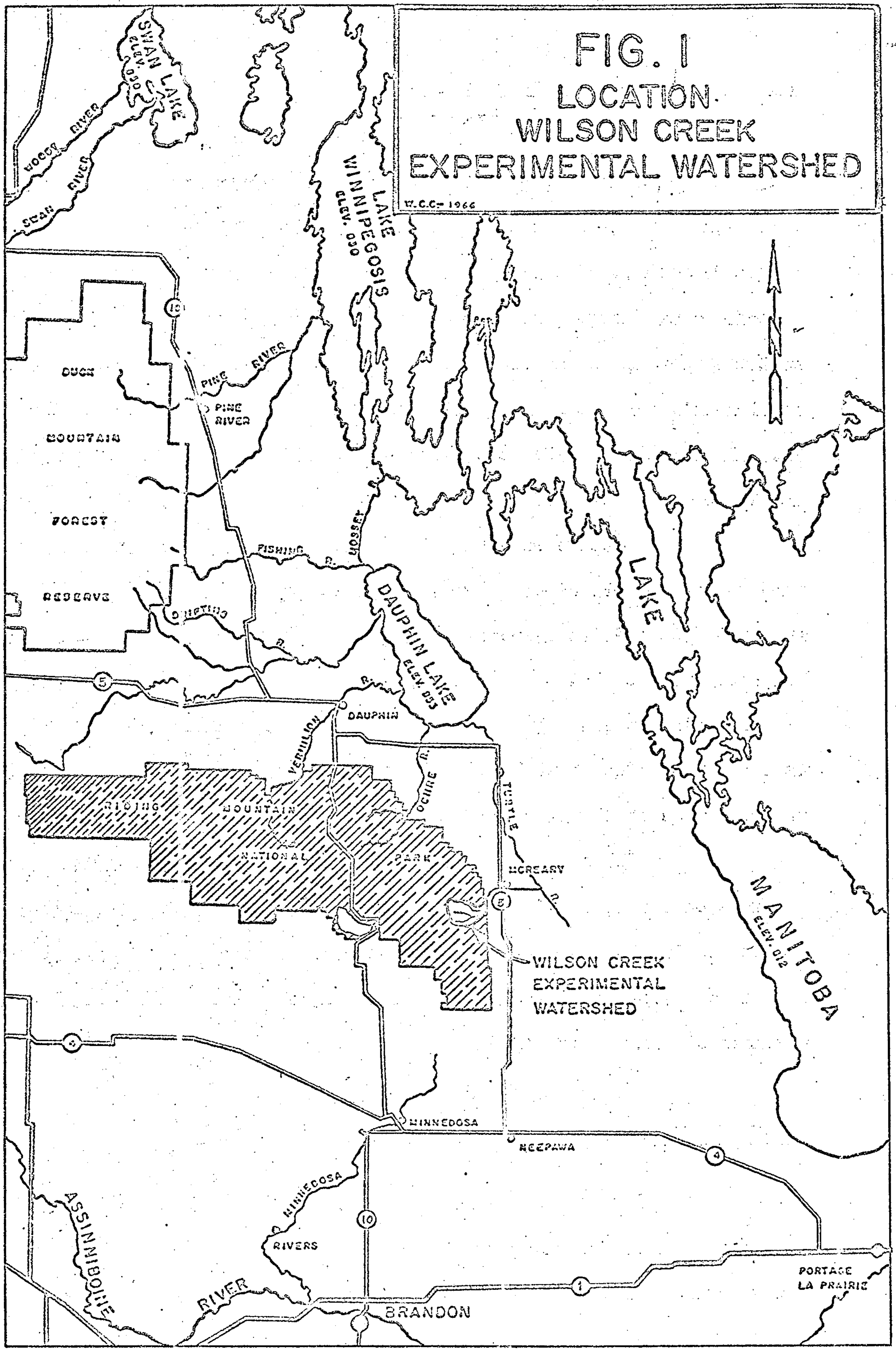


FIG. I
LOCATION
WILSON CREEK
EXPERIMENTAL WATERSHED

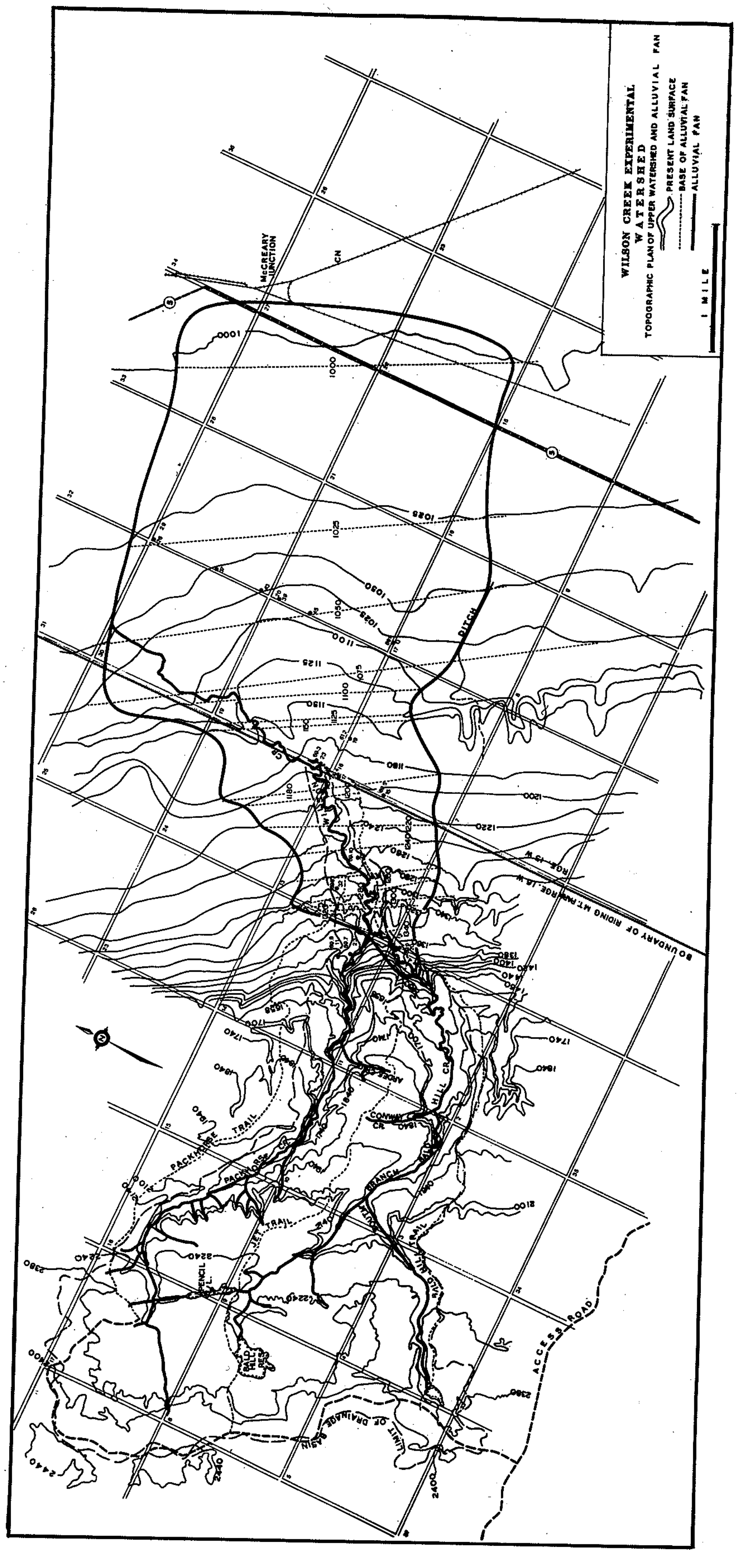
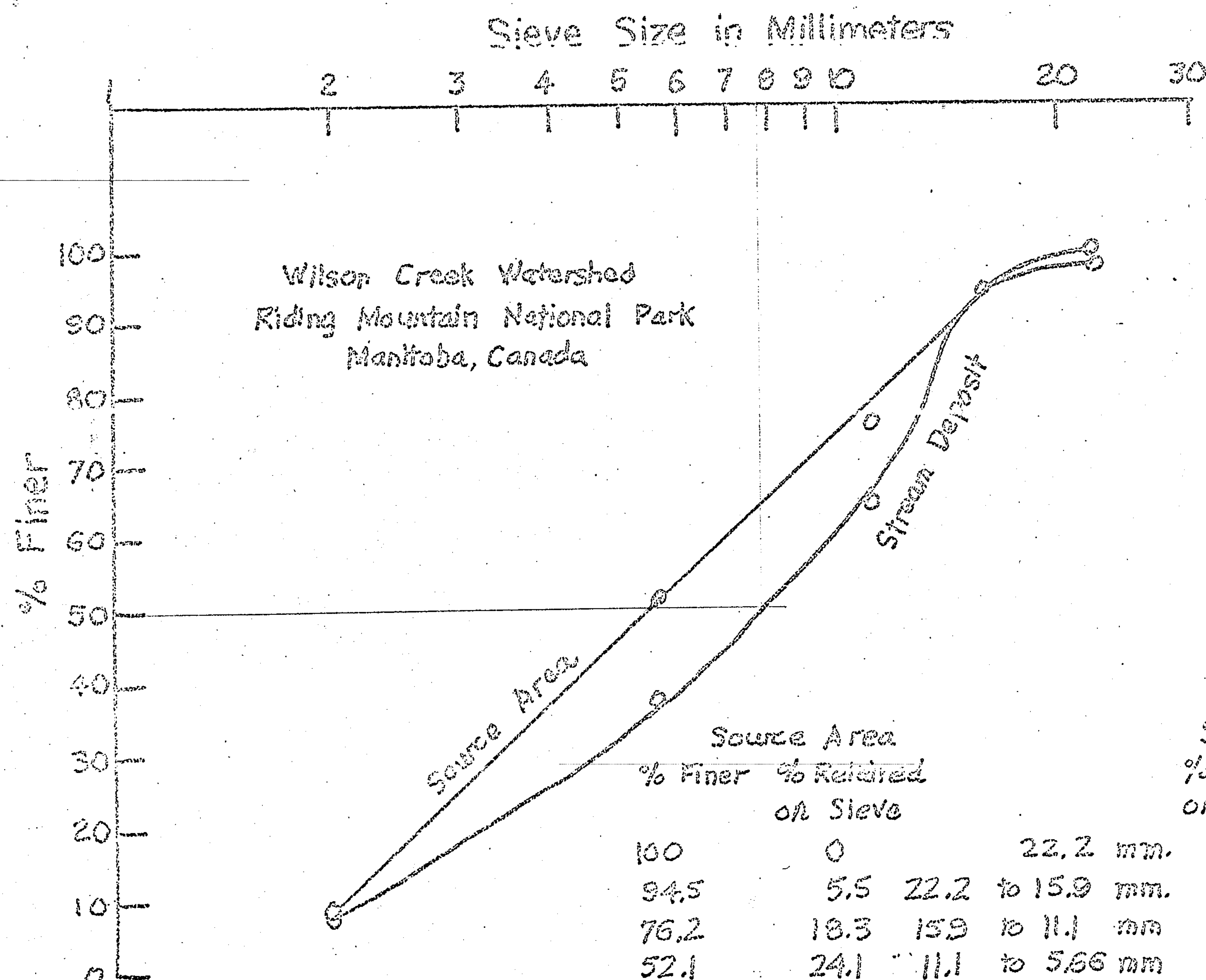
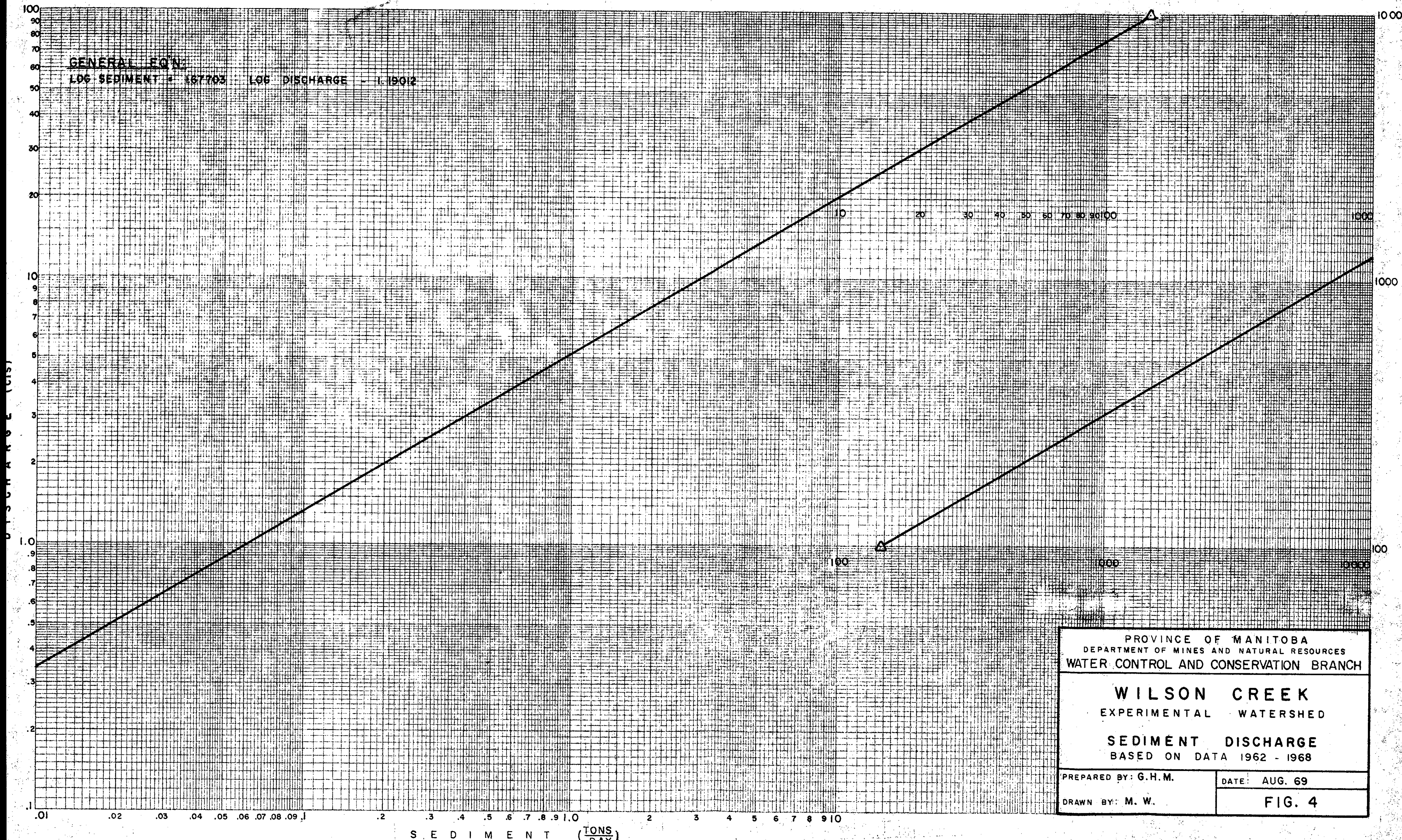

WILSON CREEK EXPERIMENTAL
WATERSHED
TOPOGRAPHIC PLAN OF UPPER WATERSHED AND ALLUVIAL FAN
PRESENT LAND SURFACE
BASE OF ALLUVIAL FAN
ALLUVIAL FAN
1 MILE
McCREARY JUNCTION
BOUNDARY OF RIDING MT. PARK
ACCESS ROAD
LIMIT OF DRAINAGE AREA
PACKHORSE TRAIL
DITCH

FIGURE 2



Source Area % Finer	Source Area % Retained on Sieve		Stream Deposit % Retained on Sieve	Stream Deposit % Finer
100	0	22.2 mm.	2.2	97.
94.5	5.5	22.2 to 15.9 mm.	2.9	94.
76.2	18.3	15.9 to 11.1 mm	29.8	65.
52.1	24.1	11.1 to 5.66 mm	27.1	38.
9.0	43.1	5.66 to 2.00 mm	30.0	8.
	9.0	2.00 mm.	8.0	

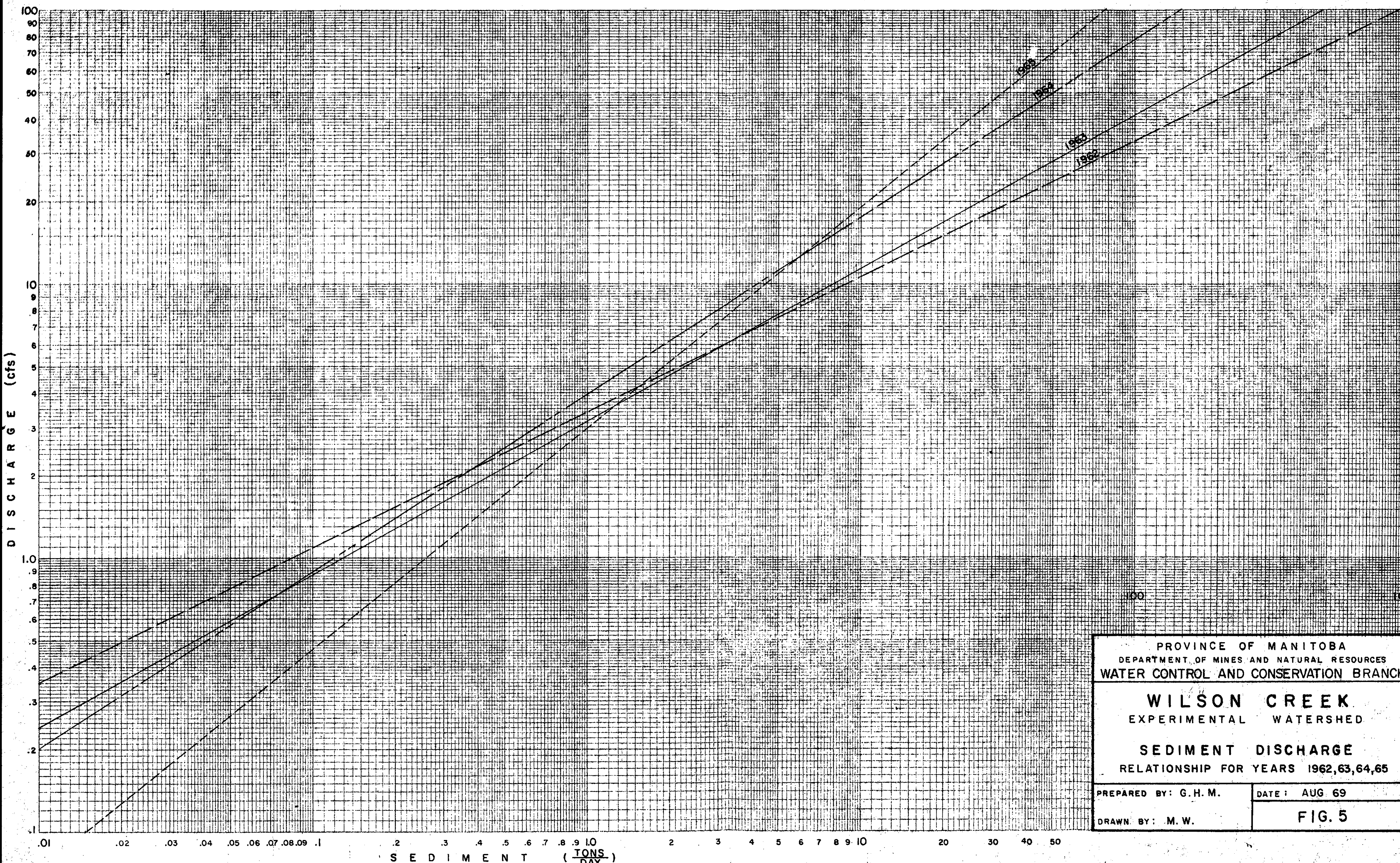


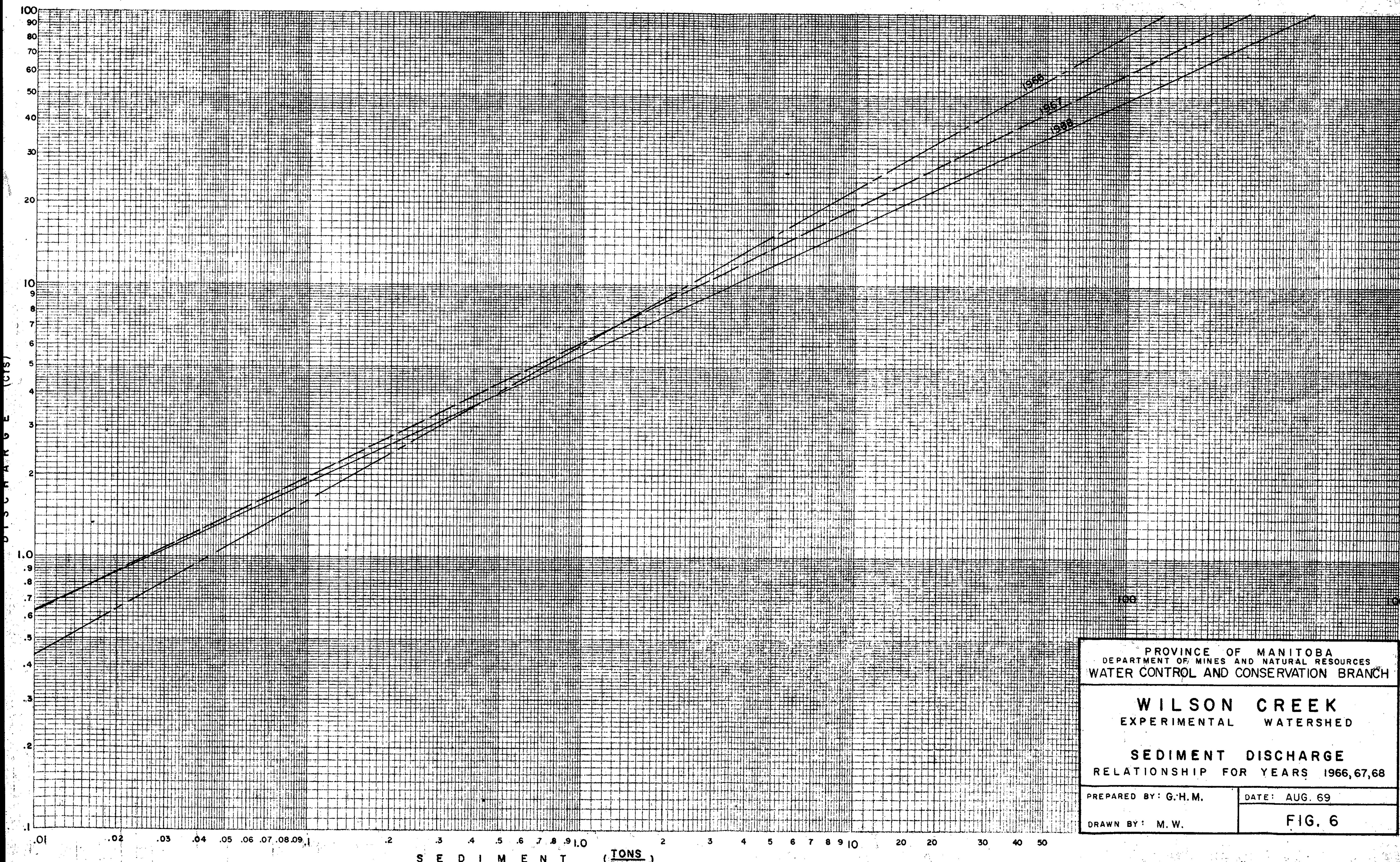
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

WILSON CREEK
EXPERIMENTAL WATERSHED

SEDIMENT DISCHARGE
BASED ON DATA 1962 - 1968

PREPARED BY: G.H.M.	DATE: AUG. 69
DRAWN BY: M. W.	FIG. 4


DISCHARGE (cfs)
SEDIMENT (TONS/DAY)
1965
1964
1963
1962
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH
WILSON CREEK
EXPERIMENTAL WATERSHED
SEDIMENT DISCHARGE
RELATIONSHIP FOR YEARS 1962,63,64,65
PREPARED BY: G.H.M.
DATE: AUG 69
DRAWN BY: M.W.
FIG. 5



PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

WILSON CREEK
EXPERIMENTAL WATERSHED

SEDIMENT DISCHARGE
RELATIONSHIP FOR YEARS 1966, 67, 68

PREPARED BY: G.H.M.	DATE: AUG. 69
DRAWN BY: M. W.	FIG. 6

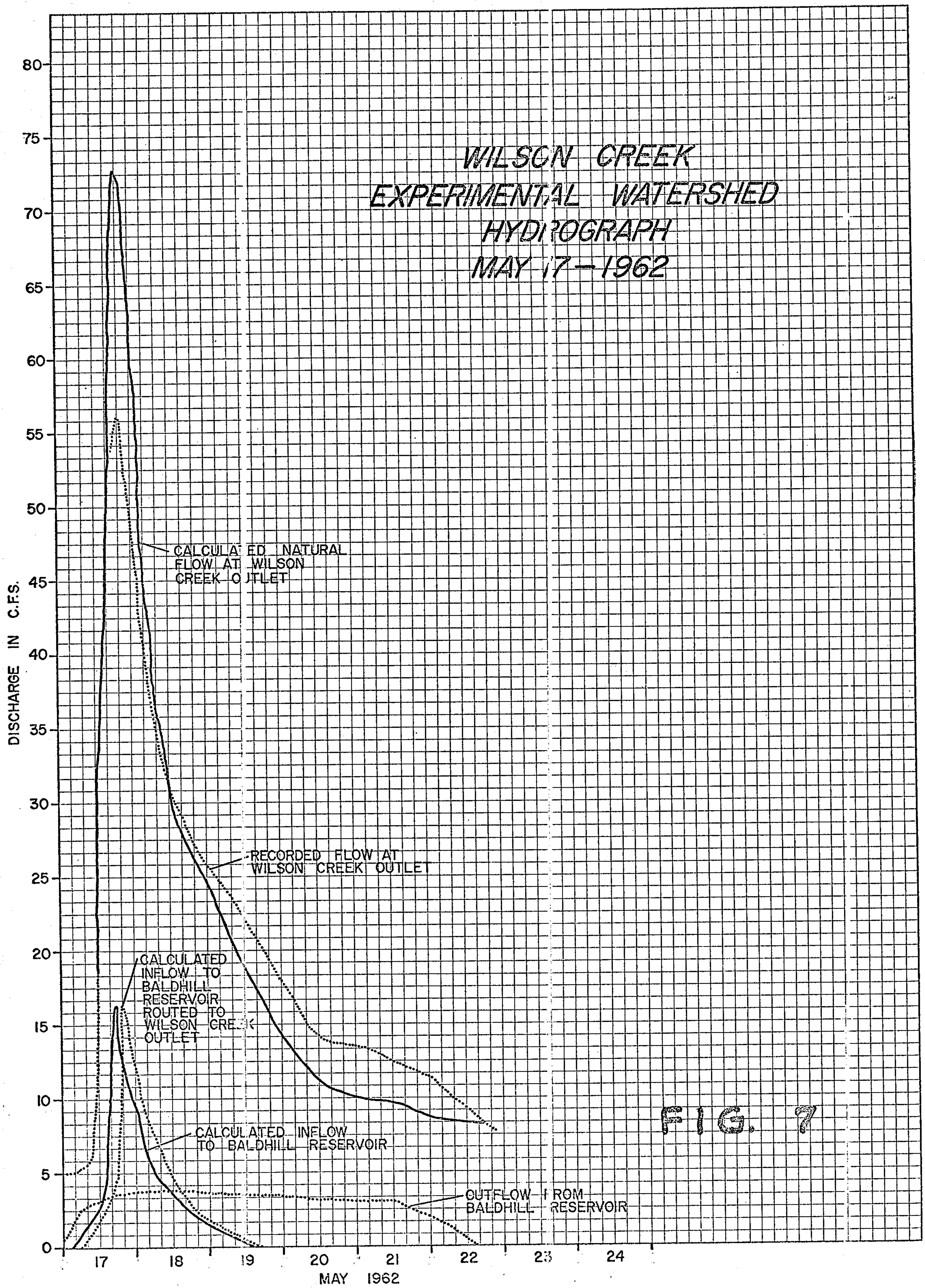
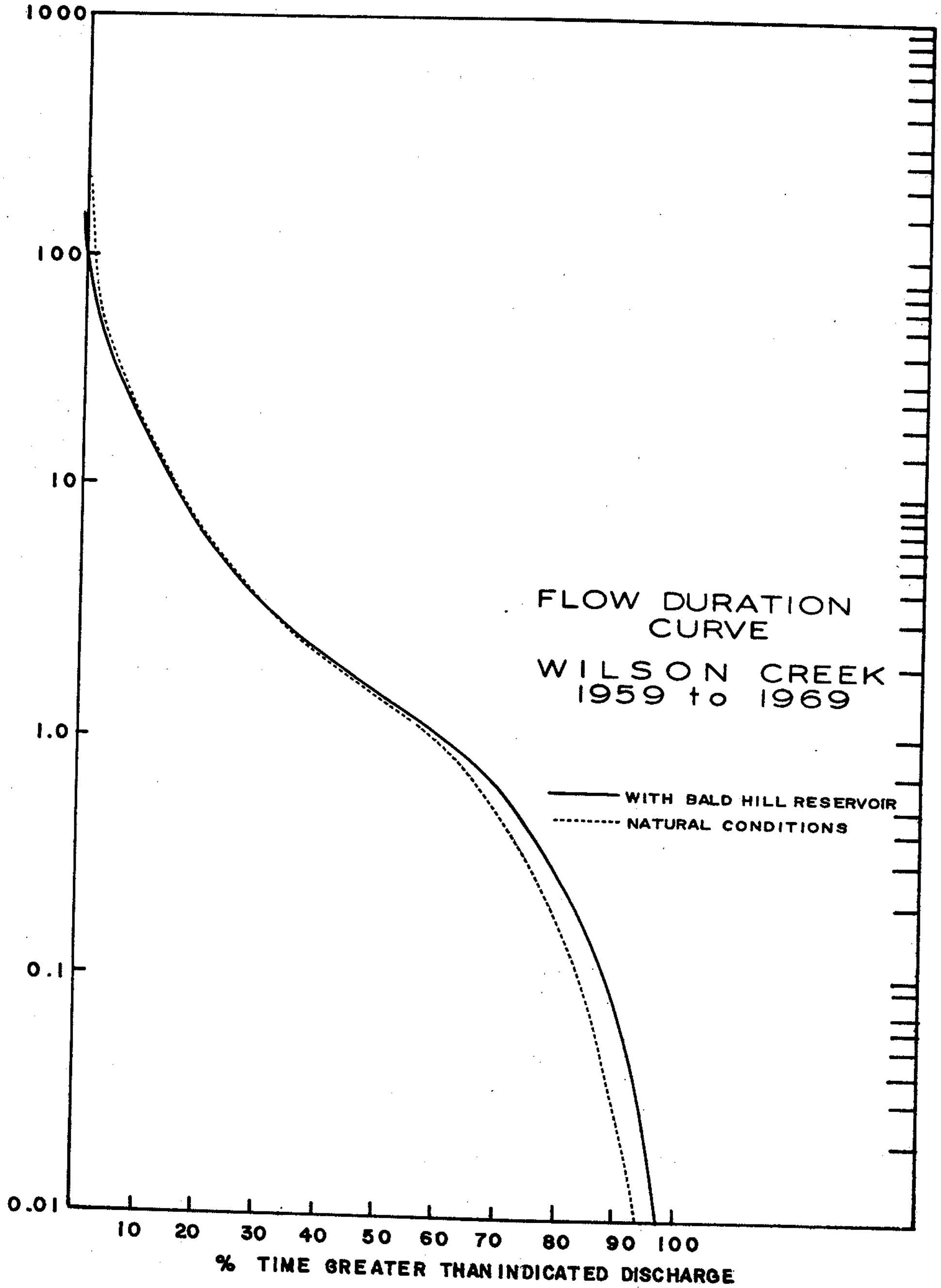

WILSON CREEK
EXPERIMENTAL WATERSHED
HYDROGRAPH
MAY 17—1962
DISCHARGE IN C.F.S.
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
CALCULATED NATURAL FLOW AT WILSON CREEK OUTLET
RECORDED FLOW AT WILSON CREEK OUTLET
CALCULATED INFLOW TO BALDHILL RESERVOIR ROUTED TO WILSON CREEK OUTLET
CALCULATED INFLOW TO BALDHILL RESERVOIR
OUTFLOW FROM BALDHILL RESERVOIR
17
18
19
20
21
22
23
24
MAY 1962

FIG. 7



1000
100
10
1.0
0.1
0.01
FLOW DURATION
CURVE
WILSON CREEK
1959 to 1969
WITH BALD HILL RESERVOIR
NATURAL CONDITIONS
10
20
30
40
50
60
70
80
90
100
% TIME GREATER THAN INDICATED DISCHARGE

FIGURE 8

FIGURE 1: Upper plateau area of watershed with tree cover and meadows.

FIGURE 2: Escarpment portion of watershed with bare shale banks.

FIGURE 3: Middle escarpment portion of watershed with coarse shale on bedrock surface.

FIGURE 4: Source area of weathered shale.

FIGURE 1: Upper plateau area of watershed with tree cover and meadows.

FIGURE 2: Escarpment portion of watershed with bare shale banks.

FIGURE 7

Middle portion of delta with buried tree stump and bedded deposits.

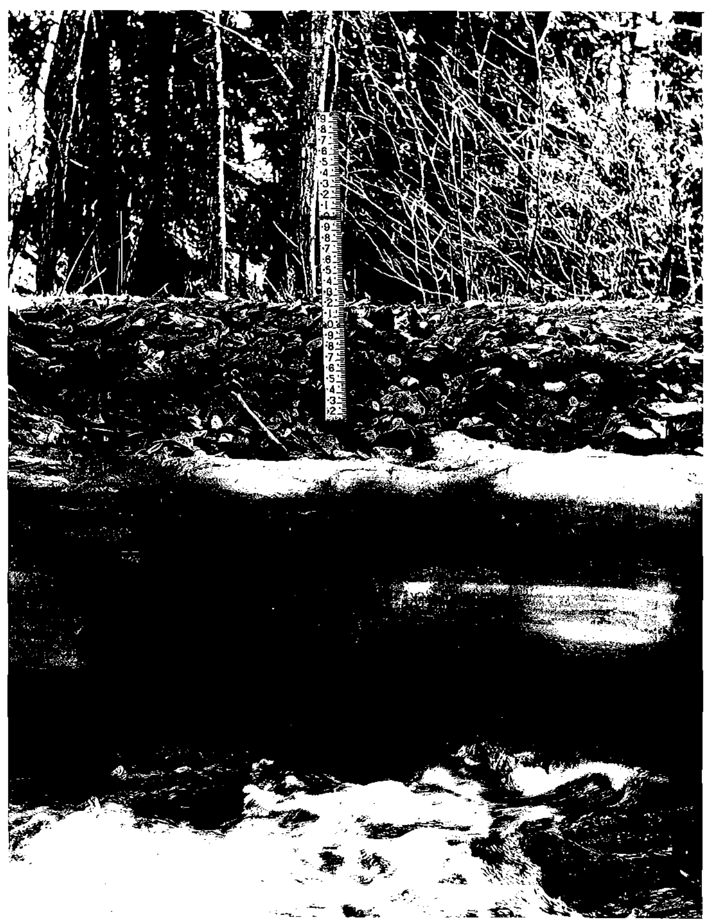


FIGURE 8

Upper delta area with recent deposits of coarse shale and gravel on winter ice cover.

APPENDIX 1

STRATIGRAPHIC DATA

WILSON CREEK DELTA

July, 1969.

WILSON CREEK TEST HOLES

69-1.	0 - 13'	Brown silty and pebbly alluvium - shale pebbles predominate.
	13' - 51'	Lacustrine sediments.
	51' - 80'	Bedrock.
69-2.	0 - 9'	Buff silty alluvium with shale pebbles.
	9' - 22'	Lacustrine sediments.
	22' - 59'	Glacial Till.
	59'	Bedrock.
69-3.	0 - 24'	Sandy shaley alluvium gravel size material.
	24' - 33'	Lacustrine sediments silts.
	33' - 65'	Glacial Till.
69-4.	0 - 17'	Brown sandy gravely alluvium.
	17' - 38'	Lacustrine sediments.
	38' - 50'	Bedrock.
69-5.	0 - 15'	Brown sandy gravely alluvium.
	15' - 50'	Lacustrine sediments (silt).
	50' - 80'	Bedrock.
69-6.	0 - 32'	Sandy silty alluvium abundant shale fragments - poorly sorted, soft and not very stiff.
	32' - 54'	Lacustrine deposits with occasional shale pebbles present.
	54' - 65'	Till?
69-7.	0 - 23'	Coarse very stoney alluvial material (shale) and cobble and pebble size material - very difficult drilling - almost like gravel.
	23' - 35'	Lacustrine? sediments and occasional shale fragments.
	35' - 50'	Bedrock.
69-8.	0 - 11'	Buff brown stoney silty alluvium mostly shale pebbles.
	11' - 35'	Brown Lacustrine silt with shale pebbles.
	35' - 50'	Brown very shaley and silty alluvial type of material - slightly washed appearance is that of a shaley gravel.
	50'	Gravely material } Actually glacial till
	65'	Sand and gravel } Actually glacial till
	65'	Bedrock.

69 - 9.	0 - 20'	Very coarse gravely alluvian - with shale fragments.
	Unable to continue.	
69- 10.	0 - 37'	Stoney silty alluvial material with shale fragments.
	37' - 74'	Clayey silt.
	74'	Bedrock.

DEPTH IN FEET

0	TOPSOIL
1	GREY CLAY
2	GREY SANDY SILT
3	SHALESTONES, GRAVEL AND CLAY
8	GREY CLAY
13	SOFT CLAY AND SHALESTONES
27	SOFT CLAY
36	SAND, GRAVEL, SHALESTONES, DIRTY AND SILTY SAND
42	STONY CLAY
43	SHALE AND BENTONITE
52	

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #21

S.W. 29-20-15W

PREPARED BY:

DATE: JULY / 69

FILE NO.

DRAWN BY: T. M.

DEPTH IN FEET

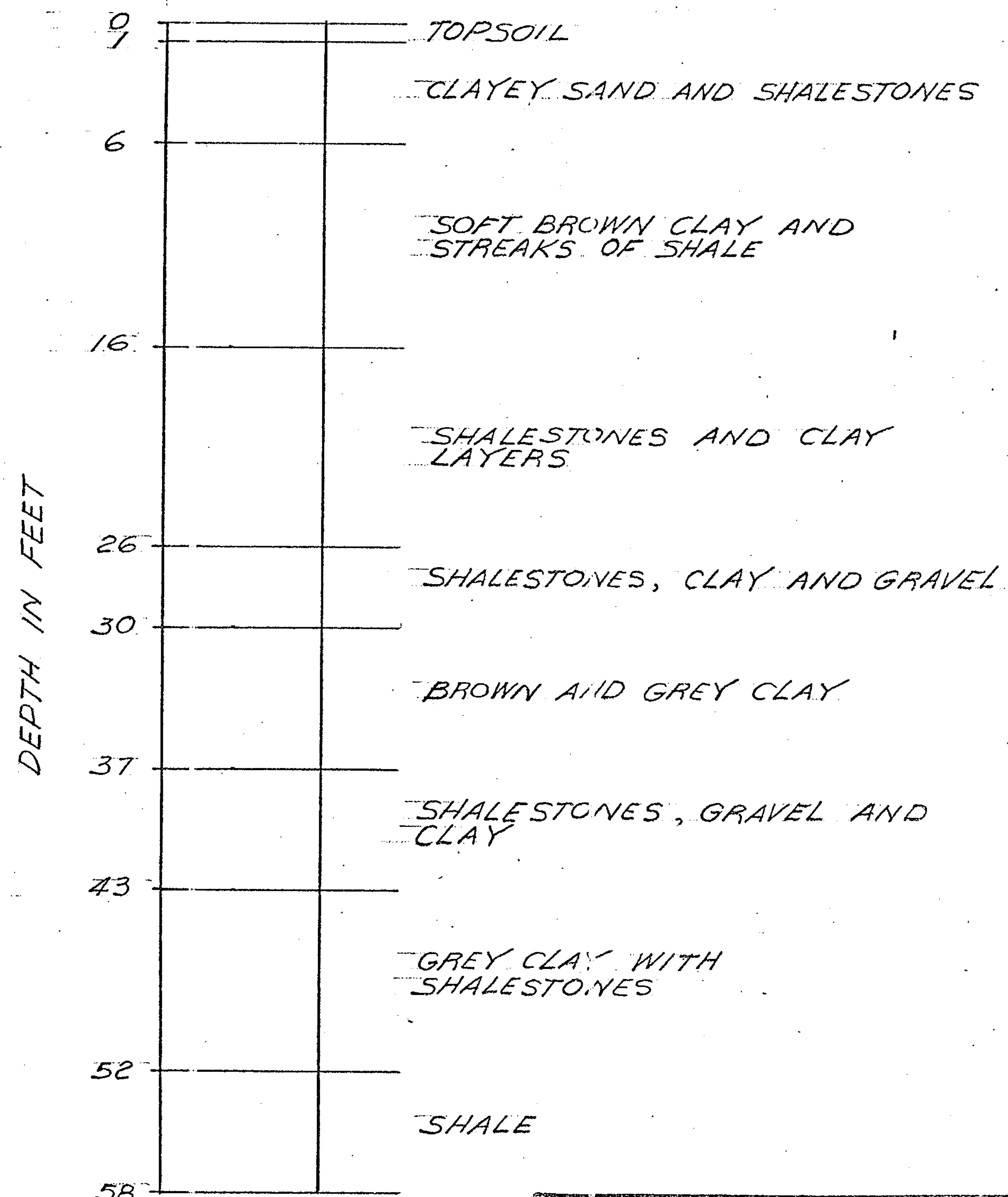
Depth (ft)	Material
0	TOPSOIL
2	SHALESTONES AND GRAVEL DIRTY
9	SOFT GREY CLAY
14	SHALESTONES AND GRAVEL
17	SOFT GREY CLAY
29	SAND AND GRAVEL IN CLAY
33	SANDY CLAY
35	SHALE
52	

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #19

S.W. 29-20-15W

PREPARED BY:	DATE: JULY / 69
DRAWN BY: T. M.	FILE NO.



PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #11

S.W. 30 - 20 - 15 W

PREPARED BY:

DATE: JULY /69

FILE NO.

DRAWN BY: T. M.

DEPTH IN FEET

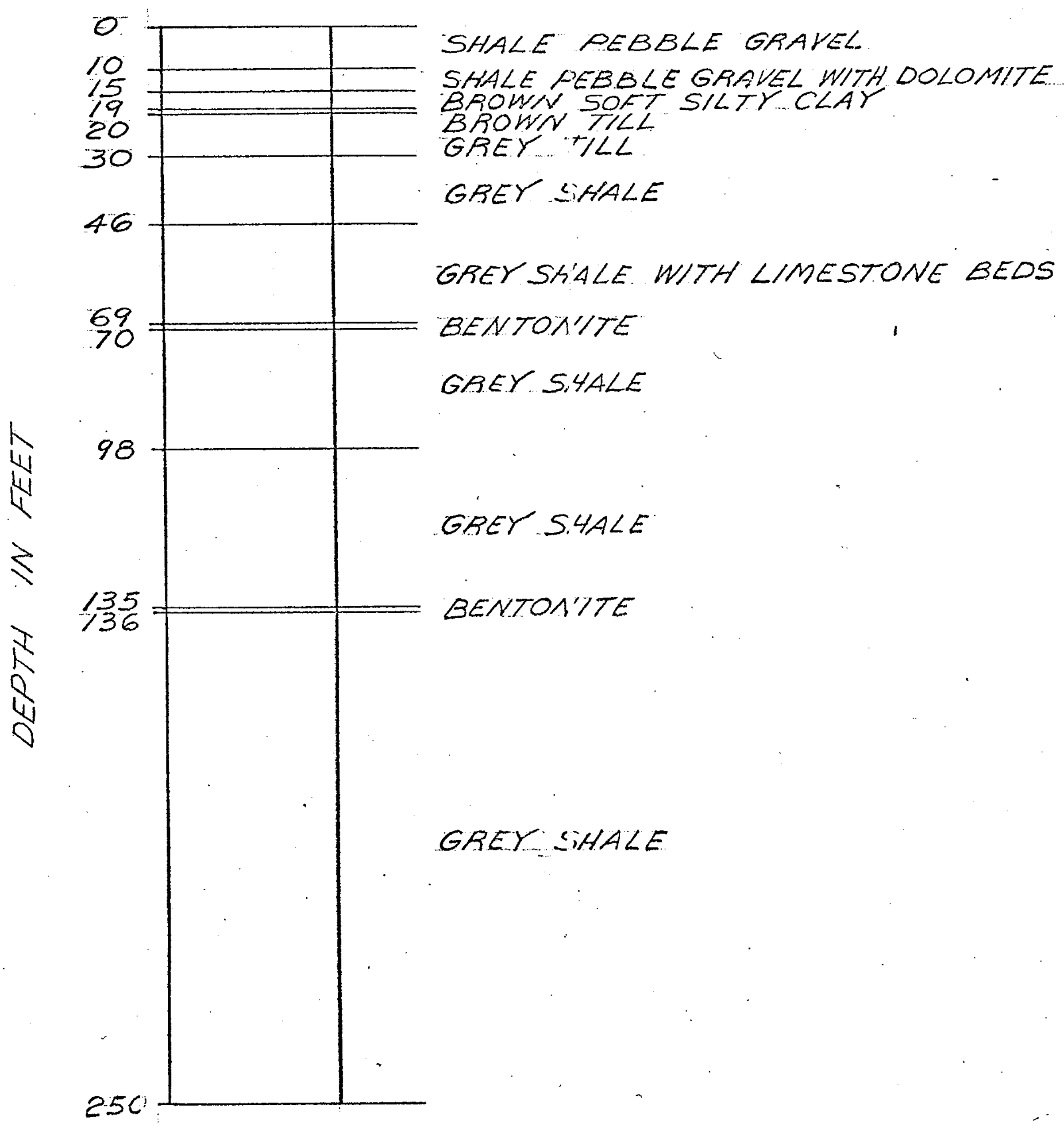
Depth (ft)	Material
0	TOPSOIL
2	SANDY CLAY
4	SAND, GRAVEL AND SHALESTONES
9	GREY CLAY
13	SAND, GRAVEL, SHALESTONES AND CLAY
43	GREY STONY CLAY
46	SHALE
62	

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #22

S.E. 30 - 20 - 15W

PREPARED BY:	DATE: JULY / 59
DRAWN BY: T. M.	FILE NO.

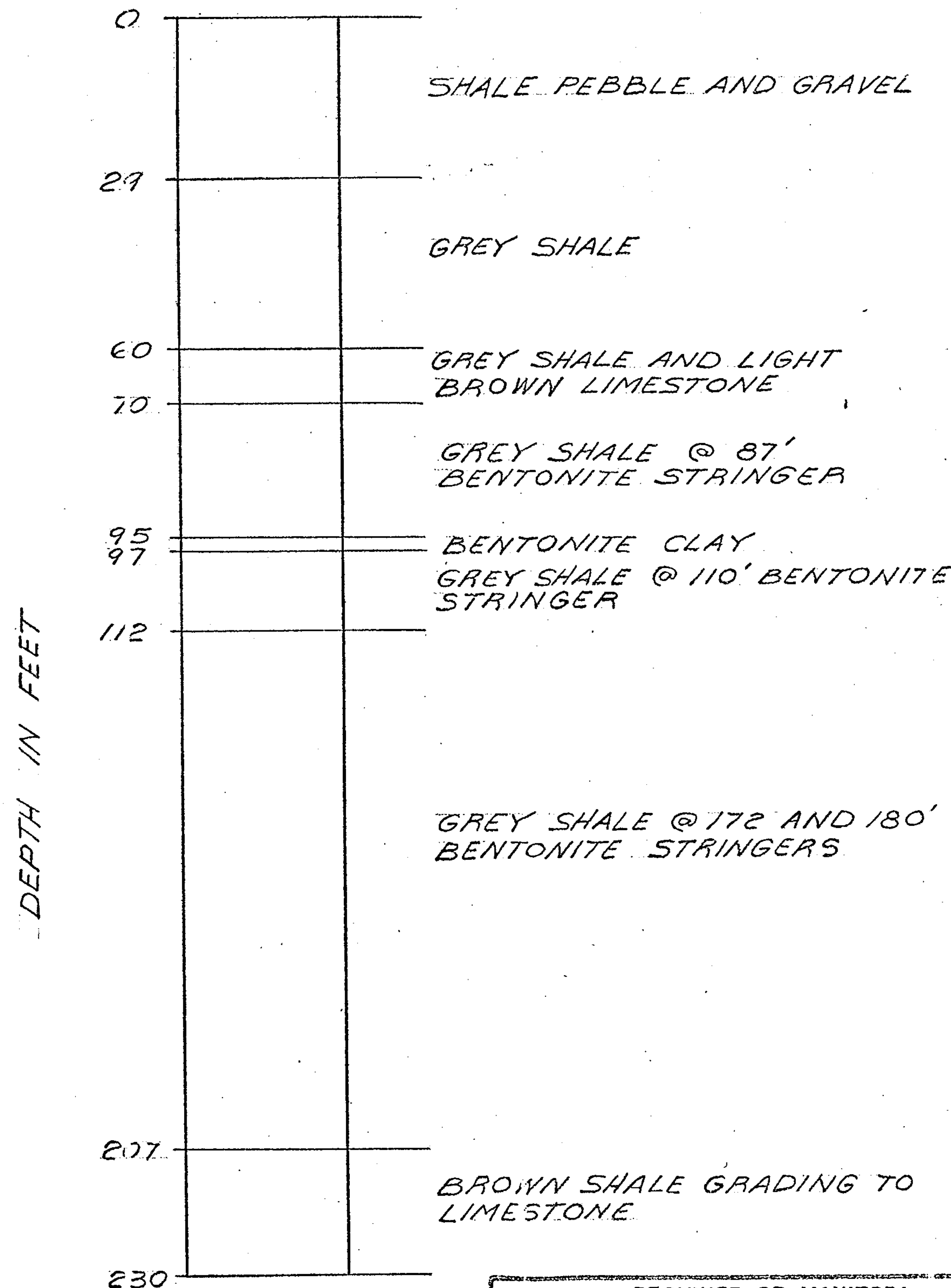


PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF PIEZOMETER # 6

S.E. 24 – 20 – 16W

PREPARED BY:	DATE: JULY / 69
	FILE NO.
DRAWN BY: T. M.	

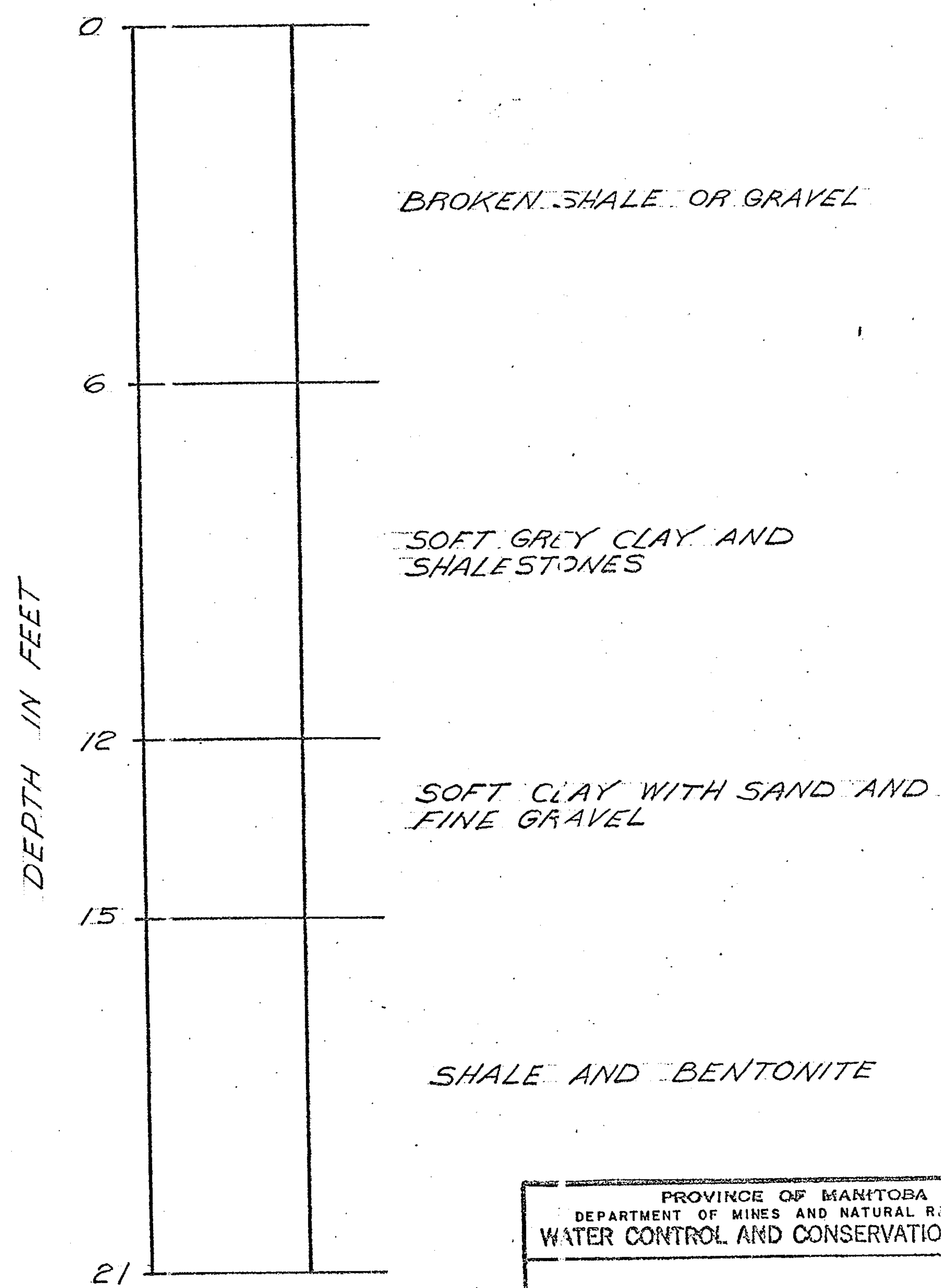


PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF PIEZOMETER # 11

N.E. 11 – 20 – 16W

PREPARED BY:	DATE: JULY/69
DRAWN BY: T. M.	FILE NO.

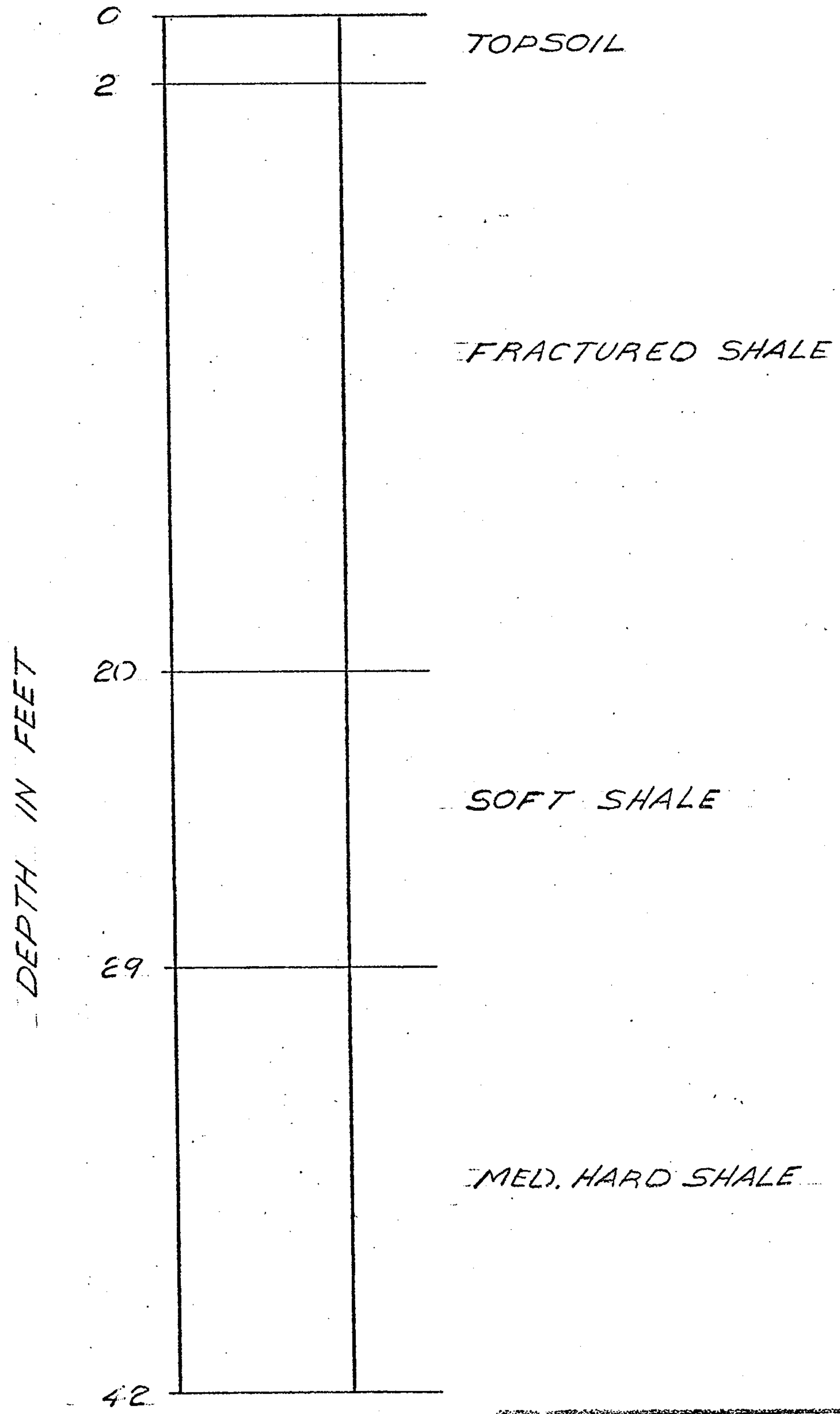


PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE # 9

N.W. 29 – 20 – 15W.

PREPARED BY:	DATE: JULY/69
DRAWN BY: T. M.	FILE NO.

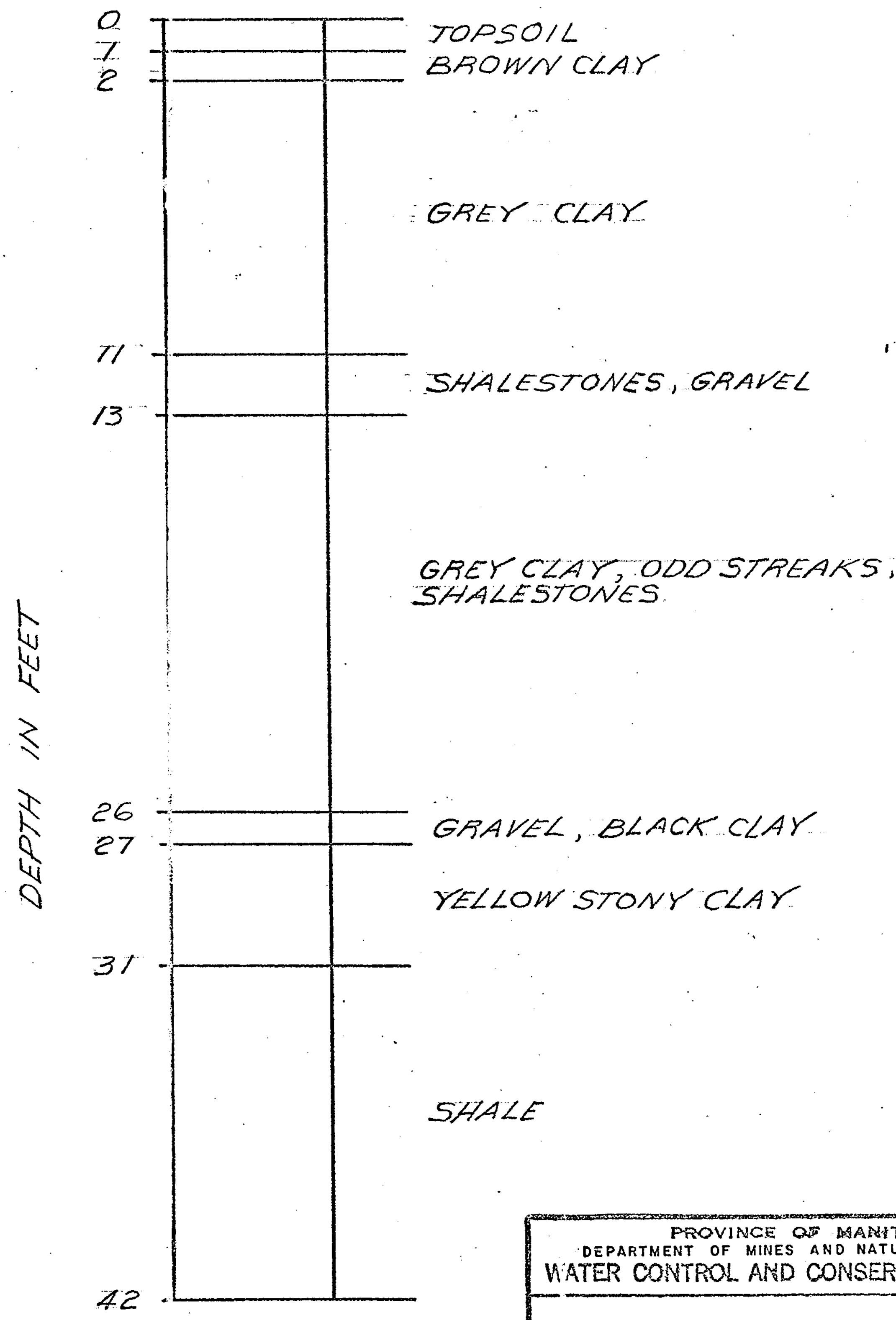


PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE # 8

S.E. 25 – 20 – 16 W

PREPARED BY:	DATE: JULY / 69
DRAWN BY: T.M.	FILE NO.



PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE # 17

S.W. 29 – 20 – 15 W

PREPARED BY:

DATE: JULY/69

FILE NO.

DRAWN BY: T. M.

DEPTH IN FEET

Depth	Material
0	TOPSOIL
1	GREY SANDY CLAY
3	SHALE STONES, SAND AND GRAVEL
10	GREY CLAY
18	SHALE STONES AND CLAY
27	CLAY WITH SHALE STREAKS
33	SHALE STONES AND GRAVEL
37	HARD SHALE STREAKS
39	SOFT CLAY
	SAND, GRAVEL AND CLAY
47	SHALE STREAKS IRONSTONE
53	

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE # 10

N.W. 20 – 20 – 15W

PREPARED BY:

DRAWN BY: T. M.

DATE: JULY / 69

FILE NO.

DEPTH IN FEET

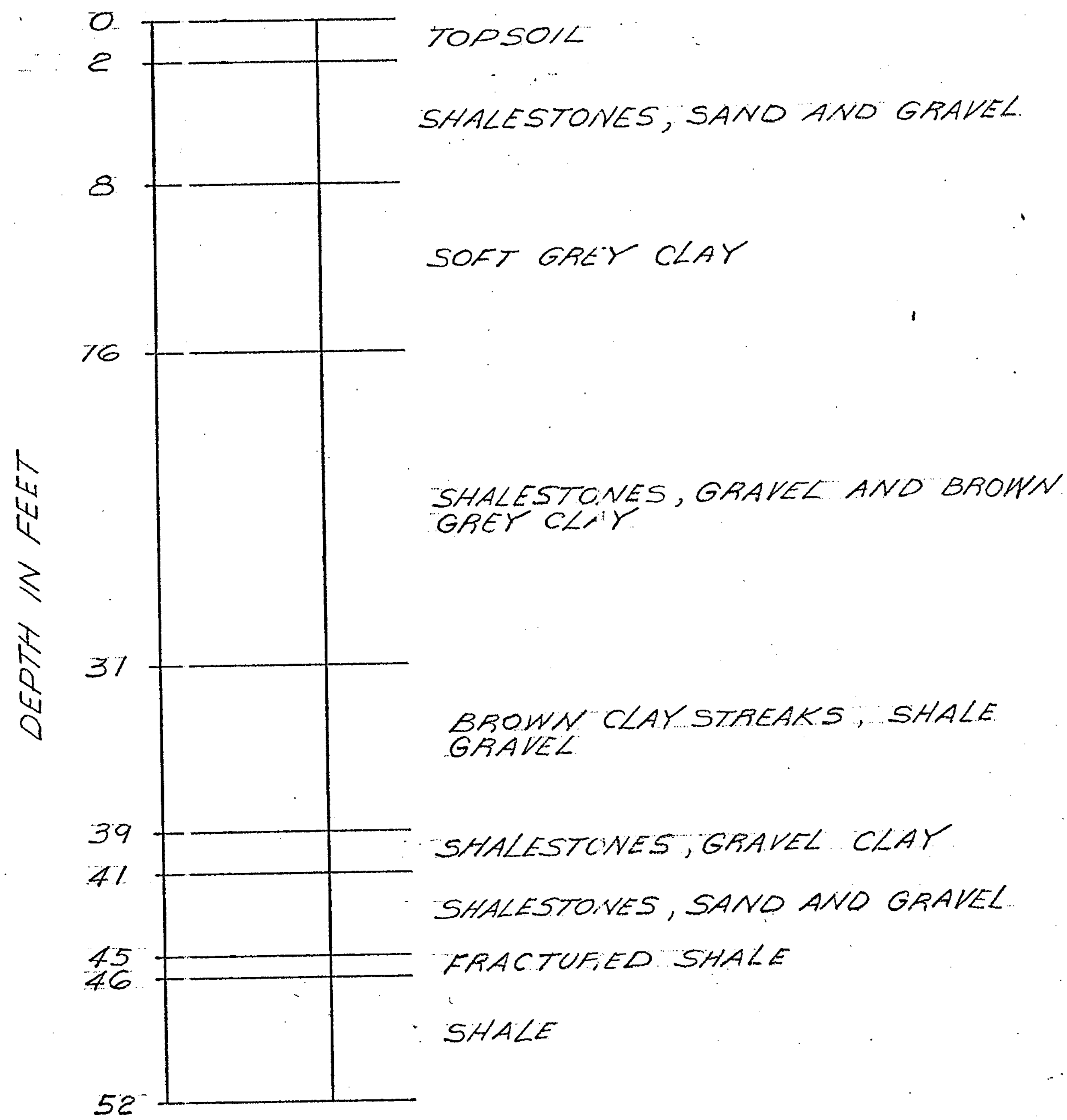
Depth (ft)	
0 – 1	TOPSOIL
1 – 5	BROWN CLAY
5 – 6	SHALESTONES
6 – 14	SOFT GREY CLAY
14 – 19	SHALESTONES, SOFT CLAY AND GRAVEL
19 – 22	BROWN CLAY
22 – 25	SOFT SHALE
25 – 42	SHALE

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE # 18

S.E. 29 – 20 – 15W

PREPARED BY:	DATE: JULY /69
DRAWN BY: T. M.	FILE NO.



PROVINCE OF MANITOBA

DEPARTMENT OF MINES AND NATURAL RESOURCES

WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #20

N.W. 20 – 20 – 15W

PREPARED BY:	DATE: JULY / 69
DRAWN BY: T. M.	FILE NO.

DEPTH IN FEET

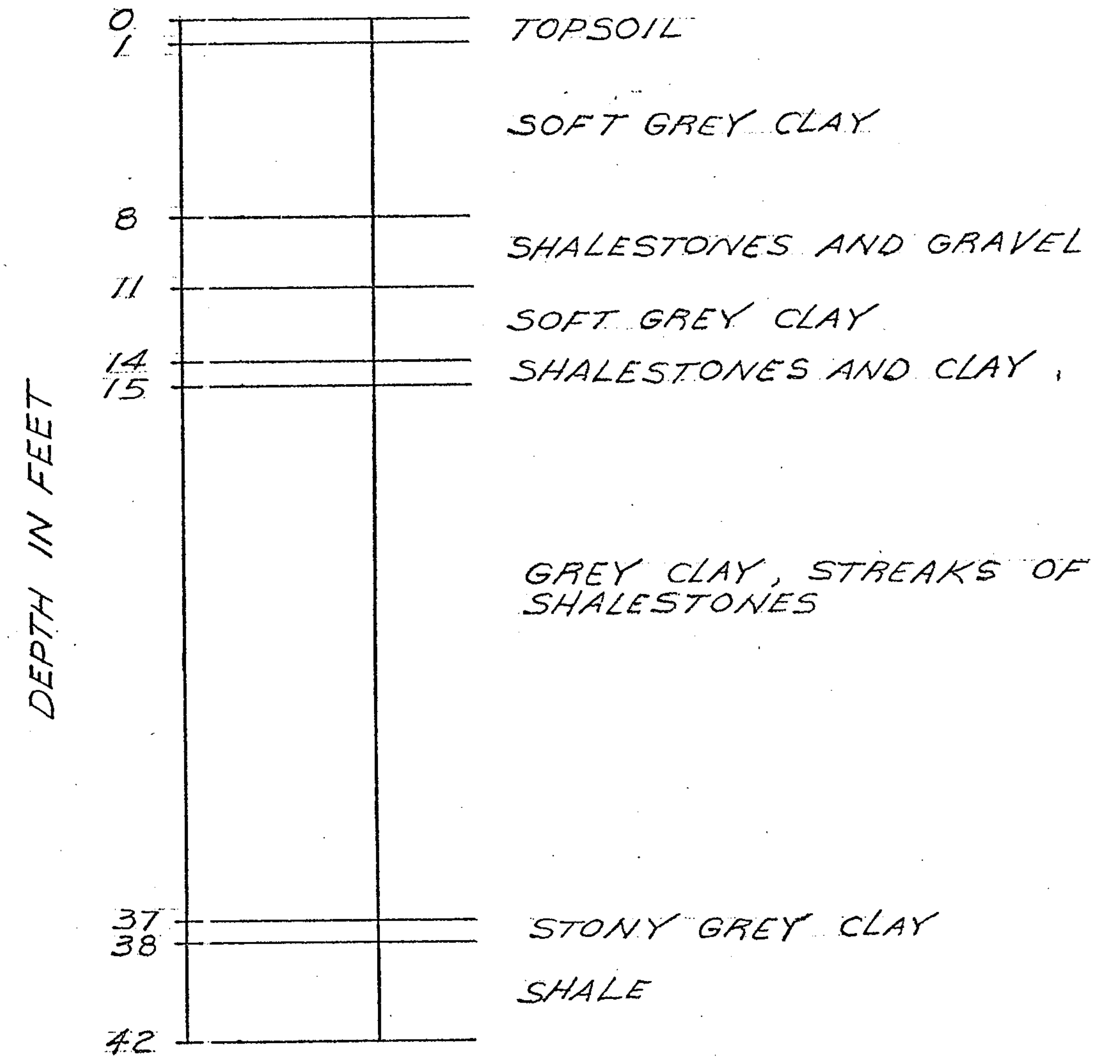
Depth (feet)	
0 – 2	TOPSOIL
2 – 11	SAND, GRAVEL, SHALESTONES AND CLAY
11 – 13	GREY CLAY
13 – 28	CLAY, SHALESTONES, GRAVEL AND SAND
28 – 41	CLAY, SHALESTONES AND GRAVEL
41 – 42	STONY CLAY

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #22A

S.E. 30 – 20 – 15 W

PREPARED BY:	DATE: JULY / 69
DRAWN BY: T. M.	FILE NO.



PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #16

S.W. 29-20-15W

PREPARED BY:	DATE: JULY /69
DRAWN BY: T. M.	FILE NO.

DEPTH IN FEET

Depth (ft)	
0 – 2	TOPSOIL
2 – 11	SHALESTONES, SAND AND GRAVEL
11 – 14	CLAY
14 – 31	SAND, GRAVEL AND SHALESTONES
31 – 37	CLAY, SAND, GRAVEL AND SHALESTONES
37 – 38	CLAY
38 – 43	BROKEN SHALE, CLAY AND GRAVEL
43 – 45	STONY CLAY AND BROKEN SHALE
45 – 50	SHALE

PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH

LOG OF TEST HOLE #22B

S.E. 30-20-15W

PREPARED BY:	DATE: JULY /69
DRAWN BY: T. M.	FILE NO.

APPENDIX 2

FLOW DURATION CURVE

CALCULATIONS

PROGRAMME TO CALCULATE

WILSON CREEK WEIR

FLOW DURATION

FLOW CHART

START

1. READ YEAR

   READ DATE, cfs.

   GO TO 1 UNTIL ALL DATA READ

2. CALL "SORT I" SUBROUTINE

3. WRITE "SORTED DATA FOR WILSON CREEK WEIR"

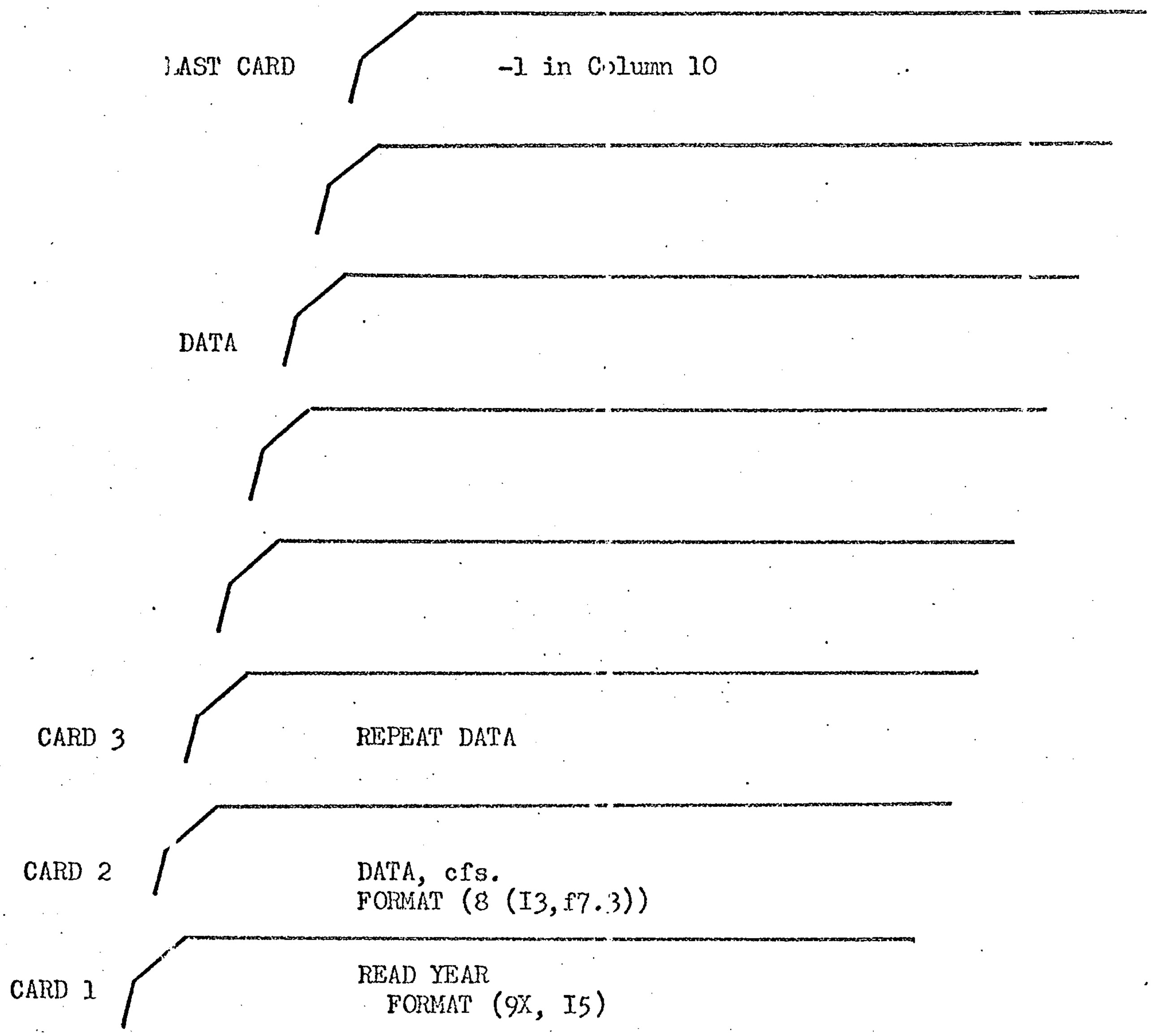
4. WRITE "CFS. PERCENT"

5. WRITE OUT SORTED VALUES AS PER 4.

END

PROGRAMME TO CALCULATE WILSON CREEK FLOW

DURATION CURVE



* Read Up

SUBROUTINE "SORT I"

1. Subroutine Sort I (XX, NN, YY)

   XX - Points, or values to be sorted

   NN - Number of points - "XX's"

   YY - Percent greater than - associated with each point XX over the interval length of NN inclusive.

2. Find largest value over interval NN.

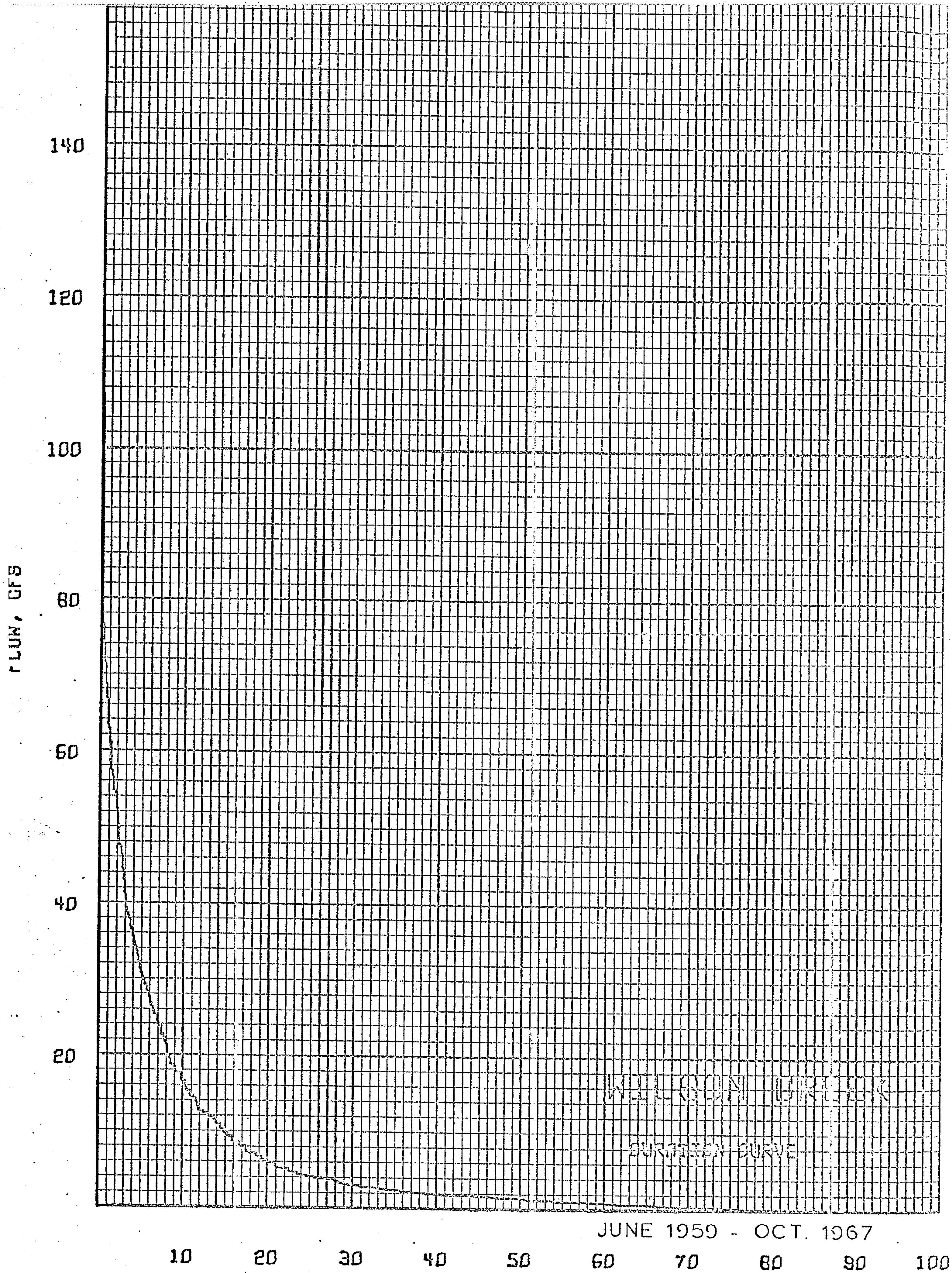
3. Place largest value at the end of the interval and replace end of interval point for largest XX value position.

4. Interval NN reduce by 1 to (NN-1)

5. Go to 2 until interval = 1

6. Associate each value XX with a percentage over the interval NN.

RETURN



FLOW, CFS
140
120
100
80
60
40
20
WILSON CREEK
DURATION CURVE
JUNE 1959 - OCT. 1967
10
20
30
40
50
60
70
80
90
100

APPENDIX 3

SEDIMENT DISCHARGE

CALCULATIONS

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Bald Hill Reservoir in Operation)

% Time Exc.	Q (cfs)	Sed. Ld.* (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
100	0	0			
			1	0	0
99	0	0			
			1	0	0
98	0	0			
			1	0.000014	0.00000014
97	0.01	0.000029			
			1	0.000029	0.00000029
96	0.01	0.000029			
			1	0.000029	0.00000029
95	0.01	0.000029			
			1	0.000075	0.00000075
94	0.03	0.00018			
			1	0.00018	0.0000018
93	0.03	0.00018			
			1	0.00018	0.0000018
92	0.03	0.00018			
			1	0.00030	0.0000030
91	0.05	0.00042			
			1	0.00067	0.0000067
90	0.08	0.00093			
			1	0.0012	0.000012
89	0.10	0.0014			
			1	0.0014	0.000014
88	0.10	0.0014			
			1	0.0014	0.000014
87	0.10	0.0014			
			1	0.0024	0.000024
86	0.17	0.0033			
			1	0.0033	0.000033
85	0.17	0.0033			
			1	0.0035	0.000035
84	0.18	0.0036			
			1	0.0036	0.000036
83	0.18	0.0036			
			1	0.0036	0.000036
82	0.18	0.0036			
			1	0.0036	0.000036
81	0.18	0.0036			

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Bald Hill Reservoir in Operation)

% Time Exc.	Q (cfs)	Sed. Ld.* (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
			1	0.0054	0.000054
80	0.27	0.0072			
			1	0.0076	0.000076
79	0.29	0.0081			
			1	0.0084	0.000084
78	0.30	0.0086			
			1	0.0086	0.000086
77	0.30	0.0086			
			1	0.0113	0.000113
76	0.40	0.0139			
			1	0.0145	0.000145
75	0.42	0.0151			
			1	0.0169	0.000169
74	0.48	0.0188			
			1	0.0195	0.000195
73	0.50	0.0202			
			1	0.0223	0.000223
72	0.56	0.0244			
			1	0.0251	0.000251
71	0.58	0.0259			
			1	0.0267	0.000267
70	0.60	0.0274			
			1	0.0285	0.000285
69	0.63	0.0297			
			1	0.0327	0.000327
68	0.70	0.0356			
			1	0.0386	0.000386
67	0.77	0.0417			
			1	0.0430	0.000430
66	0.80	0.0444			
			1	0.0444	0.000444
65	0.80	0.0444			
			1	0.0444	0.000444
64	0.88	0.0444			
			1	0.0502	0.000502
63	0.92	0.0561			
			1	0.0577	0.000577
62	0.95	0.0593			
			1	0.0620	0.000620
61	1.00	0.0646			

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Bald Hill Reservoir in Operation)

% Time Exc.	Q (cfs)	Sed. Ld.* (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
			1	0.0668	0.000668
60	1.04	0.0690			
			1	0.0753	0.000753
59	1.15	0.0817			
			1	0.0817	0.000817
58	1.15	0.0817			
			1	0.0817	0.000817
57	1.15	0.0817			
			1	0.0847	0.000847
56	1.20	0.0877			
			1	0.0909	0.000909
55	1.25	0.0940			
			1	0.0971	0.000971
54	1.30	0.1002			
			1	0.104	0.00104
53	1.36	0.108			
			1	0.111	0.00111
52	1.40	0.114			
			1	0.118	0.00118
51	1.46	0.122			
			1	0.132	0.00132
50	1.60	0.143			
			1	0.143	0.00143
49	1.60	0.143			
			1	0.150	0.00150
48	1.70	0.157			
			1	0.165	0.00165
47	1.80	0.173			
			1	0.177	0.00177
46	1.85	0.181			
			1	0.186	0.00186
45	1.90	0.190			
			1	0.198	0.00198
44	2.00	0.206			
			1	0.206	0.00206
43	2.00	0.206			
			1	0.206	0.00206
42	2.00	0.206			
			1	0.206	0.00206
41	2.00	0.206			

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Bald Hill Reservoir in Operation)

% Time Exc.	Q (cfs)	Sed. Ld.* (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
			1	0.215	0.00215
40	2.10	0.224			
			1	0.233	0.00233
39	2.20	0.242			
			1	0.258	0.00258
38	2.37	0.274			
			1	0.277	0.00277
37	2.40	0.280			
			1	0.290	0.00290
36	2.50	0.300			
			1	0.310	0.00310
35	2.60	0.321			
			1	0.335	0.00335
34	2.74	0.350			
			1	0.373	0.00373
33	2.95	0.396			
			1	0.401	0.00401
32	3.00	0.407			
			1	0.431	0.00431
31	3.20	0.454			
			1	0.466	0.00466
30	3.30	0.478			
			1	0.517	0.00517
29	3.60	0.553			
			1	0.607	0.00607
28	4.00	0.661			
			1	0.661	0.00661
27	4.00	0.661			
			1	0.703	0.00703
26	4.30	0.745			
			1	0.760	0.00760
25	4.40	0.774			
			1	0.820	0.00820
24	4.70	0.865			
			1	0.912	0.00912
23	5.00	0.959			
			1	0.986	0.00986
22	5.50	1.13			
			1	1.21	0.0121
21	6.00	1.30			

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Bald Hill Reservoir in Operation)

% Time Exc.	Q (cfs)	Sed. Ld.* (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
			1	1.40	0.0140
20	6.50	1.49			
			1	1.59	0.0159
19	7.00	1.69			
			1	1.79	0.0179
18	7.50	1.89			
			1	2.05	0.0205
17	8.20	2.20			
			1	2.41	0.0241
16	9.10	2.62			
			1	2.87	0.0287
15	10.10	3.12			
			1	3.57	0.0357
14	11.75	4.02			
			1	4.24	0.0424
13	12.50	4.46			
			1	4.58	0.0458
12	12.90	4.70			
			1	5.53	0.0553
11	15.50	6.38			
			1	7.09	0.0709
10	17.44	7.80			
			1	8.40	0.0840
9	19.00	9.00			
			1	10.32	0.1032
8	22.15	11.64			
			1	13.2	0.132
7	25.50	14.8			
			1	16.3	0.163
6	28.50	17.8			
			1	19.4	0.194
5	31.50	21.0			
			1	24.1	0.241
4	36.65	27.1			
			1	30.9	0.309
3	42.40	34.6			
			1	43.6	0.436
2	54.40	52.6			
			1	59.9	0.599
1	63.00	67.1			

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Bald Hill Reservoir in Operation)

% Time Exc.	Q (cfs)	Sed. Ld.* (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
			1	190.6	1.906
0	158.00	314.1			

TOTAL: 4.67879 Tons/Day

* SEDIMENT LOAD IS CALCULATED USING THE EQUATION:

$$\text{Sed.} = \text{Antilog}\ [1.67703(\text{Log } Q) - 1.19012]$$

e.g. if Q = 1 cfs;

$$\text{Sed.} = \text{Antilog}\ [-1.19012]$$

$$= \text{Antilog}\ [\bar{2}.80988]$$

$$= 0.646 \text{ Tons/Day.}$$

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Natural Conditions)

% Time Exc.	Q (cfs)	Sed. Ld. (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
100	0.0	0.0			
			1	0.0	0.0
99	0.0	0.0			
			1	0.0	0.0
98	0.0	0.0			
			1	0.0	0.0
97	0.0	0.0			
			1	0.0	0.0
96	0.0	0.0			
			1	0.0	0.0
95	0.0	0.0			
			1	0.0	0.0
94	0.0	0.0			
			1	0.000015	0.00000015
93	0.01	0.000029			
			1	0.000029	0.00000029
92	0.01	0.000029			
			1	0.000029	0.00000029
91	0.01	0.000029			
			1	0.00006	0.0000006
90	0.02	0.000091			
			1	0.00013	0.0000013
89	0.03	0.00018			
			1	0.00018	0.0000018
88	0.03	0.00018			
			1	0.00022	0.0000022
87	0.04	0.00029			
			1	0.00061	0.0000061
86	0.08	0.00093			
			1	0.00093	0.0000093
85	0.08	0.00093			
			1	0.0012	0.000012
84	0.10	0.0014			
			1	0.0014	0.000014
83	0.10	0.0014			
			1	0.0024	0.000024
82	0.17	0.0033			
			1	0.0033	0.000033
81	0.17	0.0033			

WILSON CREEK
SUSPENDED SEDIMENT CALCULATIONS
(Natural Conditions)

% Time Exc.	Q (cfs)	Sed. Ld. (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
				0.0035	0.000035
80	0.18	0.0036			
			1	0.0036	0.000036
79	0.18	0.0036			
			1	0.0036	0.000036
78	0.18	0.0036			
			1	0.0041	0.000041
77	0.21	0.0047			
			1	0.006	0.00006
76	0.27	0.0072			
			1	0.0079	0.000079
75	0.30	0.0086			
			1	0.0086	0.000086
74	0.30	0.0086			
			1	0.0091	0.000091
73	0.32	0.0096			
			1	0.0120	0.00012
72	0.41	0.0145			
			1	0.0157	0.000157
71	0.45	0.0169			
			1	0.0185	0.000185
70	0.50	0.0202			
			1	0.0219	0.000219
69	0.55	0.0237			
			1	0.0248	0.000248
68	0.58	0.0259			
			1	0.0267	0.000267
67	0.60	0.0274			
			1	0.0285	0.000285
66	0.63	0.0297			
			1	0.0327	0.000327
65	0.70	0.0356			
			1	0.0386	0.000386
64	0.77	0.0417			
			1	0.0430	0.000430
63	0.80	0.0444			
			1	0.0444	0.000444
62	0.80	0.0444			
			1	0.0444	0.000444
61	0.88	0.044			

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Natural Conditions)

% Time Exc.	Q (cfs)	Sed. Ld. (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
			1	0.0502	0.000502
60	0.92	0.0561			
			1	0.0577	0.000577
59	0.95	0.0593			
			1	0.0620	0.000620
58	1.00	0.0646			
			1	0.702	0.000702
57	1.10	0.0757			
			1	0.0787	0.000787
56	1.15	0.0817			
			1	0.0817	0.000817
55	1.15	0.0817			
			1	0.0847	0.000847
54	1.20	0.0877			
			1	0.0909	0.000909
53	1.25	0.0940			
			1	0.0940	0.000940
52	1.25	0.0940			
			1	0.101	0.00101
51	1.36	0.108			
			1	0.111	0.00111
50	1.40	0.114			
			1	0.114	0.00114
49	1.40	0.114			
			1	0.129	0.00129
48	1.60	0.143			
			1	0.143	0.00143
47	1.60	0.143			
			1	0.147	0.00147
46	1.66	0.151			
			1	0.162	0.00162
45	1.80	0.173			
			1	0.177	0.00177
44	1.85	0.181			
			1	0.185	0.00185
43	1.90	0.190			
			1	0.198	0.00198
42	2.00	0.206			
			1	0.206	0.00206
41	2.00	0.206			

WILSON CREEL

SUSPENDED SEDIMENT CALCULATIONS
(Natural Conditions)

% Time Exc.	Q (cfs)	Sed. Ld. (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
			1	0.206	0.00206
40	2.00	0.206			
			1	0.212	0.00212
39	2.07	0.219			
			1	0.231	0.00231
38	2.20	0.242			
			1	0.258	0.00258
37	2.37	0.274			
			1	0.274	0.00274
36	2.37	0.274			
			1	0.287	0.00287
35	2.50	0.300			
			1	0.311	0.00311
34	2.60	0.321			
			1	0.336	0.00336
33	2.74	0.350			
			1	0.374	0.00374
32	2.96	0.398			
			1	0.403	0.00403
31	3.00	0.407			
			1	0.431	0.00431
30	3.20	0.454			
			1	0.469	0.00469
29	3.32	0.483			
			1	0.526	0.00526
28	3.66	0.569			
			1	0.615	0.00615
27	4.00	0.661			
			1	0.667	0.00667
26	4.05	0.674			
			1	0.713	0.00713
25	4.33	0.753			
			1	0.778	0.00778
24	4.50	0.804			
			1	0.865	0.00865
23	4.90	0.927			
			1	0.959	0.00959
22	5.10	0.991			
			1	1.07	0.0107
21	5.50	1.13			

WILSON CREEK

SUSPENDED SEDIMENT CALCULATIONS

(Natural Conditions)

% Time Exc.	Q (cfs)	Sed. Ld. (Tons/ Day)	% Time Interv.	Avg. Sed. Load	Contrib. To Total
20	6.00	1.30	1	1.21	0.0121
19	6.50	1.49	1	1.40	0.014
18	7.40	1.85	1	1.67	0.0167
17	8.20	2.20	1	2.01	0.0201
16	9.00	2.57	1	2.39	0.0239
15	9.75	2.94	1	2.76	0.0276
14	11.20	3.71	1	3.33	0.0333
13	12.50	4.46	1	4.08	0.0408
12	12.90	4.70	1	4.58	0.0458
11	14.80	5.92	1	5.31	0.0531
10	16.80	7.33	1	6.62	0.0662
9	18.80	8.85	1	8.09	0.0809
8	22.00	11.51	1	10.18	0.1018
7	24.60	13.9	1	12.705	0.12705
6	28.50	17.8	1	15.85	0.1585
5	32.40	22.0	1	19.9	0.199
4	35.75	26.0	1	24.0	0.24
3	42.40	34.6	1	30.3	0.303
2	55.0	53.6	1	44.1	0.441
1	66.20	73.1	1	63.35	0.6335
0	193.0	439.5	1	256.3	2.563

TOTAL: 5.3283 Tons/Day

LOG SEDIMENT = 1.67703 x Log Discharge - 1.19012

PARTICLE DENSITY

Canada #2 - Stream Deposit Material Below Lower Wilson Creek Gage 8/30/61

Sieve Size	Weight (g)	Volume (cc)	Dry Density (g/cc)	Wet Wgt. (g)	Wet Density (g/cc)
>22.2 mm	8.334	5.10	1.6		
22.2 to 15.9 mm	1.596	1.01	1.6		
	3.818	2.35	1.6		
	3.847	2.46	1.6		
	4.439	2.90	1.5		
	3.451	2.02	1.7		
	2.850	1.72	1.7		
22.2 to 15.9 mm	6.142	3.72	1.6		
15.9 to 11.1 mm	2.814	1.80	1.6		
	1.319	0.810	1.6		
	0.764	0.450	1.7		
	1.451	0.865	1.7		
	4.016	2.56	1.6		
	0.941	0.545	1.7		
	1.096	0.655	1.7		
	2.981	1.91	1.6		
15.9 to 11.1 mm	3.907	2.30	1.7		
15.9 to 11.1 mm	10.52	6.29	1.7	13.00	2.1
11.1 to 5.66 mm	10.72	6.22	1.7	13.30	2.1

$\bar{x} = 1.6$

PARTICLE DENSITY

Canada #1 - Source Area Stream-Bed - Pack Horse Creek - Wilson Creek Watershed 8/30/61

Sieve Size	Weight (g)	Volume (cc)	Dry Density (g/cc)	Wet Wgt. (g)	Wet Density (g/cc)
22.2 to 15.9 mm	4.139	2.35	1.8	5.16	2.2
	1.090	0.545	2.0		
	3.391	2.06	1.6		
	1.388	0.775	1.8	1.80	2.3
	2.426	1.36	1.8	3.12	2.3
22.2 to 15.9 mm	2.694	1.60	1.7	3.40	2.1
15.9 to 11.1 mm	1.412	0.865	1.6	1.90	2.2
	1.372	0.815	1.7		
	0.595	0.320	1.9		
	1.455	0.860	1.7		
	0.957	0.605	1.6		
	1.441	0.855	1.7	1.87	2.2
15.9 to 11.1 mm	0.989	0.635	1.6		
Σ 15.9 to 11.1 mm	10.72	5.99	1.8	13.93	2.3
Σ 11.1 mm to 5.66 mm	10.74	5.53	1.9	12.97	2.3

$\bar{x} = 1.7$

APPENDIX 4

RESERVOIR ROUTING

CALCULATIONS

PROGRAMME TO CALCULATE
BALD HILL RESERVOIR
INFLOW HYDROGRAPH

FLOW CHART

Start

Read Storage Table Values

Read Number of Points per Month & Month

Read Day, Time, Well Elevation

Calculations

1. Outflow from Card (#17+02) C = .185
2. Storage Using Sub Routine Tab Par
3. Average Inflow
4. Accumulated Inflow

Output

1. Heading - Date, Time, Gauge H_T, Outflow, Inflow, Accumulate Inflow
2. Month & Units
3. Output as Per 1

Last Card Blank

End

PROGRAMME TO CALCULATE
INFLOW TO BALD HILL DAM

END CARD BLANK

MORE JOBS

DATA CON'T.

CARD N+2 — DATA, DATE, TIME, WELL WATER ELEV.
FORMAT (2I5, F10.2)
i.e. bbb23 b 2460bbb2331.05

CARD N+1 — NUMBER OF ELEVATIONS, AND MONTH
FORMAT (I5, A5)

CARD 3 — DATA CON'T.

CARD 2 — TABLE VALUES X, UNEQUAL SPACED,
Y - EQUALLY SPACED
FORMAT (2F 10.2)

CARD 1 — NUMBER OF TABLE VALUES FOR STORAGE CURVE
FORMAT (I5)

* NOTE: Programme #1 has calculated Average inflows for the period.

Programme #2 has calculated inflow on the time period.

LIMITATIONS:

1. Each calculated month must not have exceeded 1,000 calculations.

2. Before each period exceeds any normal interval (1 hour, 2 hours, etc.) it must have the 24 hour reading beginning a new day. (The time would become negative as the value of $(T_2 - T_1)$ is used and it changes when (T_1) becomes 24 hours to (T_2) only). Once the 24 hour period has been passed any following 24 hour periods with any hour may be used (i.e. 800, 800 hours).

BASIC EQUATIONS USED:

$$\text{Outflow (cfs)} = C_1 \, A \, (2GH)^{\frac{1}{2}}$$

$$= 0.185 \times 3.1416 \times (1)^2/4 \times (2 \times 32.174 \, (\text{Elev} - 2321.02))^{\frac{1}{2}}$$

Storage - interpolation by the continuous parabola method - Willard M. Snyder, Journal of the Hydraulics Division - July, 1961

$$\text{Inflow (avg)}_{cfs} = \text{Outflow(avg)}_{cfs} + \text{Storage change}_{cfs}$$

$$\Delta\text{Storage}_{cfs} = \Delta\text{storage}_{acre\text{-}ft} \; 43{,}560/86400 \times 24/(T_2 - T_1)$$

1 acre-ft = 43,560 cu.ft.

1 cfs-day = 86,400 cu.ft.

$T_1;T_2$ are in hours

SUBROUTINE TABPAR

Ref: Vol. 87, No. Hy 4, July 1961.

"JOURNAL OF THE HYDRAULICS DIVISION"

by

Willard M. Snyder

Start

Subroutine Tabpar (xx, y, tx, ty, n) "xx" - Entry point, "y" - interpolated value, "tx, ty" - table values corresponding to xx and y, "n" - number of table values. Note - TX's must be equally spaced on its respective axis.

Check XX with lower interpolation point

Check XX with upper interpolation point

Locate XX on the interval

Calculate YØ1

Calculate Y

Return

End

<u>Subroutine Tabpar (XX, Y, TX, TY, N)</u>

<u>Variables:</u>

XX - known value for X, or Y for which interpolated value of Y or X is required

Y - interpolated value for corresponding value of XX

TX - table value X, or Y, equally spaced on the interval (also corresponds to XX values)

TY - table value of Y or X, unequally spaced on the interval (also corresponds to Y - interpolated value)

N - number of table value points of (TX, TY); (N,N)

Range of Interpolation:

Interpolation is carried out above the second lowest point and below the second highest point.

Messages:

If interpolation is required above or below the range; there is no attempt made to interpolate but the point is written out and the statement "Point X = ________ above (or below) table value T(N-1), (or 2)

Reference:

"Journal of the Hydraulics Division" - July 1961

"Continuous Parabolic Interpolation" - by Willard M. Snyder

Example:

Data:

```
bbbb4
bbbbb2.5bbbbbb40.0bb
bbbbb2.6bbbbbb60.0bb
bbbbb2.7bbbbbb90.0bb
bbbbb2.8bbbbb130.0bb
```

answer 18.56

For example check 3RR Ref. - M Snyder P. 107

BALD HILL DAM

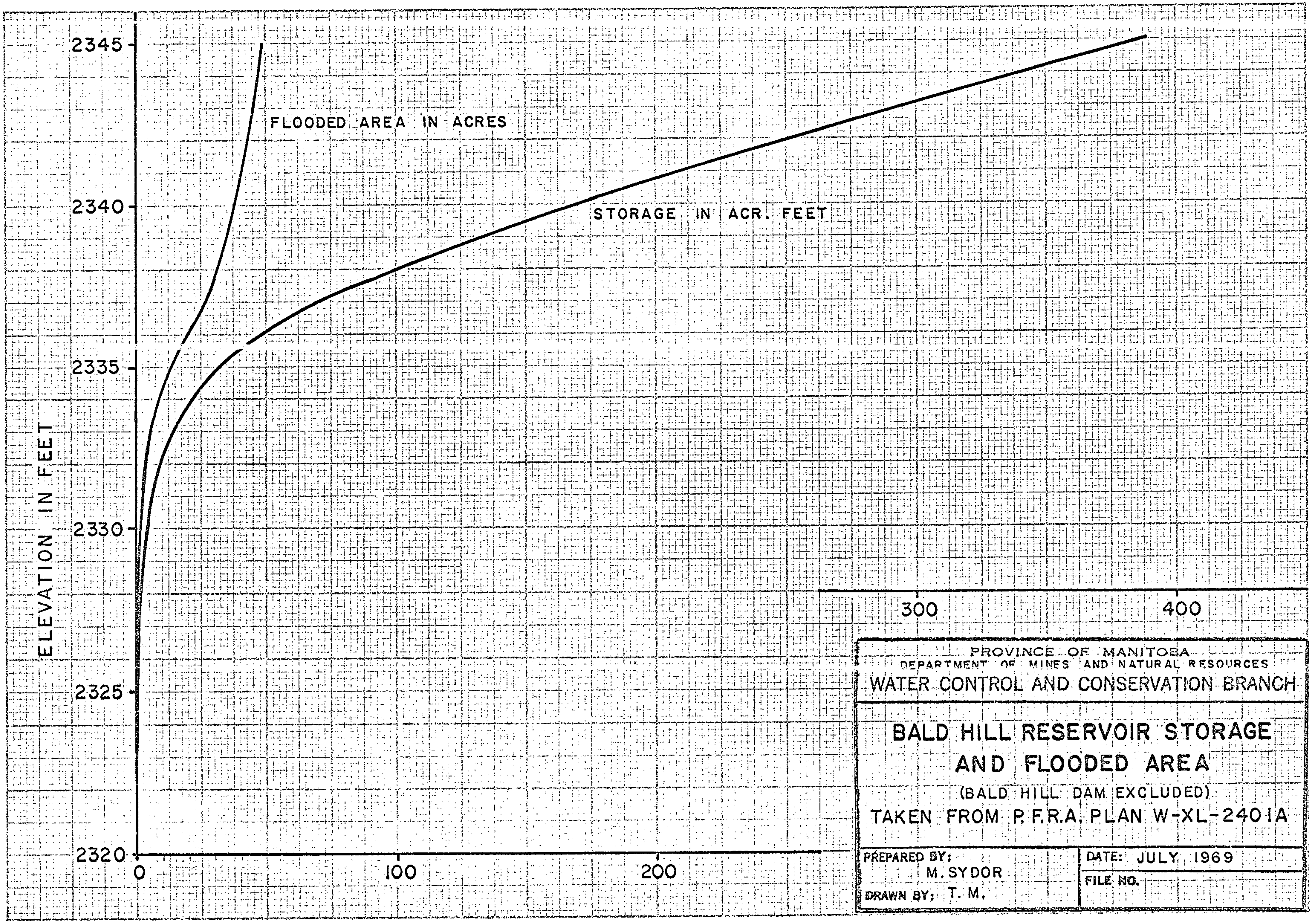
Storage Curve

Dam Included

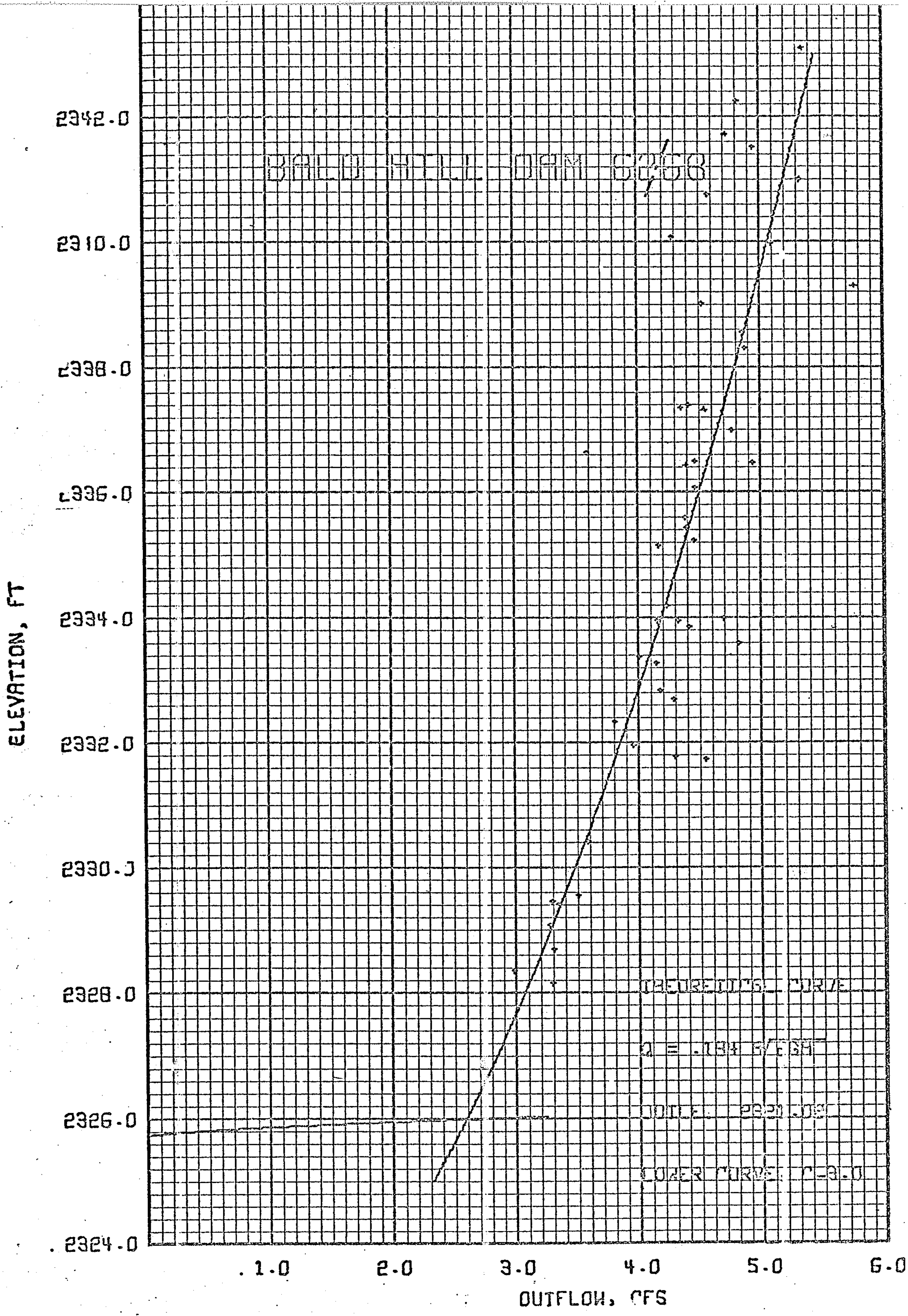
Elev. (ft.)	Area (acres)	Avg. (acres)	Δ S (acr. ft.)	ΣΔS (acr. ft.)
2323.0	0.0			0
2324.0	0.07	0.04	0.04	0.04
2325.0	0.16	0.11	0.11	0.15
2326.0	0.40	0.28	0.28	0.43
2327.0	0.60	0.5	0.5	0.93
2328.0	0.83	0.7	0.7	1.6
2329.0	1.25	1.0	1.0	2.7
2330.0	1.73	1.5	1.5	4.2
2331.0	2.65	2.2	2.2	6.4
2332.0	3.80	3.2	3.2	9.6
2333.0	5.80	4.8	4.8	14.4
2334.0	8.50	7.2	7.2	21.5
2335.0	12.52	10.5	10.5	32.1
2336.0	19.0	15.8	15.8	47.8
2337.0	27.5	23.25	23.25	71.1
2338.0	31.7	29.60	29.60	100.7
2339.0	35.0	33.35	33.35	134.0
2340.0	37.65	36.3	36.3	170.3
2341.0	40.3	39.00	39.0	209.3
2342.0	42.0	41.45	41.5	250.8
2343.0	44.9	43.75	43.8	294.5
2344.0	47.1	46.00	46.0	340.5
2345.0	48.70	47.90	47.9	388.4

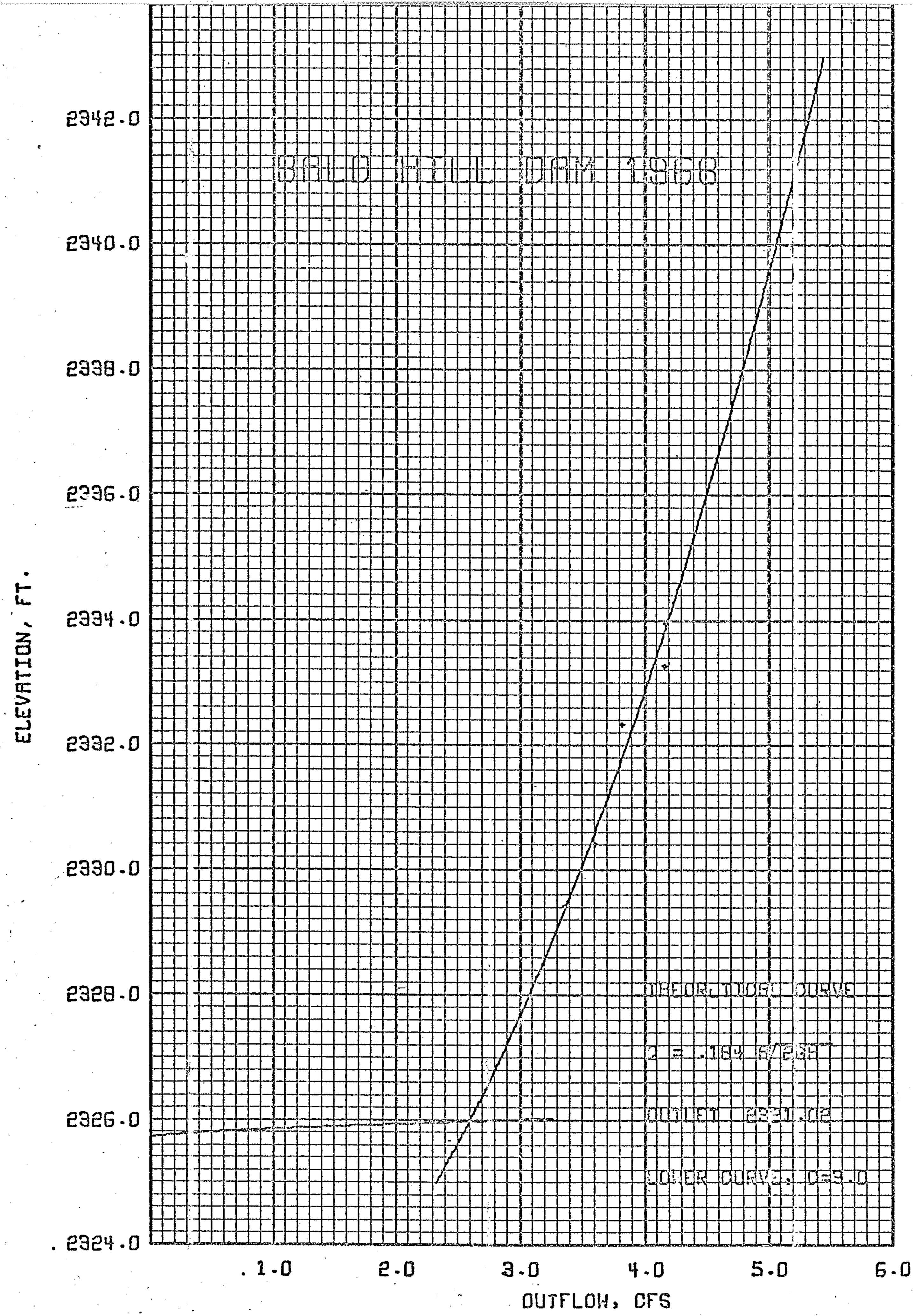
June 12, 1969

M.Sydor

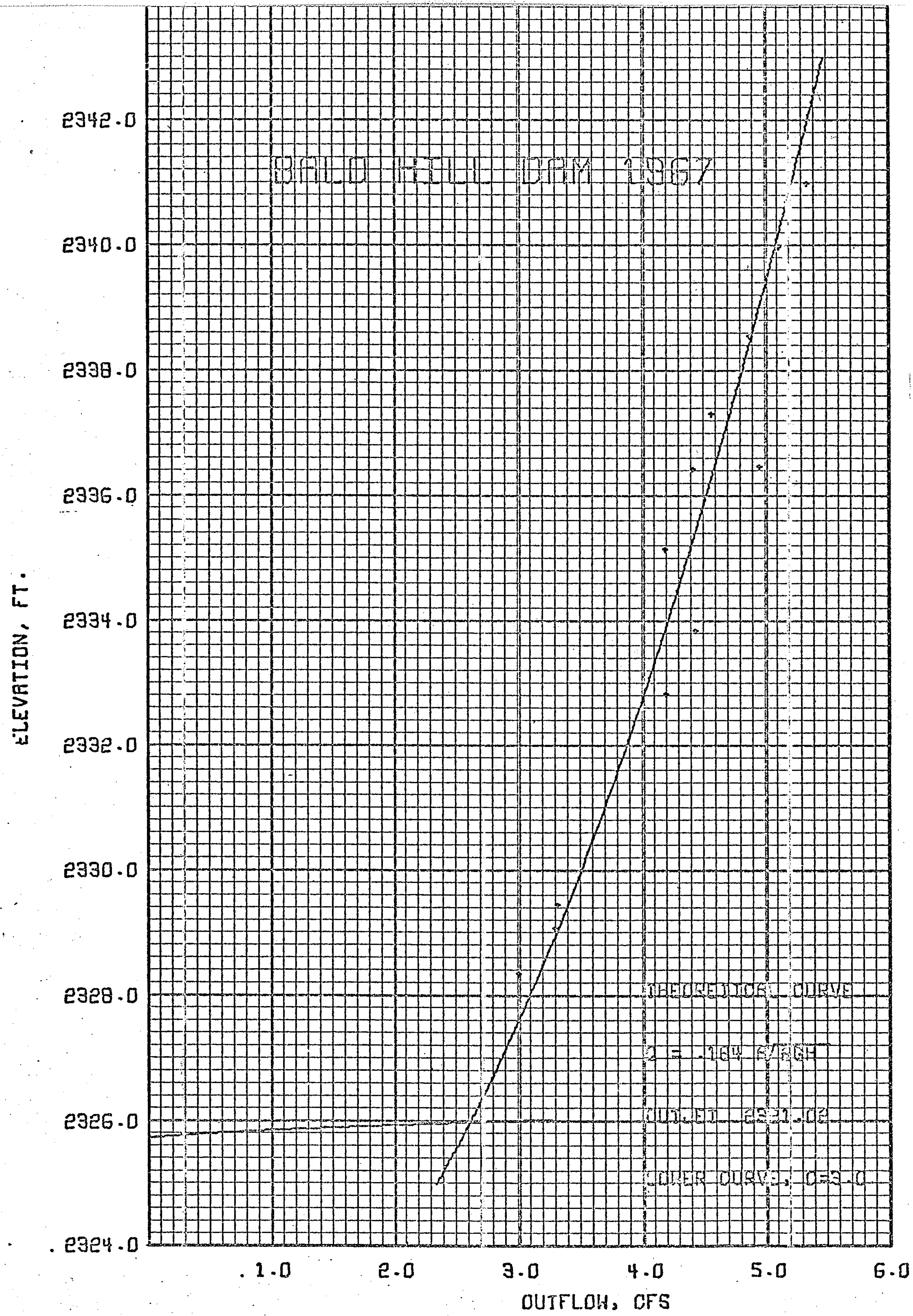


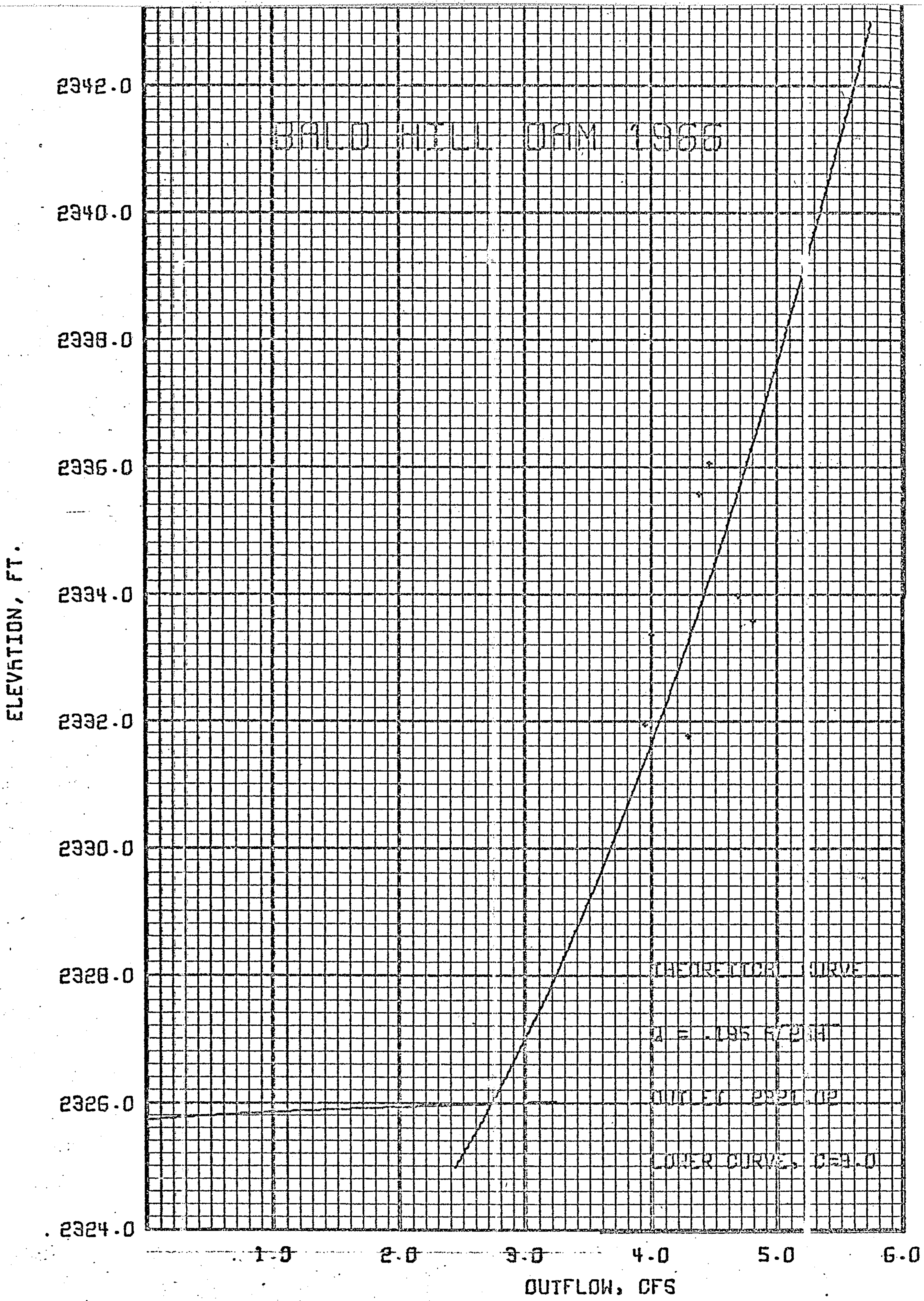
FLOODED AREA IN ACRES
STORAGE IN ACR. FEET
ELEVATION IN FEET
2345
2340
2335
2330
2325
2320
0
100
200
300
400
PROVINCE OF MANITOBA
DEPARTMENT OF MINES AND NATURAL RESOURCES
WATER CONTROL AND CONSERVATION BRANCH
BALD HILL RESERVOIR STORAGE
AND FLOODED AREA
(BALD HILL DAM EXCLUDED)
TAKEN FROM P.F.R.A. PLAN W-XL-2401A
PREPARED BY: M. SYDOR
DRAWN BY: T. M.
DATE: JULY 1969
FILE NO.

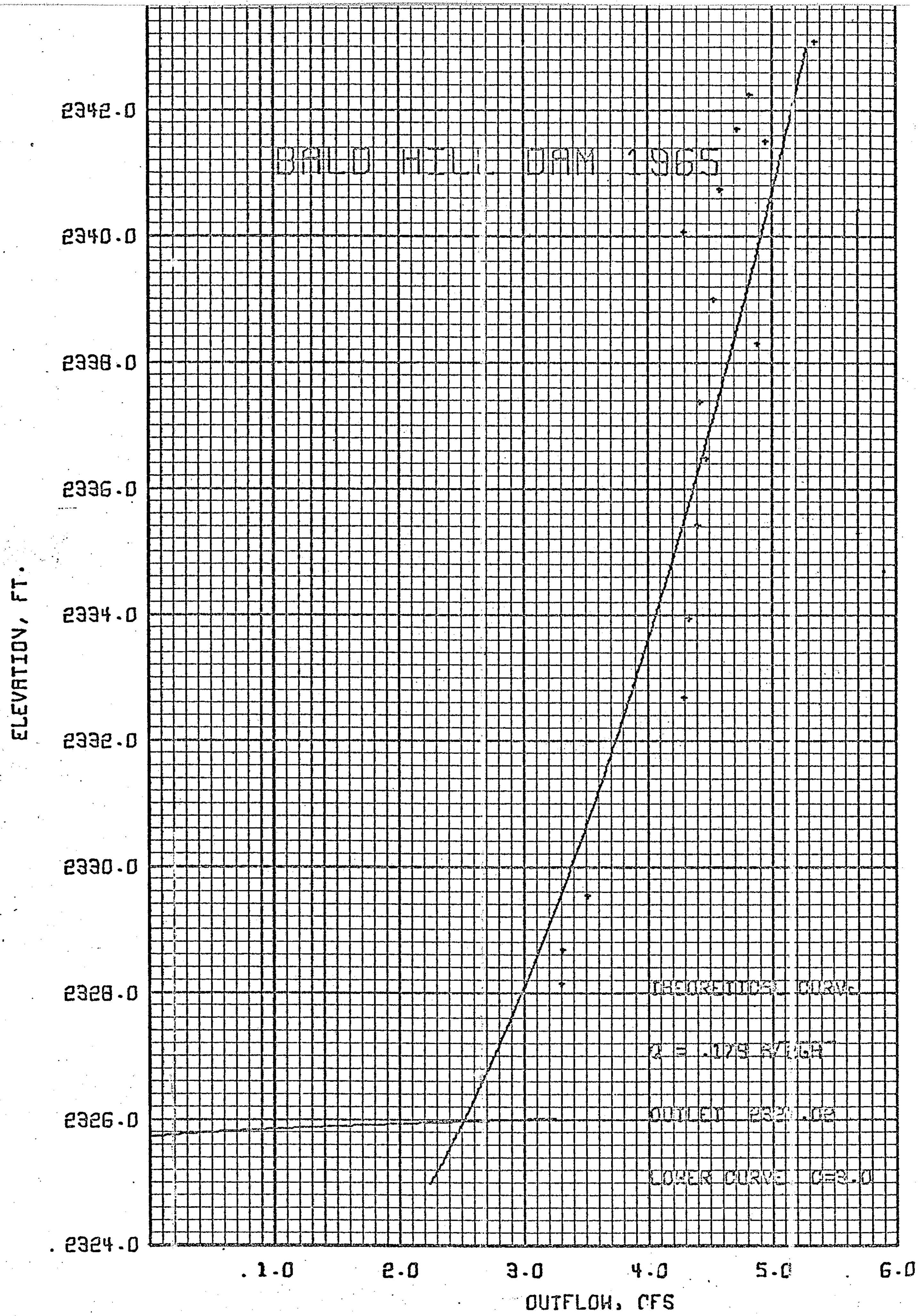

BALD HILL DAM 6/68
THEORETICAL CURVE
LOWER CURVE C=3.0
ELEVATION, FT
2342.0
2340.0
2338.0
2336.0
2334.0
2332.0
2330.0
2328.0
2326.0
2324.0
1.0
2.0
3.0
4.0
5.0
6.0
OUTFLOW, CFS

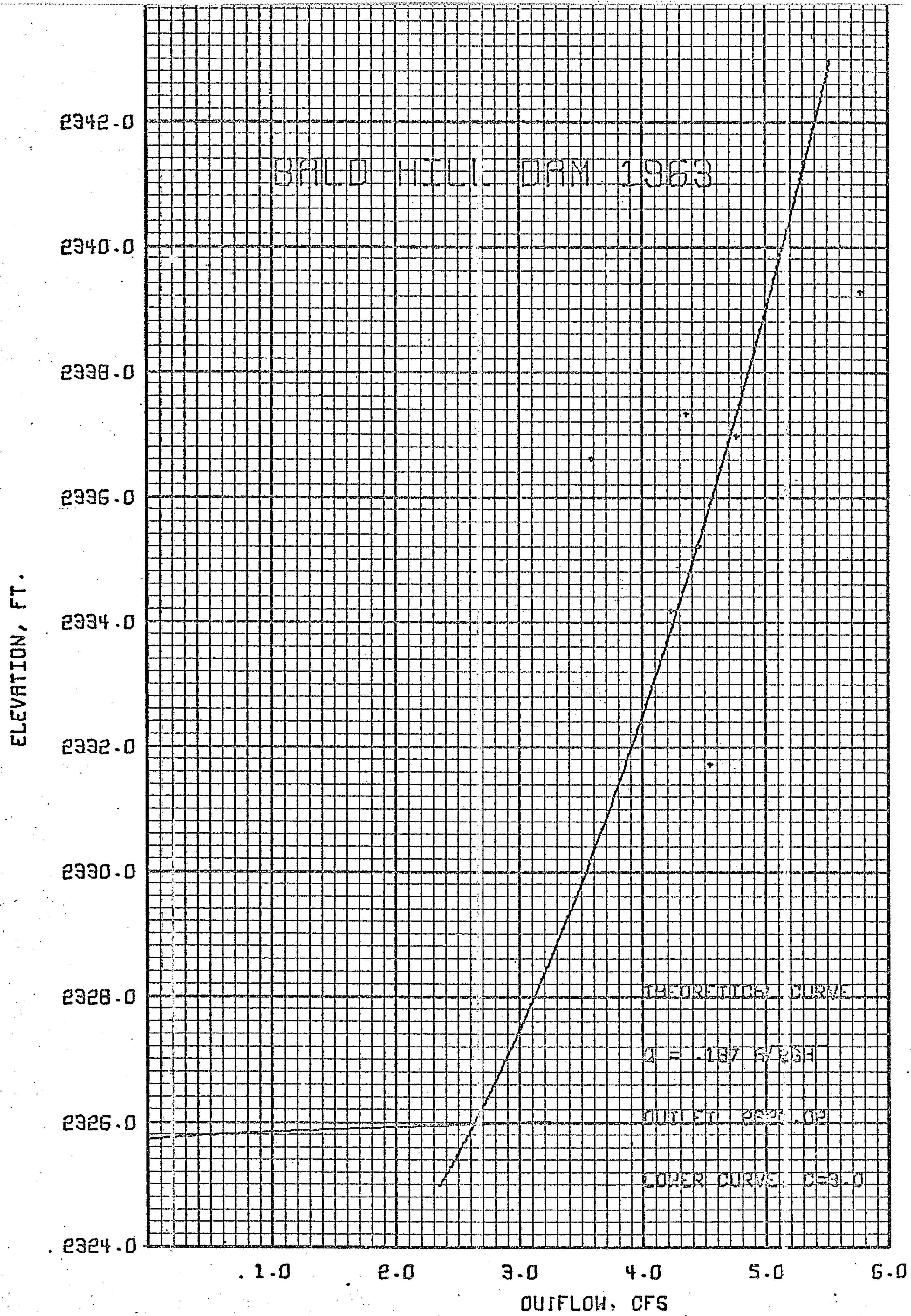


BALD HILL DAM 1968
ELEVATION, FT.
2342.0
2340.0
2338.0
2336.0
2334.0
2332.0
2330.0
2328.0
2326.0
2324.0
1.0
2.0
3.0
4.0
5.0
6.0
OUTFLOW, CFS


BALD HILL DAM 1967
THEORETICAL CURVE
ELEVATION, FT.
2342.0
2340.0
2338.0
2336.0
2334.0
2332.0
2330.0
2328.0
2326.0
2324.0
1.0
2.0
3.0
4.0
5.0
6.0
OUTFLOW, CFS


BALD HILL DAM 1966
THEORETICAL CURVE
LOWER CURVE, C=3.0
2342.0
2340.0
2338.0
2336.0
2334.0
2332.0
2330.0
2328.0
2326.0
2324.0
ELEVATION, FT.
1.0
2.0
3.0
4.0
5.0
6.0
OUTFLOW, CFS


BALD HILL DAM 1965
ELEVATION, FT.
2342.0
2340.0
2338.0
2336.0
2334.0
2332.0
2330.0
2328.0
2326.0
2324.0
1.0
2.0
3.0
4.0
5.0
6.0
OUTFLOW, CFS
THEORETICAL CURVE
OUTLET
LOWER CURVE


BALD HILL DAM 1963
ELEVATION, FT.
2342.0
2340.0
2338.0
2336.0
2334.0
2332.0
2330.0
2328.0
2326.0
2324.0
1.0
2.0
3.0
4.0
5.0
6.0
OUTFLOW, CFS
THEORETICAL CURVE
LOWER CURVE, C=3.0

RUNOFF RECORD

File: 66-8-1

BASIN WILSON CREEK D.A. 5557.0 acres 8.678 sq.mi.

Rating table NOV. 1966

PERIOD: From AUG. 5 - 1400 C.S.T. to AUG. 15 - 2400 C.S.T. 1966

GAUGE DATUM ELEV. - 1) ZERO FLOW 73.61 2) FLOAT AT REST 70.30 3) LOWEST INTAKE 73.61

DATE & TIME	TIME INTER-VAL Min.	GAUGE HEIGHT Ft.	RATE OF RUNOFF: TOTAL RUNOFF In./hr	BASE FLOW HEIGHT Ft.	BASE FLOW In./hr	SURFACE RUNOFF In./hr	AVERAGE RATE FOR TIME INTERVAL	TOTAL RUNOFF: FOR TIME INTERVAL	ACCUMU-LATED	C.F.S
1400	1 HR.	73.84	.00024	73.84	.00024	.00000	.00024	.00024	.00024	1.35
1500	1 "	73.84	.00024	73.84	.00024		.00024	.00024	.00048	1.35
1600	1 "	73.83	.00023	73.83	.00023		.00024	.00024	.00072	1.30
1700	1 "	73.83	.00023	73.83	.00023		.00023	.00023	.00095	1.30
1800	1 "	73.83	.00023	73.83	.00023		.00023	.00023	.00118	1.30
1900	1 "	73.83	.00023	73.83	.00023		.00023	.00023	.00141	1.30
2000	1 "	73.83	.00023	73.83	.00023		.00023	.00023	.00164	1.30
2100	1 "	73.83	.00023	73.83	.00023		.00023	.00023	.00187	1.30
2200	1 "	73.83	.00023	73.83	.00023		.00023	.00023	.00210	1.30
2300	1 "	73.83	.00023	73.83	.00023		.00023	.00023	.00233	1.30
2400	1 "	73.82	.00021	73.82	.00021		.00022	.00022	.00255	1.20
0100	1 "	73.82	.00021	73.82	.00021		.00021	.00021	.00276	1.20
0200	1 "	73.82	.00021	73.82	.00021		.00021	.00021	.00297	1.20
0300	1 "	73.82	.00021	73.82	.00021		.00021	.00021	.00318	1.20
0400	1 "	73.82	.00021	73.82	.00021		.00021	.00021	.00339	1.20
0500	1 "	73.82	.00021	73.82	.00021		.00021	.00021	.00360	1.20
0600	1 "	73.82	.00021	73.82	.00021		.00021	.00021	.00381	1.20
0700	1 "	73.82	.00021	73.82	.00021	.00000	.00021	.00021	.00402	1.20
0800	1 "	73.83	.00023	73.82	.00021	.00002	.00022	.00022	.00424	1.30
0900	1 "	73.84	.00024	73.82	.00021	.00003	.00023	.00023	.00447	1.35
1000	1 "	73.88	.00028	73.82	.00021	.00007	.00026	.00026	.00473	1.60
1100	1 "	73.91	.00032	73.82	.00021	.00011	.00030	.00030	.00503	1.80
1200	1 "	73.92	.00033	73.82	.00021	.00012	.00032	.00032	.00535	1.85
1300	1 "	73.93	.00034	73.82	.00021	.00013	.00034	.00034	.00569	1.90
1400	1 "	73.94	.00035	73.82	.00021	.00014	.00034	.00034	.00603	1.95
500	1 "	73.97	.00039	73.82	.00021	.00018	.00037	.00037	.00640	2.20
1600	1 "	73.98	.00041	73.82	.00021	.00020	.00040	.00040	.00680	2.30
700	1 "	73.99	.00044	73.82	.00021	.00023	.00042	.00042	.00722	2.45
1800	1 "	74.01	.00050	73.82	.00021	.00029	.00047	.00047	.00769	2.60

Conversion factor for D.A. 1 cfs = .000178 In./hr. Sheet No. 1 of 2

1436 ADD 1100.00 FT. TO ALL GAUGE HEIGHTS.

RUNOFF RECORD

File: 66-8-1

BASIN WILSON CREEK D.A. 5557.0 acres 8.678 sq.mi.

Rating table NOV. 1966

PERIOD: From AUG. 5 - 1400 C.S.T. to AUG. 15 - 2400 C.S.T. 1966

GAUGE DATUM ELEV. - 1) ZERO FLOW 73.61 2) FLOAT AT REST 70.30 3) LOWEST INTAKE 73.61

DATE & TIME	TIME INTER-VAL Min.	GAUGE HEIGHT Ft.	RATE OF RUNOFF: TOTAL RUNOFF In./hr	RATE OF RUNOFF: BASE FLOW HEIGHT Ft.	RATE OF RUNOFF: BASE FLOW In./hr	RATE OF RUNOFF: SURFACE RUNOFF In./hr	AVERAGE RATE FOR TIME INTERVAL	TOTAL RUNOFF: FOR TIME INTERVAL	TOTAL RUNOFF: ACCUMU-LATED	c.f.s.
1900	1 HR.	74.02	.00053	73.82	.00021	.00032	.00052	.00052	.00821	3.00
2000	1 "	74.05	.00066	73.82	.00021	.00045	.00060	.00060	.00881	3.70
2100	1 "	74.24	.00281	73.82	.00021	.00260	.00174	.00174	.01055	15.80
2200	1 "	74.40	.00668	73.82	.00021	.00647	.00474	.00474	.01529	37.50
2300	1 "	74.58	.01251	73.82	.00021	.01230	.00960	.00960	.02439	70.30
2400	1 "	74.58	.01251	73.82	.00021	.01230	.01251	.01251	.03740	70.30
0100	1 "	74.73	.01787	73.82	.00021	.01766	.01519	.01519	.05259	100.40
0200	1 "	74.80	.02031	73.82	.00021	.02010	.01909	.01909	.07168	114.10
0300	1 "	74.76	.01894	73.95	.00036	.01858	.01962	.01962	.09130	106.40
0400	1 "	74.74	.01823	74.00	.00046	.01777	.01858	.01858	.10988	102.40
0500	1 "	74.75	.01858	74.06	.00071	.01787	.01842	.01842	.12830	104.40
1000	5 HRS	74.69	.01645	74.16	.00160	.01485	.01752	.08760	.21590	92.40
1200	2 "	74.63	.01439	74.18	.00186	.01253	.01542	.03084	.24674	80.85
1400	2 "	74.51	.01005	74.20	.00214	.00791	.01222	.02444	.27118	56.45
1700	3 "	74.50	.00968	74.23	.00263	.00705	.00986	.02958	.30076	54.40
2400	7 "	74.39	.00641	74.29	.00384	.00257	.00804	.05628	.35704	36.00
1000	10 "	74.36	.00566	74.36	.00560	.00000	.00602	.06020	.41724	31.45
1100	1 HR	74.37	.00586	74.37	.00586	A	.00573	.00573	.42297	32.95
1500	4 HRS	74.37	.00586	74.37	.00586		.00586	.02344	.44641	32.95
2400	9 "	74.32	.00457	74.32	.00457		.00522	.04698	.49339	25.70
2400	24 "	74.27	.00339	74.27	.00339		.00398	.09552	.58891	19.05
2400	24 "	74.17	.00173	74.17	.00173		.00256	.06144	.65035	9.70
2400	24 "	74.10	.00098	74.10	.00098		.00136	.03264	.68299	5.50
2400	24 "	74.13	.00125	74.13	.00125		.00112	.02688	.70987	7.00
2400	24 "	74.12	.00116	74.12	.00116		.00120	.02880	.73867	6.50
2400	24 "	74.10	.00098	74.10	.00098		.00107	.02568	.76435	5.50
2400	24 "	73.93	.00057	73.93	.00057	.00000	.00078	.01872	.78307	3.20

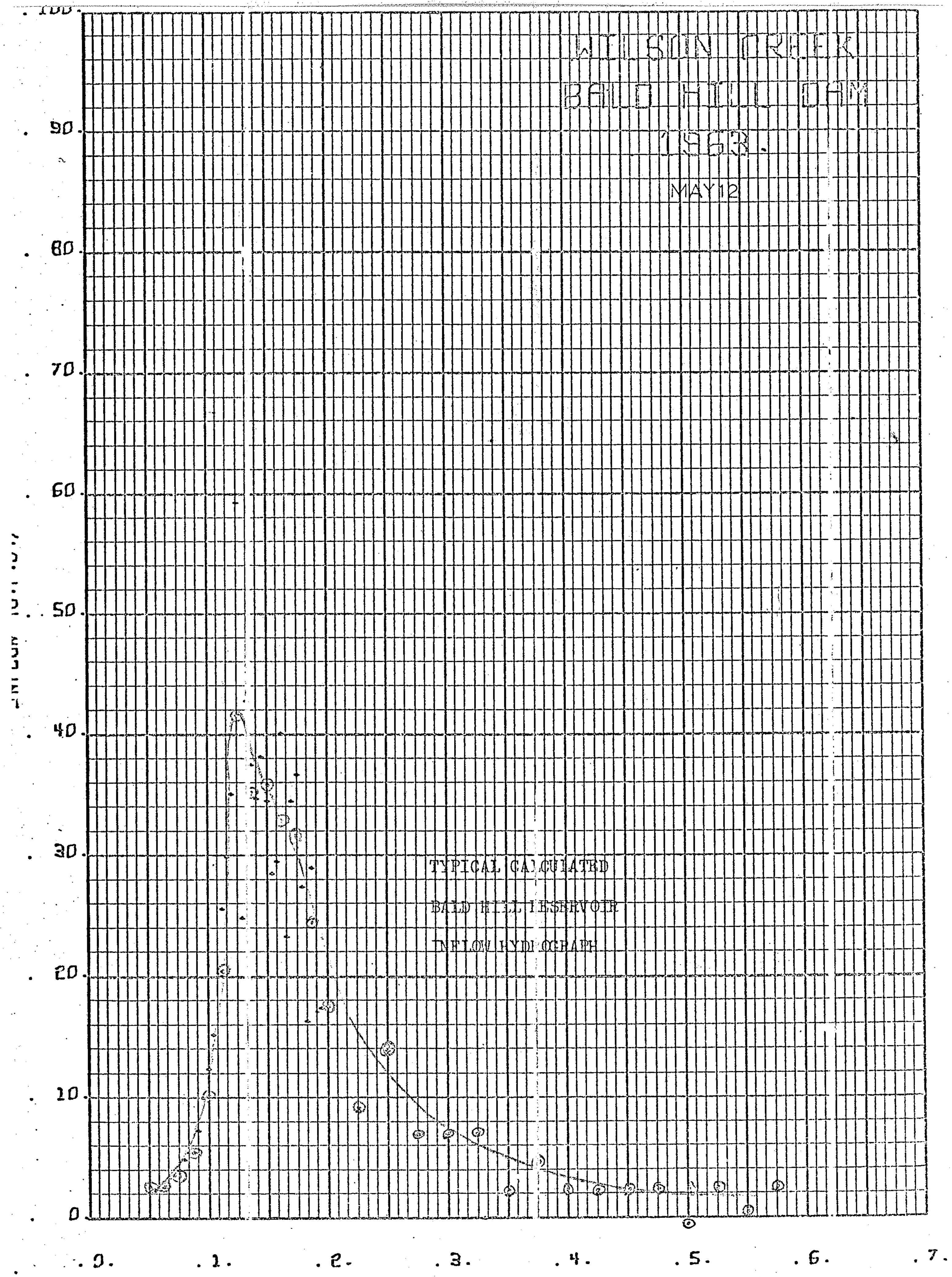
A SMALL AMOUNT OF RAIN FELL ON AUG. 12 & 15

.Conversion factor for D.A. 1 cfs = .000178 In./hr.

Sheet No. 2 of 2

9436 ADD 1100.00 FT TO ALL GAUGE HEIGHTS.

DATE AUG	TIME 66HR	7UA7E HT 6T	STORAGE ACRE-FT	OUTFLOW, CFS	INFLOW CFS	ACC INFLOW CFS
6	1200	2325.74	0.34	2.53	2.53	0.0
6	1500	2325.74	0.34	2.53	2.53	7.60
6	1800	2325.74	0.34	2.53	2.53	15.19
6	2100	2325.74	0.34	2.53	2.53	22.79
6	2400	2332.10	10.00	3.88	42.20	149.38
7	300	2334.55	26.79	4.29	71.77	364.69
7	600	2335.35	36.91	4.41	45.20	500.28
7	1200	2335.95	45.84	4.50	24.47	647.10
7	1800	2336.15	50.62	4.53	12.55	722.42
7	2400	2336.20	51.67	4.54	6.66	762.36
8	500	23*6.20	51.87	4.54	4.54	785.36
8	1200	2336.15	50.82	4.53	2.72	804.11
8	1800	2336.10	49.79	4.53	2.45	818.83
8	2400	2336.00	47.80	4.51	0.50	821.85
9	2400	2335.60	40.73	4.45	0.91	843.79
10	2400	2335.00	32.10	4.36	0.06	845.12
11	2400	2334.25	23.78	4.24	0.11	847.67
12	1400	2333.80	19.82	4.17	0.77	858.52
12	1500	2333.80	19.82	4.17	4.17	862.68
12	1600	2334.10	22.39	4.22	35.37	898.05
12	1700	23*4.20	23.31	4.23	15.36	913.40
12	2400	2333.95	21.06	4.19	0.32	915.64
13	1200	2333.45	17.24	4.11	0.30	919.23
13	2400	2332.70	12.74	3.98	-0.49	913.30
14	600	2332.20	10.42	3.90	-0.74	908.87
14	1200	2331.10	6.67	3.70	-3.76	886.31
14	1800	2330.70	5.64	3.63	1.59	895.85
14	2400	2328.35	1.94	3.16	-4.09	871.34
15	400	2325.74	0.34	2.53	-2.00	863.36
15	2400	2325.74	0.34	2.53	2.53	914.01


WILSON CREEK
BALD HILL DAM
1963.
MAY 12
TYPICAL CALCULATED
BALD HILL RESERVOIR
INFLOW HYDROGRAPH
100
90
80
70
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