ASPECTS CONCERNING SEDIMENTATION OF AVONLEA RESERVOIR

SEDIMENT SURVEY SECTION
APPLIED HYDROLOGY DIVISION
WATER RESOURCES BRANCH
ENVIRONMENT CANADA

1978

Acknowledgements

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Abstract

Sediment filling of Avonlea reservoir has been proceeding at a rate of 31.5 dam ^{3}/yr. (25.5 acre-ft./yr) based on information obtained from the volumetric surveys completed in 1974 compared with those at construction. Under past flow conditions the reservoir will have a useful life expectancy in the order of 90 years.

The concern initially that the reservoir was losing storage capacity at a faster rate was due to the fact that the original reservoir capacity was incorrectly determined. Results from this study show that sedimentation rates for Avonlea reservoir are normal for its environmental and drainage basin characteristics.

A review of equations and formulae designed to predict sediment yields for environments such as Avonlea showed them at variance with the value obtained from this study of 15.8 tonnes/km^2/yr.

Table of Contents

Table of Contents (Cont'd)

List of Figures

List of Tables

Chapter 1 Introduction

Sedimentation is a natural process that should always be considered in reservoir design and maintenance. The primary concern is the rate of sedimentation and its effect on reducing the useful water storage and supply life of a reservoir. This study will determine a sedimentation rate and life expectancy for Avonlea reservoir, a reservoir located in the prairie region of Saskatchewan.

A qualitative and quantitative analysis of the drainage basin has been included to add to a more complete understanding of the factors affecting sedimentation for this particular watershed.

Current trends in the study of reservoir sedimentation in Canada have been in the precise measurement of the submerged morphology, with the aid of a hydrographic data acquisition system. This system referred to as the Hydac-100 was developed by the Staff of the Sediment Survey Section, Environment Canada. The data obtained from this system can be used to determine accurately sediment volume changes and is contributing to a more complete understanding of the sedimentation process.

This study will also assess various equations and formulae that have been developed to predict sediment yields. The results from these will be compared to the actual measured value to indicate whether or not they are applicable to such basins and environments as Avonlea.

Chapter 2 Drainage Basin Characteristics

2.1 Introduction

Avonlea Creek, one of the largest tributaries draining into Moose Jaw Creek, is located about 80 km southwest of the City of Regina (Fig. 1). The watershed is located to the northeast of the Missouri Coteau and is divided from Moose Jaw Creek by the Blackfoot Ridge.

The drainage area for Avonlea reservoir is 825 km^2, most of which is in agricultural use. It is this area which generates both the runoff required to maintain water storage within the 6035 dam^3 (4893 acre-ft) capacity reservoir; and the sediment which tends to reduce that storage capacity.

When discussing sedimentation, the environmental factors which are acting on the drainage basin must be considered and the degree to which they influence sediment yields and erosion rates must be evaluated. The factors affecting the drainage area have been classified into two categories, active and passive (Guy, 1964).

Climate is considered to be the most active factor in the active factor's category; while under passive factors, variables such as soil characteristics, geology and vegatation are all considered to be important.

Guy (1970) presents a more complete understanding of the interrelations between variables composing the active and passive factors and how they affect erosion and transportation of sediment.

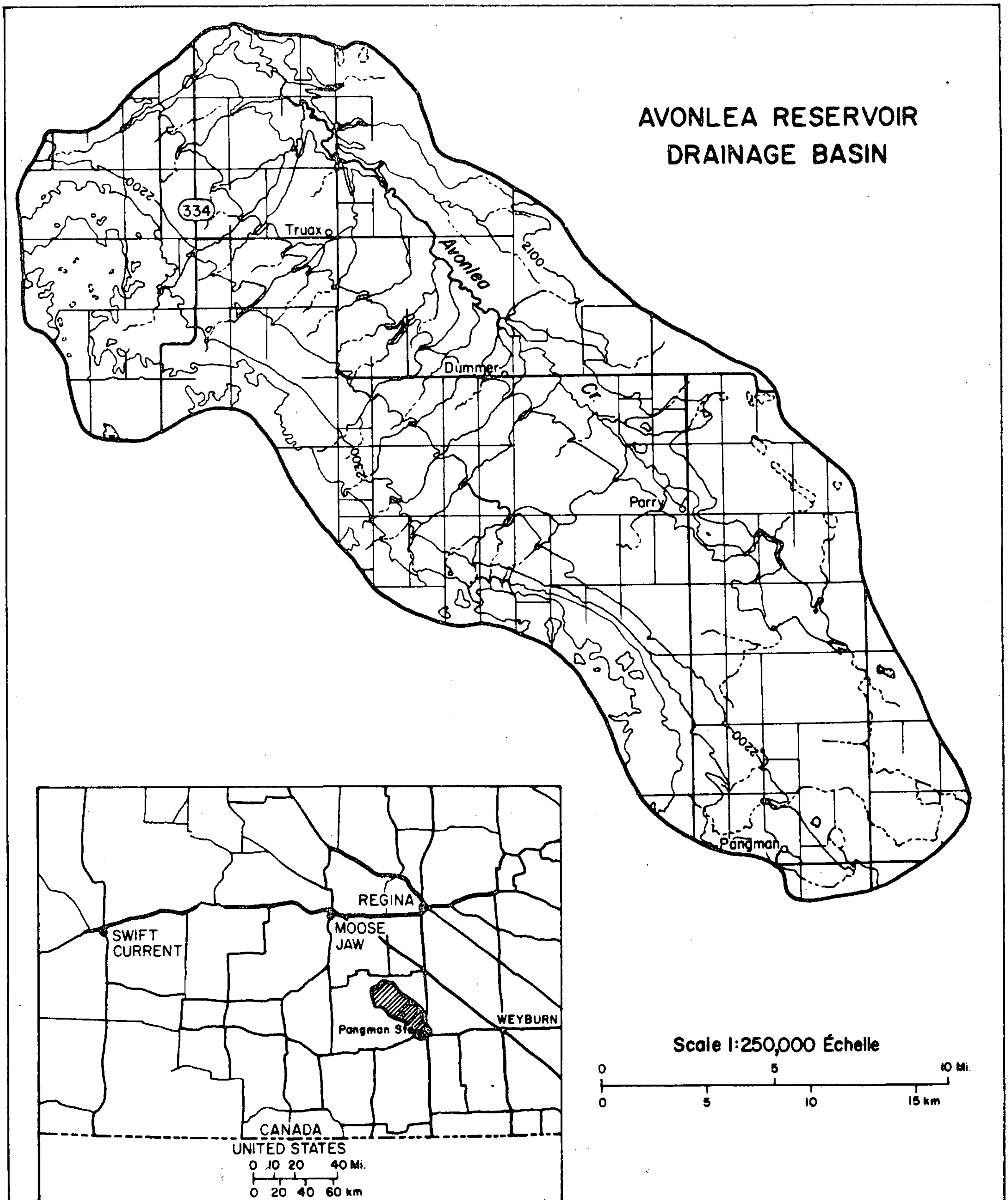

AVONLEA RESERVOIR
DRAINAGE BASIN
334
Truax
Avonlea
Cr.
Dummer
Parry
Pangman
2200
2100
2300
REGINA
MOOSE
JAW
SWIFT
CURRENT
WEYBURN
Pangman St.
CANADA
UNITED STATES
0 10 20 40 Mi.
0 20 40 60 km
Scale 1:250,000 Échelle
0 5 10 Mi.
0 5 10 15 km

FIGURE 1

2.2 Climate

The variables which make climate the important active factor are precipitation, temperature and wind (Guy, 1970). Generally, the Avonlea drainage area has a cool, semi-arid continental type of climate.

Water plays the most important role in the transport of sediment and erosion of the land surface. The total annual precipitation averages only 380 to 400 mm (Ellis, 1967). However, about 40% of this precipitation falls during the months of June, July and August (Longley, 1972). Even more important is the fact that the precipitation comes in the form of extensive storms, which contribute to high sediment concentrations from sheet and gully erosion. Another important event is spring runoff. Runoff from snowmelt accounts for a further 25% of the total annual precipitation (Ellis, 1967). Relatively unprotected surfaces allow runoff to remove large volumes of material.

Another point which should be mentioned about precipitation is that it is unreliable; large variations in the total amount have been recorded from year to year (Table 1). Within the 10 year period total annual precipitation fluctuated from 325 to 575 mm.

Potential evapotranspiration has been used as a good indicator of drought susceptibility of an area. A potential evapotranspiration value of 560 mm was calculated for this area using 1921-1950 data (Longley, 1972). Assuming a minimum 100 mm required

TABLE 1

PRECIPITATION (M.M.)

STATION - WILCOX, SASKATCHEWAN

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL
1967	22.85	10.16	54.61	17.02	13.21	35.81	10.92	14.22	95.50	39.37	26.16	7.62	347.46
1968	23.00M	1.27	1.27	2.03	25.15	22.61	35.56	147.57	36.58	5.59	10.16	12.70	323.49
1969	38.10	22.86	17.78	43.43	26.92	60.71	49.53	18.80	30.99	58.42	18.09M	15.24	400.87
1970	30.48	27.80M	15.24	76.71	69.60	32.04	28.96	25.91	65.28	27.43	22.86	17.78	490.09
1971	10.16	10.16	40.64	28.19	6.35	66.80	47.75	52.10M	3.81	46.23	13.21	25.40	350.80
1972	20.32	68.58	11.43	9.14	74.17	45.97	32.26	35.05	25.15	17.79	25.40	20.32	385.58
1973	0.00	15.24	16.51	48.51	16.51	104.39	23.37	18.29	46.74	12.19	40.64	38.10	380.49
1974	53.34	73.66	43.18	34.29	96.52	16.51	57.15	114.81	24.38	22.86	.25	40.64	577.59
1975	8.89	20.32	48.26	93.47	23.37	56.64	18.03	85.60	59.18	21.59	16.51	35.56	487.42
1976	22.85	27.94	73.66	8.64	69.09	176.53	53.59	8.64	5.08	1.27	7.62	27.94	482.85
MEAN	23.00	27.80	32.26	36.14	42.09	66.80	35.71	52.10	39.27	25.27	18.09	24.13	422.66

M - MEAN VALUE

Source: Canada Atmospheric Environment Service, Monthly Record to maintain soil moisture, would mean that 460 mm of precipitation must fall to maintain sufficient soil moisture. As Table 1 shows, there is high percentage of years in which the total precipitation would be below 460 mm. However, irrigation practices have been applied to maintain a minimum soil moisture and reduce possible drought conditions.

Temperatures also vary considerably. Actual summer temperatures above 38°C and winter temperatures below -45°C have been recorded, with an annual mean of 2.5°C (Longley, 1972). This area is prone to alternate freezing and thawing which has the effect of expanding soil which decreases cohesion. This in turn decreases the tractive force necessary for erosion to occur during spring runoff. High summer temperatures account for the high evapotranspiration value, which decreases soil moisture. This makes the soil more susceptible to wind erosion, which is quite active in the area.

Wind dislodges the loose soil particles and can move them considerable distances. The many "blow-outs" throughout the area show the harsh effects of wind erosion. The prevailing winds are westerly; warm, dry "chinook" winds from the southwest and colder northwesterly winds. The winds on a whole are considered to be light, but convective storms produce strong, gusty winds which can remove much soil in a relatively short period of time.

2.3) Surface and Subsurface Conditions

2.3.1) Geology

The erosional regime of an area is ultimately conditioned by the geology within any given climatic zone. Furthermore, analysis of geological formations helps establish sediment characteristics, which affect sedimentation rates.

The stratigraphical succession for the Avonlea drainage basin is indicated in Table 2.

Table 2

ERA	PERIOD	FORMATION	LITHOLOGY
Mesozoic	Upper Cretaceous	Whitemud	- sand and clay
		Sand E	- mostly coarse sand and some clay
		Eastend	- mostly fine sand and some clay
		Bearpaw	- mostly dark shales

Source: Geological Paper 37-26, 1937

The bedrock surface in part is composed of grey, montmorillonitic clays and shales of the Bearpaw formation. The Eastend formation consists of fine sand and silt which overlie the Bearpaw formation. The succession then passes to the coarse sand E formation, which consists of massive yellowish grey, feldspathic sand. The final formation is that of the Whitemud, which consists of mostly white arenanceous clay (Fraser et al., 1935).

Exposures of bedrock are found mostly along the creek valleys and on the northeast face of Blackfoot Ridge where the streams have developed badland topography. Exposures of the Eastend and Sand E occur along Avonlea Creek and its tributaries, and along some valleys wouthwest of Truax. (Fig. 1) The only exposures of the Whitemud formation are found along Avonlea Creek (Wickenden and Graham, 1937).

In Pleistocene times the whole area was covered by continental ice sheets; glacial drift consisting mostly of boulder clay and till now form surface deposits. The melting of the ice sheets formed glacial lake Regina which produced lacustrine deposits composed of well sorted silts and clays that cover the lower area of the drainage area (Wickenden and Graham, 1937).

2.3.2) <u>Soils and Land Use</u>

The soils developed on the glacial till and derived from marine shales (Bearpaw Formation) of Cretaceous age are Solonetzic Dark Brown soils, belonging to the Trossachs Association (Ellis et al., 1967). The parent material of the Trossachs Association is olive gray to grayish brown in colour, and sandy clay loam to heavy clay loam in texture. The presence of salts in the Bearpaw shales is what makes the soil moderate to highly saline.

A characteristic of the Trossach soil is an uneven or hummocky surface, a result of wind eroded pits commonly referred to as "blow-outs" or "burn-outs" (Joel et al., 1936). The pits may become so numerous in some areas that they make the land totally unsuitable for agriculture (Fig. 2). Furthermore, these shallow pits affect normal drainage and can turn areas into wetlands (Fig. 2). The pits also act as collectors of high concentrations of soluble salts, which makes areas unsuitable for most types of vegetation.

Most of the area in the drainage basin can be classified as either class 4 or class 5, according to the the ARDA land capability classification, mapsheet (Willow Bunch Lake - 72H). These classes mean that the soils have severe structural limitations and depending on the proportion of pits in an area, classification can be even further lowered.

The conditions are suitable for wheat which is the most extensively grown crop. Mixed farming and ranching is dominant in areas not suitable for wheat production.

2.3.3) Vegetation

The native vegetation of the area may be considered as of mixed prairie type and is closely related to climatic conditions (Ellis et al., 1967). The high temperatures and warm summer winds combine to make soil moisture the limiting factor in growth. This makes drought-resistant plants such as grasses the dominant vegetation

AIRPHOTO A216517 - 18, AVONLEA RESERVOIR

Fig. 2

in the area. The native vegetation is apparent in areas which are unsuitable for cultivation. These areas which are unsuitable are designated as pasture lands.

The arid slopes are dominated by grasses and low sedges, while wet sloughs are inhabitated by moisture-loving plants such as sedges, grasses and rushes. Highly saline areas are characterized by a vegetative cover of alkali grass, and wild barley where the soil has been disturbed. Trees are almost absent from the area (Ellis et al., 1967).

2.4) Drainage Basin Analysis

A quantitative analysis, supplemented with qualitative information allows for a more complete understanding of the relationships which exist among variables within a drainage system. Quantitative analysis of watershed geomorphology is applied to normally developed watersheds, where the chief agents, running water and associated mass gravity movements over time has developed the surface geometry (Strahler, 1964).

Stream ordering is one of the first steps in drainage basin analysis. In this study Strahler's modified version of Horton's method of stream numbering was applied. Air photos (scale 1/85,000) were used to identify as many tributaries as possible. A larger scale would have been more accurate, but these were the only photos available that covered the area.

For stream order analysis, a regression equation is obtained by relating number of streams to stream order (Fig. 3). This in turn allows a bifurcation ratio (Rb) 3.59 to be calculated for the drainage basin. Bifurcation ratios characteristically range between 3.0 and 5.0 for watersheds in which the geologic structures do not distort the drainage pattern (Strahler, 1964). Therefore it would appear the Avonlea Creek drainage pattern is not influenced by geologic structures.

Hypsometric (area-altitude) analysis is useful in that it determines the stage of the basin in the erosional cycle. This type of analysis was first developed by Langbein for large drainage basins and modified by Strahler for application to small drainage basins of low order.

The shape of the hypsometric curve varies in early stages of the development of the drainage basin, but once equilibrium is attained (mature stage) there will be little change, despite lowering of relief (Strahler, 1957).

The hypsometric curve obtained for Avonlea drainage basin follows closely that of the path of the mature stage and suggests that there will be little change in its erosional capabilities over geologic time. (Fig.4)

Drainage density is an important indicator of the linear scale of land-form elements in stream eroded topography (Strahler, 1964). Drainage density values of less than 5.0 km/km^2 are considered coarse (Gregory & Walling, 1973).

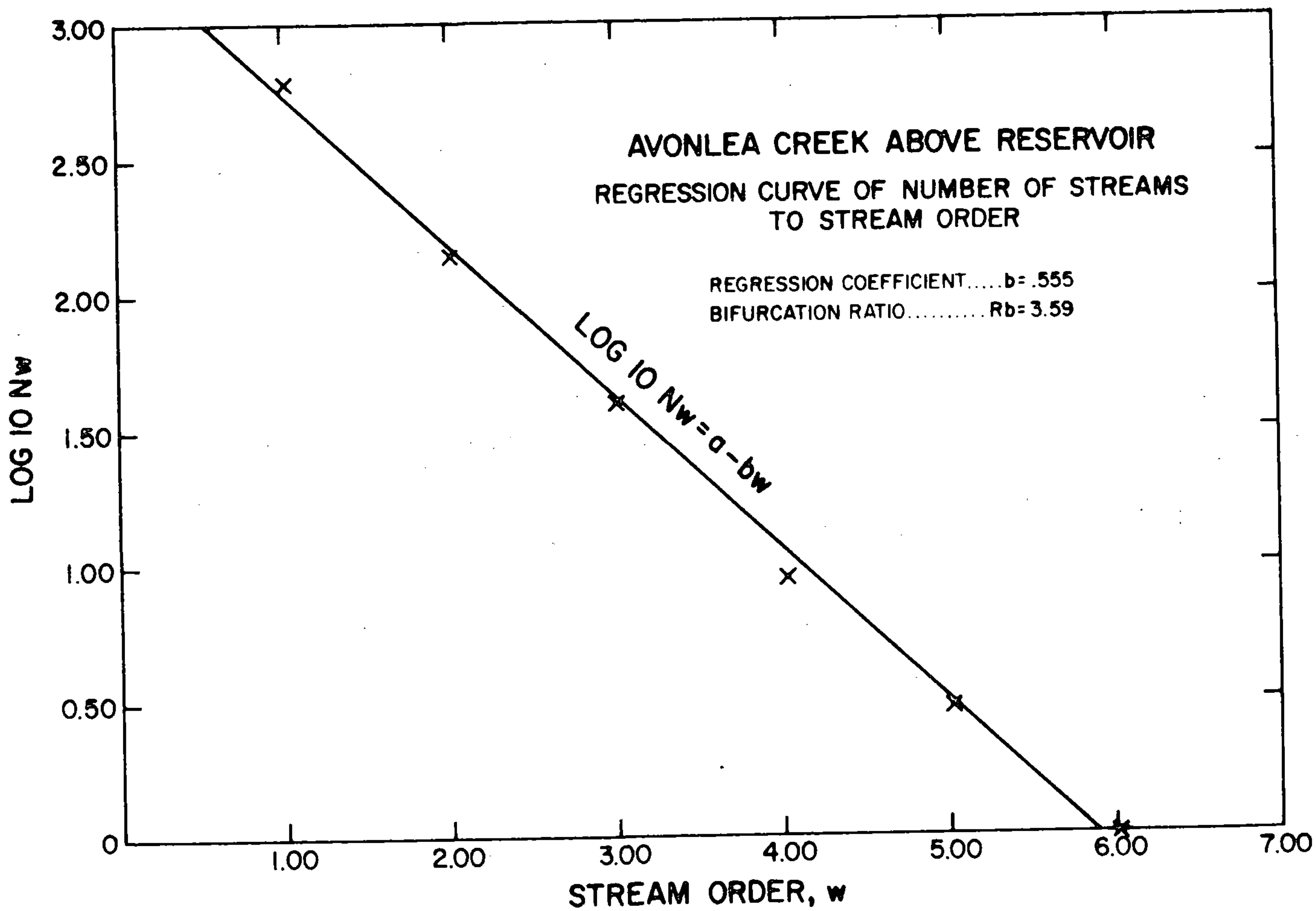
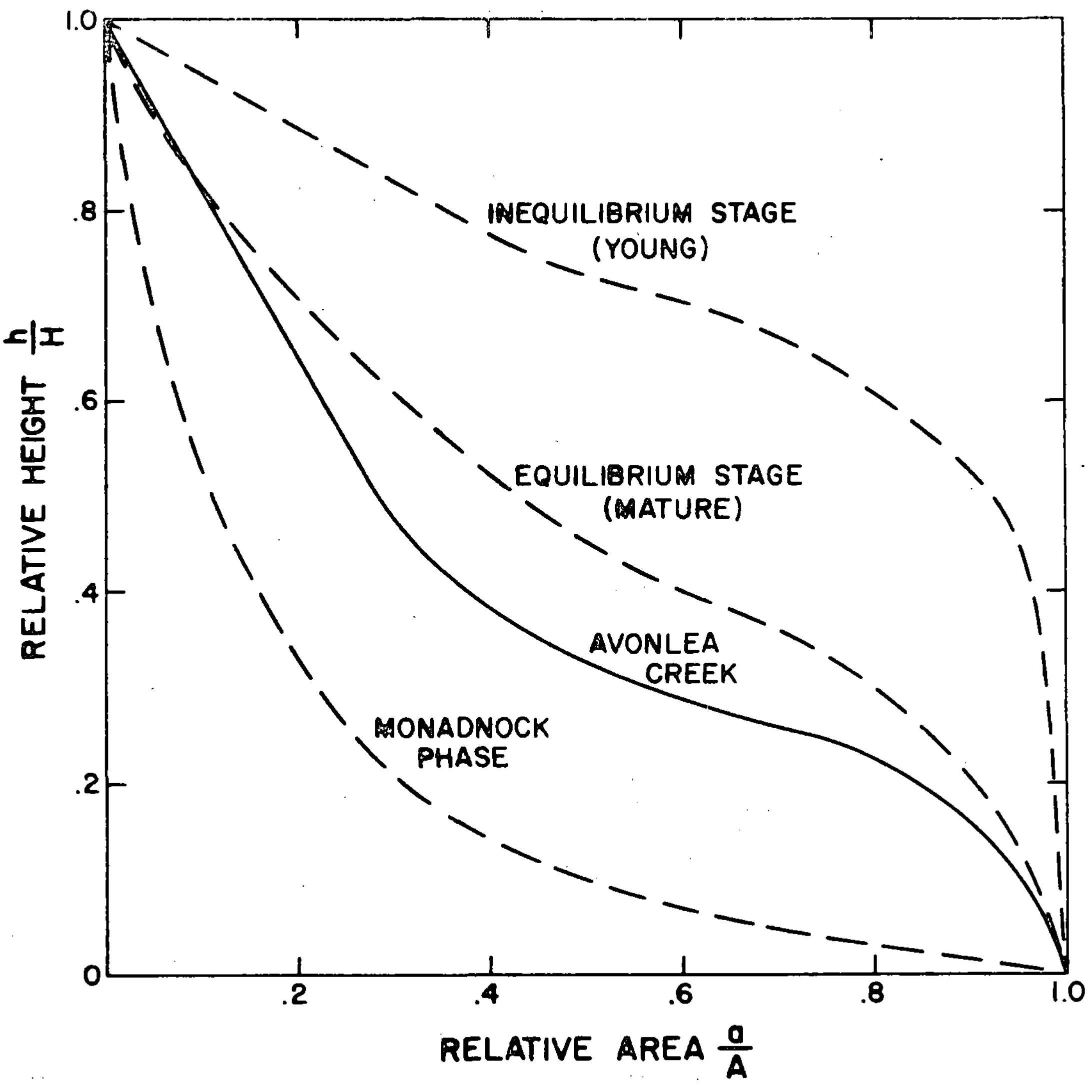

AVONLEA CREEK ABOVE RESERVOIR
REGRESSION CURVE OF NUMBER OF STREAMS TO STREAM ORDER
REGRESSION COEFFICIENT.....b=.555
BIFURCATION RATIO.........Rb=3.59
LOG 10 Nw=a-bw
LOG 10 Nw
STREAM ORDER, w
3.00
2.50
2.00
1.50
1.00
0.50
0
1.00
2.00
3.00
4.00
5.00
6.00
7.00

FIG. 3



AVONLEA CREEK

HYPSOMETRIC CURVE
RELATIVE HEIGHT
TO
RELATIVE AREA

FIG. 4

The drainage density analysis of Avonlea Creek produced a value of .89 km per km^2. Coarse values are usually found in areas of permeable rocks and of low rainfall intensity, (Gregory & Walling, 1973) these conditions are apparent in the drainage area. The density value, however, is low even to be considered as coarse.

Drainage pattern is also important in determining subsurface conditions. The Avonlea drainage pattern would be classified as dendritic. A dendritic pattern is usually associated with bedrock strata which are more or less horizontal and homogeneous in texture (Chow, 1964).

Chapter 3 Techniques and Equipment Used in Sedimentation Study of Avonlea Reservoir

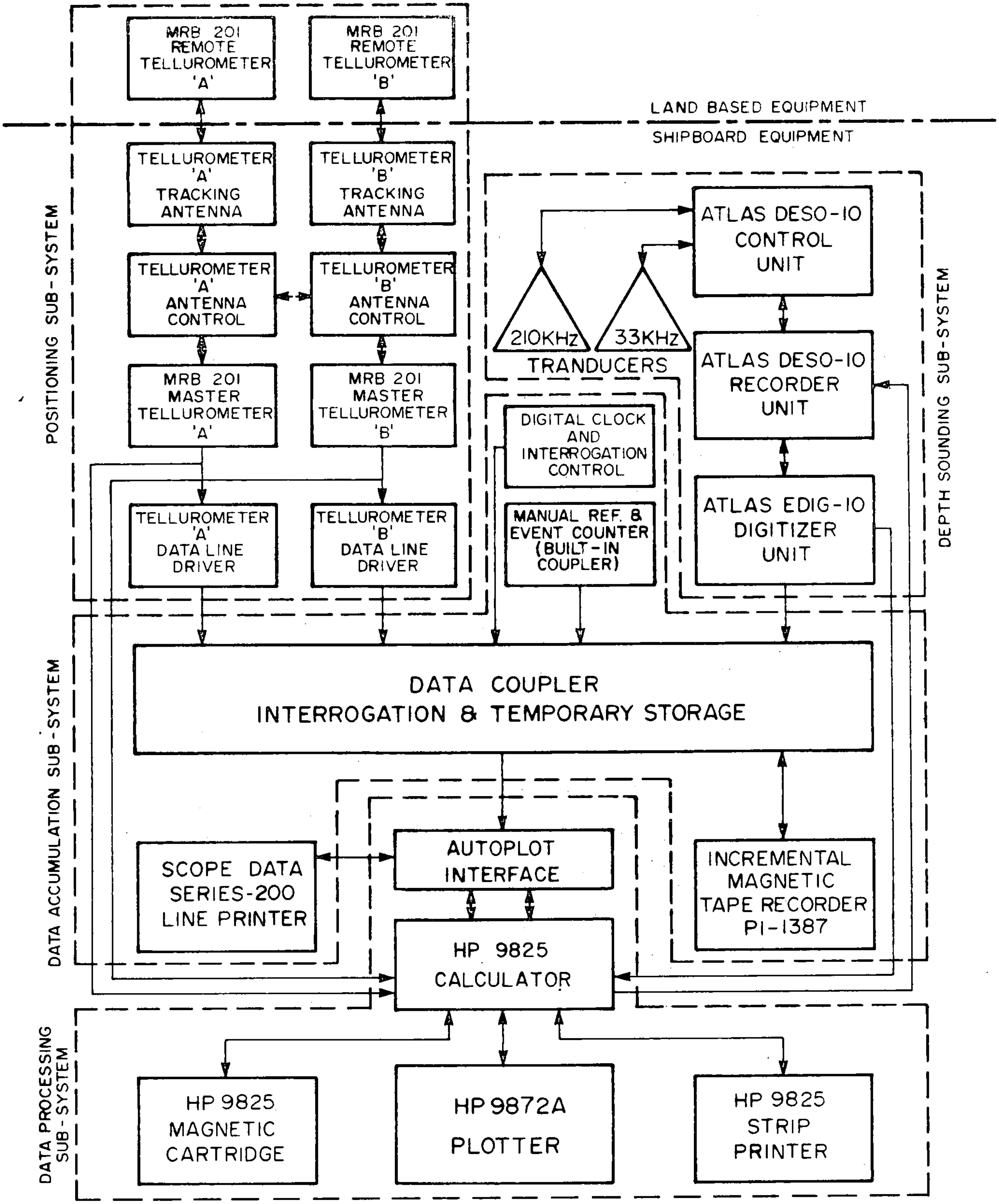
3.1 Introduction

Cooke and Doornkamp (1974) review equations which have been derived by Fournier (1960), Douglas (1967), and Langbein and Schumm (1958) to predict sediment yields using precipitation as the significant variable. Other equations, such as Musgraves' and the universal soil loss equation (1947) are used to predict soil loss from a watershed, which in turn is used to estimate sediment yields (Chow, 1964). Equations such as these must be recognized as providing only best available estimates of sediment production rather than absolute data.

Now sophisticated hydrographic data acquisition survey systems such as the Hydac-100 have been developed to accurately measure and allow computation sediment quantities.

3.2 The Hydrographic Data Acquisition System, Hydac-100 and Survey Procedures

The system used in this particular study was developed by Sediment Survey of Canada, to collect, reduce and analyze data required to study sedimentation rates and distributions in rivers, reservoirs, and estuaries. The data collection system is comprised of two dynamic distance measuring devices, an echo-sounder/digitizer, a precision electronic digital clock, a data coupler, a magnetic tape recorder, a line printer, a programmable calculator, and a plotter. The working relationships of the individual components and sub-systems is shown in Fig. 5. Detailed information on the



THE HYDAC-100
A HYDROGRAPHIC DATA ACQUISITION SYSTEM
FIGURE 5

system is available in the report by Durette and Zrymiak (1978), but the operating principles are outlined below.

The system can be divided into four sub-systems:

1) positioning sub-system

2) depth sounding sub-system

3) data accumulation and storage sub-system

4) data processing sub-system.

3.2.1 Positioning Sub-system

The dynamic positioning of the vessel is accomplished through two systems of electronic range measuring devices (MRB tellurometers). Each system consists of a remote unit on shore, a tracking antennae, a tracking antenna control, a master unit, and a data line driver on board the survey vessel. (Fig. 6). The tellurometers have an accuracy of ±1.5 metres under dynamic conditions with a boat speed in the order of 30 knots, and a range of 50 km.

3.2.2 Depth Sounding Sub-system

This sub-system comprises a control unit (Atlas-Deso-10) and a recorder unit with two transducers of different frequencies, 210 KHZ and 33 KHZ and digitizer unit (Atlas-Edig-10). The system uses ultrasonic pulses for depth measurement. A short sound pulse is emitted by the transducers in the form of an 8° beam vertically down towards the bottom. The accuracy of measurement is dependent on the accuracy of reading from the recording paper, but is within ±5 cm. The range of this unit is 0 to 280 metres. The digitizer evaluates and provides a digital output of the depth, with the smallest measuring unit being 5 cm.

HYDAC - 100

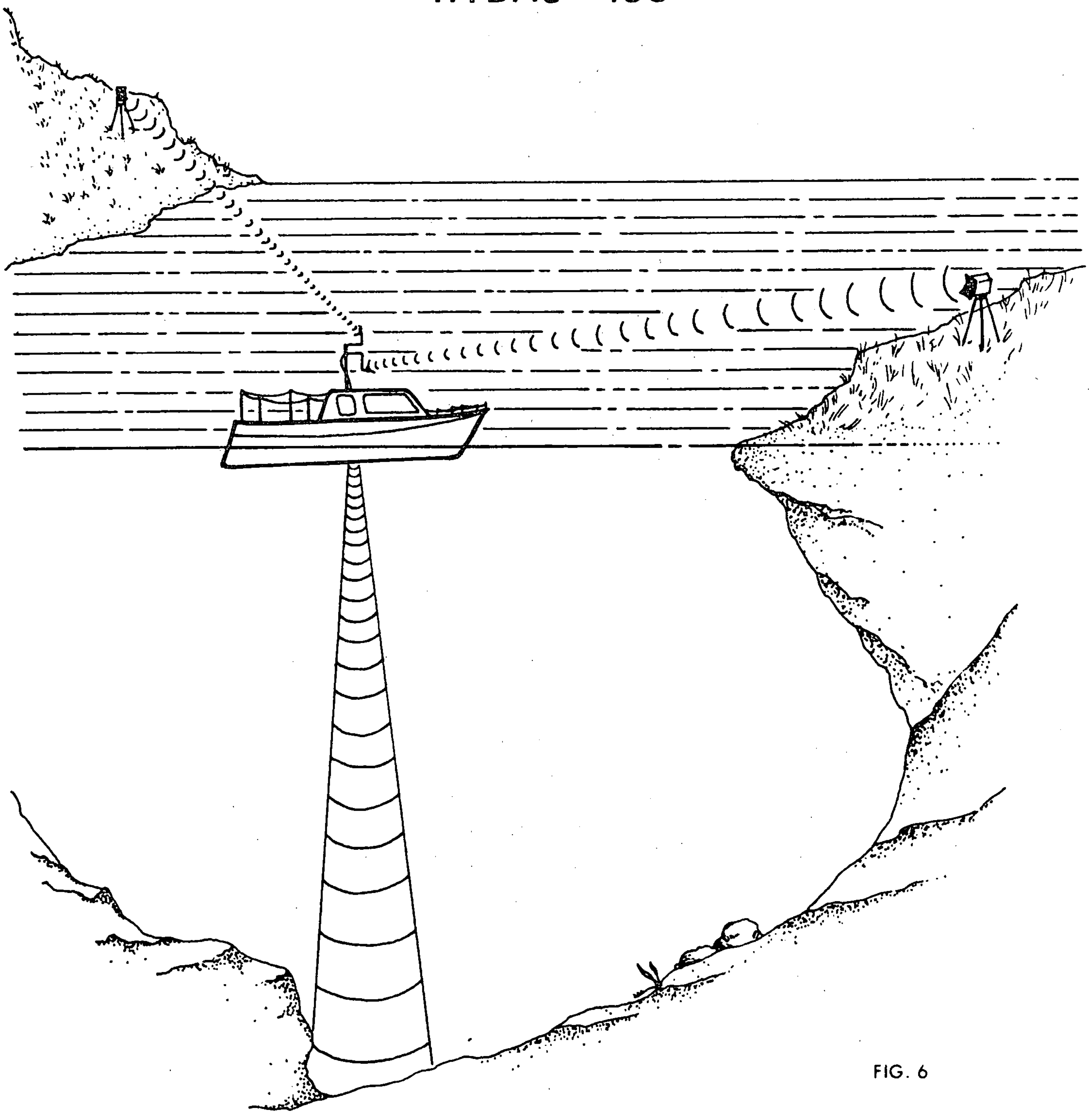


FIG. 6

3.2.3 Data Accumulation and Storage Sub-system

The heart of the Hydac-100 is the data coupler which is capable, on command, of interrogating up to ten peripheral devices. The coupler temporarily stores the data, inserts house-keeping characters and outputs the results onto a magnetic tape recorder (P1-1387) and a digital line printer (Scope Data Series-200).

3.2.4 Data Processing Sub-system

This sub-system monitors the performance of all the instruments and optimizes the quality of the data collected by improving the survey data density grid, through a continuous plot of the survey vessel position.

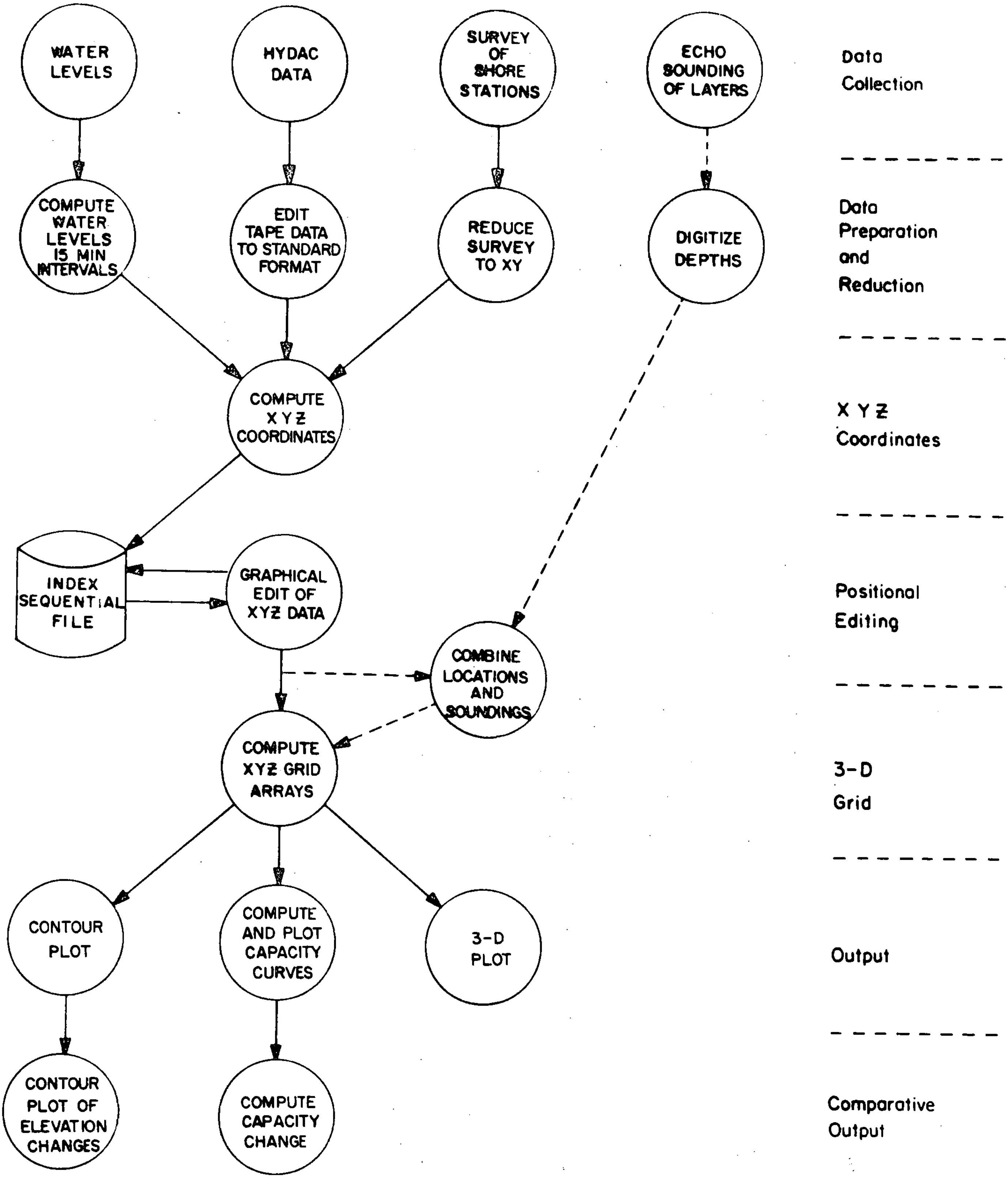
3.2.5 Survey Method

The survey of Avonlea reservoir was done using the Area Survey Method. This survey procedure consists of establishing the water surface elevation, fixing shore positions, measuring depth with simultaneous referencing to the shore positions and traversing the body of water according to a previously established survey pattern. In small bodies of water such as Avonlea reservoir a closed system of surveying is used. The advantage of this is that a grid survey pattern combined with area method allows total coverage of the body of water.

3.2.6 Data Reduction and Analysis

A flowchart is provided to show the steps involved from once the data is collected to the final outputs that can be obtained (Fig. 7).

FIGURE 7
HYDRA* SYSTEM FLOW CHART



* HYdrographic Data Reduction and Analysis

3.3 Sampling Techniques and Equipment

3.3.1 Instantaneous Horizontal Sampler

To collect suspended sediment concentrations an instantaneous horizontal sampler was used (Fig. 8) (Stichling, 1969).

A representative value is obtained by taking three samples at a location. The first sample is taken approximately 0.15 M below the water surface, another at 0.5 of the total depth and one 0.9 of total depth. The three values are then used to obtain an average value.

Suspended sediment analysis results were obtained by using the filtration method of analysis (Guy, 1969).

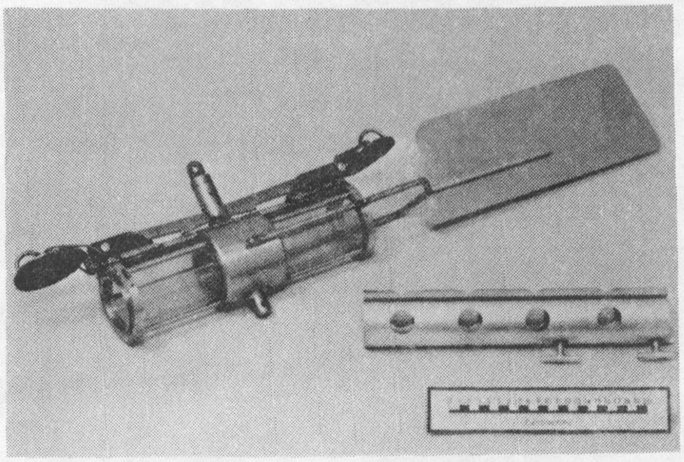
3.3.2 Modified Phleger Corer Sampler (Model 840-A)

The Phleger sampler obtains sediment cores 3.5 cm in diameter and up to 61 cm long; samples are retained in an easy removable clear buterate liner (Fig. 9). This in turn allows inplace densities to be calculated as well as using the sample material for determining particle size distribution.

The weighted Phleger sampler is dropped from the side of the boat and is driven into the sediment, sampler and sample are then retrieved. The sample remains intact due to hydrostatic pressure.

Fig. 8

Horizontal Instantaneous Sampler



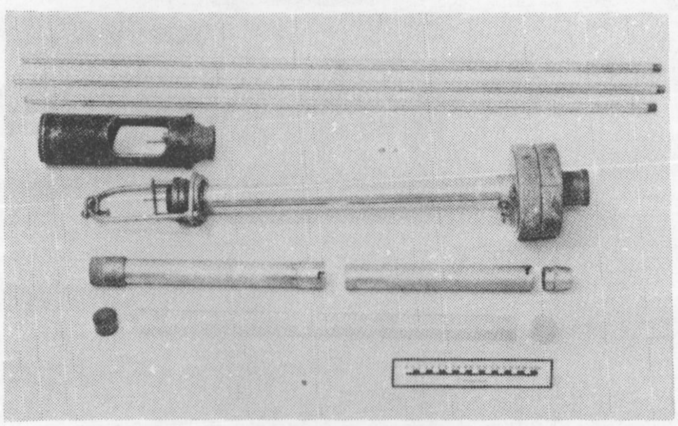


Fig. 9

Modified Phleger Corer Sampler (Model 840-A)

Chapter 4 Reservoir Data Analysis and Results

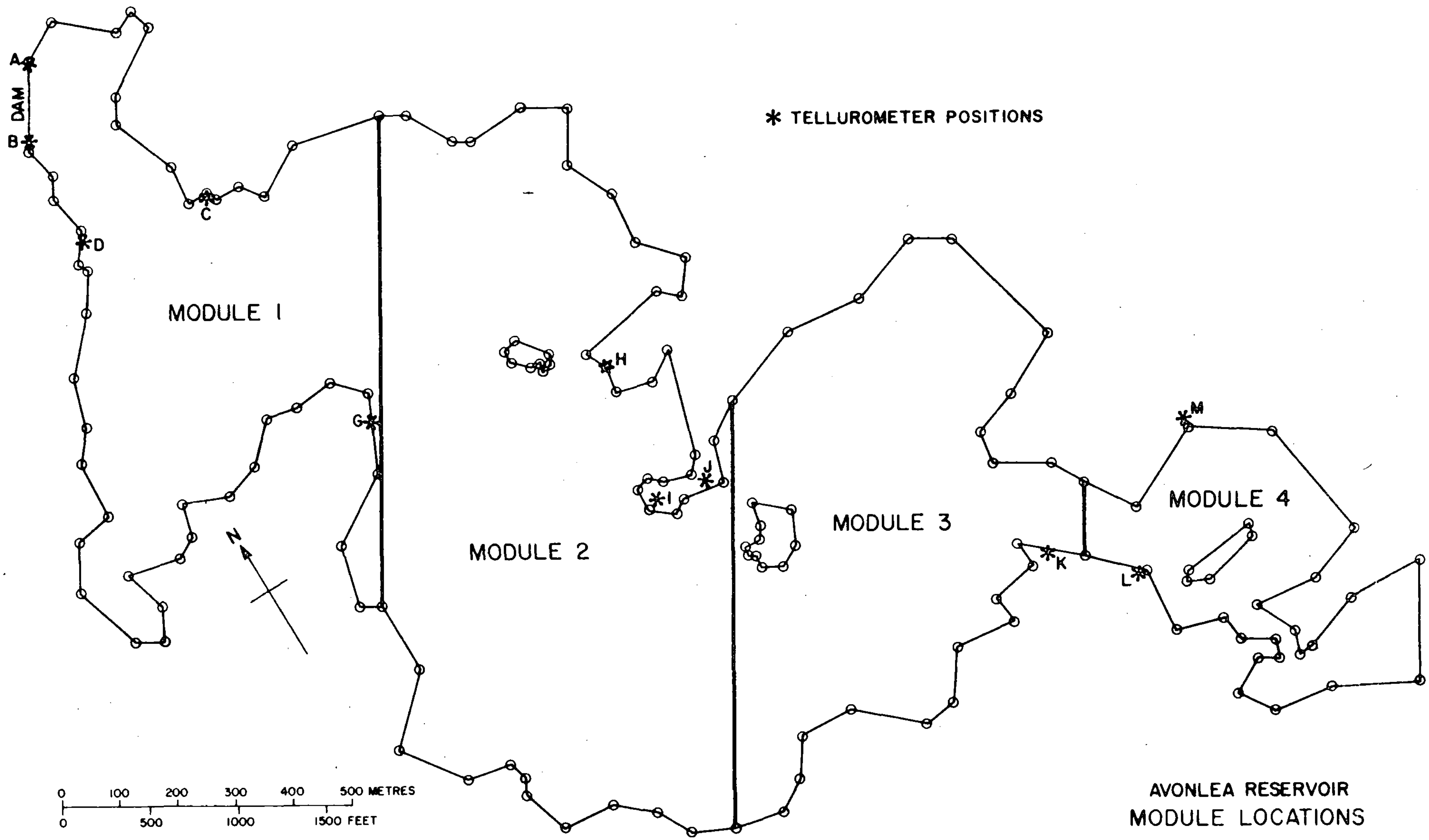
4.1 Description of Avonlea Reservoir

The Avonlea dam was constructed in 1963 by P.F.R.A. for the main purpose of providing irrigation water for the Avonlea Water Users Association. The reservoir would have a storage capacity of 6035 dam^3 (4893 acre-ft.) when the water level was at full supply level 597.6 M (1960.5 ft.). Of the storage capacity, 600 dam^3 (486 acre-ft.) is dead storage and 5435 dam^3 (4407 acre-ft.) is live storage.

This storage capacity figure differs from that of an earlier reported value of 7400 dam^3 (6000 acre-ft.). It was found while analyzing the 1974 survey results that there appeared to be an unusually high capacity loss due presumably to sedimentation, if the initial capacity was 7400 dam^3 (6000 acre-ft.). With the aid of original reservoir plans, an error was found to exist in the area computations. This was corrected and a revised storage capacity value was calculated.

4.2 The Capacity Study

The capacity study was undertaken and completed in September 1974. Avonlea reservoir was divided into four modules for data collection purposes, and analysis (Fig. 10). Modules are useful in that they allow individual areas to be analyzed separately, as well as the entire reservoir. This is the first volumetric survey to be completed other than the initial calculation of the reservoir capacity. However, once another survey is completed the



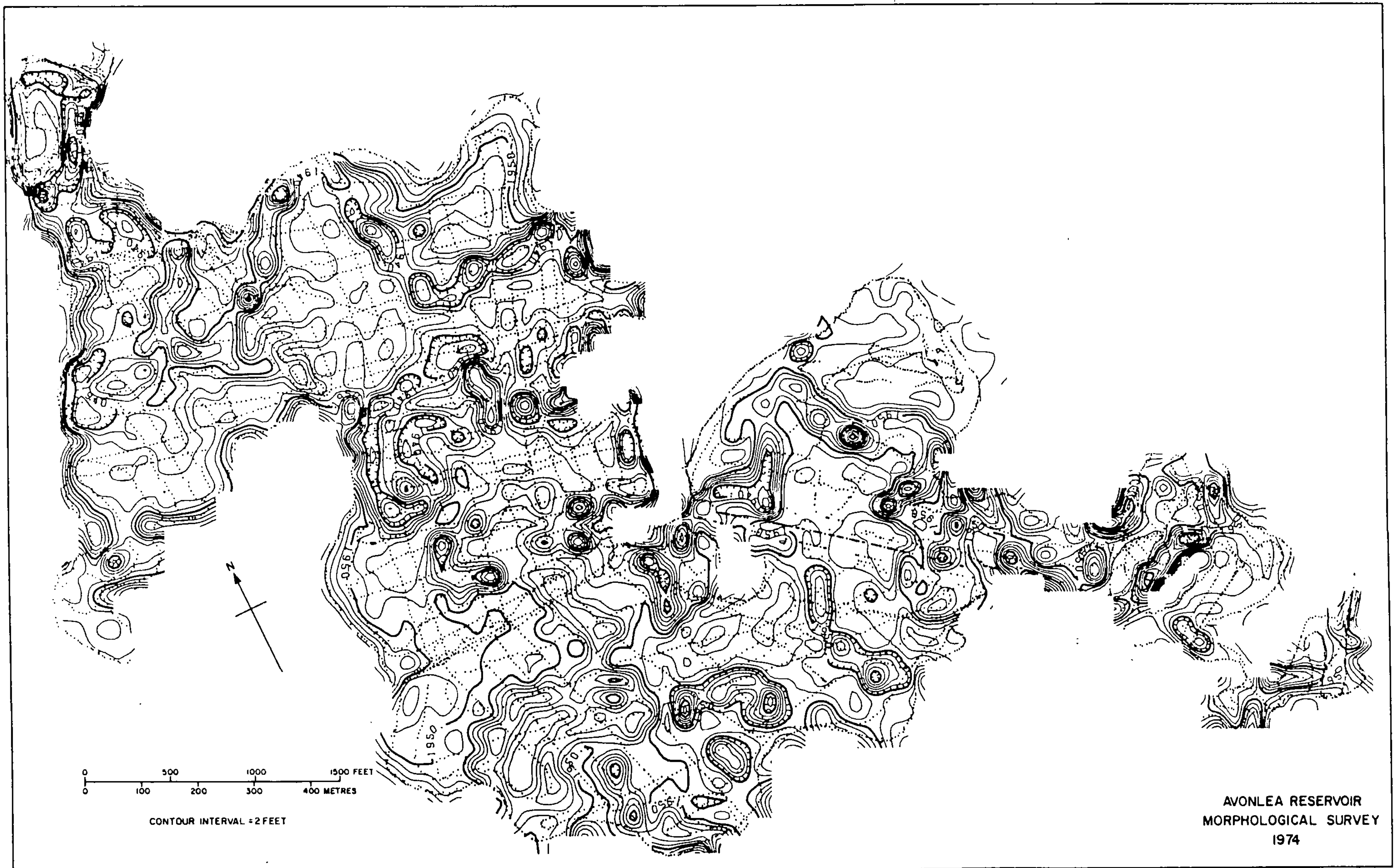
AVONLEA RESERVOIR
MODULE LOCATIONS

FIG. 10

individual modules can be analyzed for capacity change and also, areas of aggradation and degradation within the reservoir can be defined. The results from this study can be used to compute changes in capacity, due to sedimentation, by direct comparison to the original capacity.

The data which can be used for analysis is presented in three different forms; a contour map, an elevation capacity table and capacity curve. These are available for each module as well as the entire reservoir. A contour map is useful in that it allows analysis of the bed geometry (Fig. 11). The elevation capacity table (Table 3) for Avonlea reservoir provides a capacity value for specific elevations and the capacity curve provides an analog interpretation of the tabulated values (Fig. 12).

The capacity survey results show an overall loss in capacity of 346 dam^3 (280 acre-ft.) if one compares the 1963 to the 1974 capacity curve at full supply level. This in turn gives us a sedimentation rate of 31.5 dam^3 (25.5 acre-ft.) per annum. This sedimentation rate is based on results of the past eleven years. Below 592 m (1942 ft.) elevation is dead storage, which accounts for 660 dam^3 (486 acre-ft.) of the total storage capacity. Results show that the dead storage capacity has been decreased by 336 dam^3 (272 acre-ft.) a 56% loss in dead storage capacity. This loss rate in dead storage means that in the near future the dead storage will be full and live storage will then begin to be reduced. From 592 m (1942 ft.) to the 595.9 m (1955 ft.) elevation a further



AVONLEA RESERVOIR
MORPHOLOGICAL SURVEY
1974

FIG. 11

TABLE 3

SEDIMENT SURVEY SECTION
OTTAWA, ONT.
AUGUST, 1976

AVONLEA RESERVOIR 1976

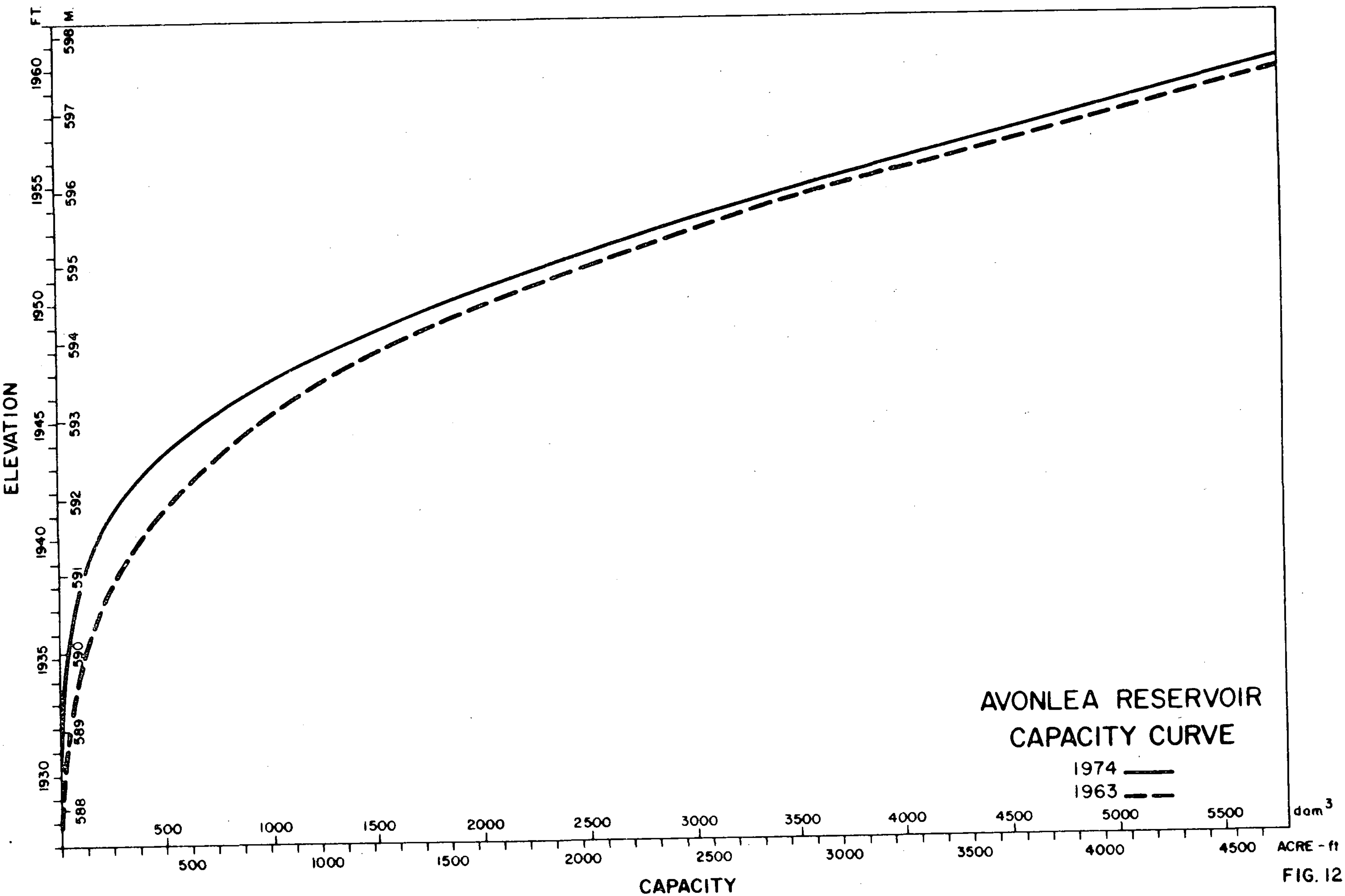
ELEVATION - CAPACITY TABLE

ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)
1927.50	.0	1940.00	119.8	1952.50	1955.4		
1928.00	.1	1940.50	139.0	1953.00	2096.3		
1928.50	.2	1941.00	160.9	1953.50	2261.5		
1929.00	.4	1941.50	185.9	1954.00	2391.2		
1929.50	.7	1942.00	214.3	1954.50	2545.5		
1930.00	1.0	1942.50	246.9	1955.00	2704.0		
1930.50	1.6	1943.00	283.7	1955.50	2866.0		
1931.00	2.4	1943.50	324.5	1956.00	3031.2		
1931.50	3.3	1944.00	369.4	1956.50	3199.8		
1932.00	4.5	1944.50	419.0	1957.00	3371.6		
1932.50	6.0	1945.00	473.5	1957.50	3545.9		
1933.00	7.8	1945.50	533.6	1958.00	3721.9		
1933.50	9.9	1946.00	599.5	1958.50	3898.9		
1934.00	12.5	1946.50	670.8	1959.00	4076.7		
1934.50	15.7	1947.00	747.7	1959.50	4254.9		
1935.00	19.6	1947.50	830.3	1960.00	4433.5		
1935.50	24.2	1948.00	918.1	1960.50	4612.3		
1936.00	29.6	1948.50	1011.1	1961.00	4791.3		
1936.50	36.0	1949.00	1109.5	1961.50	4970.4		
1937.00	43.5	1949.50	1213.8	1962.00	5149.7		
1937.50	52.3	1950.00	1324.4				
1938.00	62.5	1950.50	1440.4				
1938.50	74.2	1951.00	1561.2				
1939.00	87.6	1951.50	1687.2				
1939.50	102.8	1952.00	1818.7				

CONVERSION

ACRE-FEET X 1.2335 = CUBIC DECAMETRES (dam^3)

FEET X .3048 = METRES (M)


AVONLEA RESERVOIR
CAPACITY CURVE
1974
1963
ELEVATION
FT.
M.
1930
1935
1940
1945
1950
1955
1960
588
589
590
591
592
593
594
595
596
597
598
CAPACITY
dam3
ACRE - ft
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
FIG. 12

57 dam^3 (46 acre-ft.) of sediment has been deposited. However, erosion of the banks have accounted for an increase in 47 dam^3 (38 acre-ft.) of capacity in the upper elevations of the reservoir; which gives the net loss value of 10 dam^3 (8 acre-ft.) above 592 m (1942 ft.) for a total loss due to sedimentation of 346 dam^3 (280 acre-ft.).

Information on the individual modules is available from the tables and figures in Appendix A.

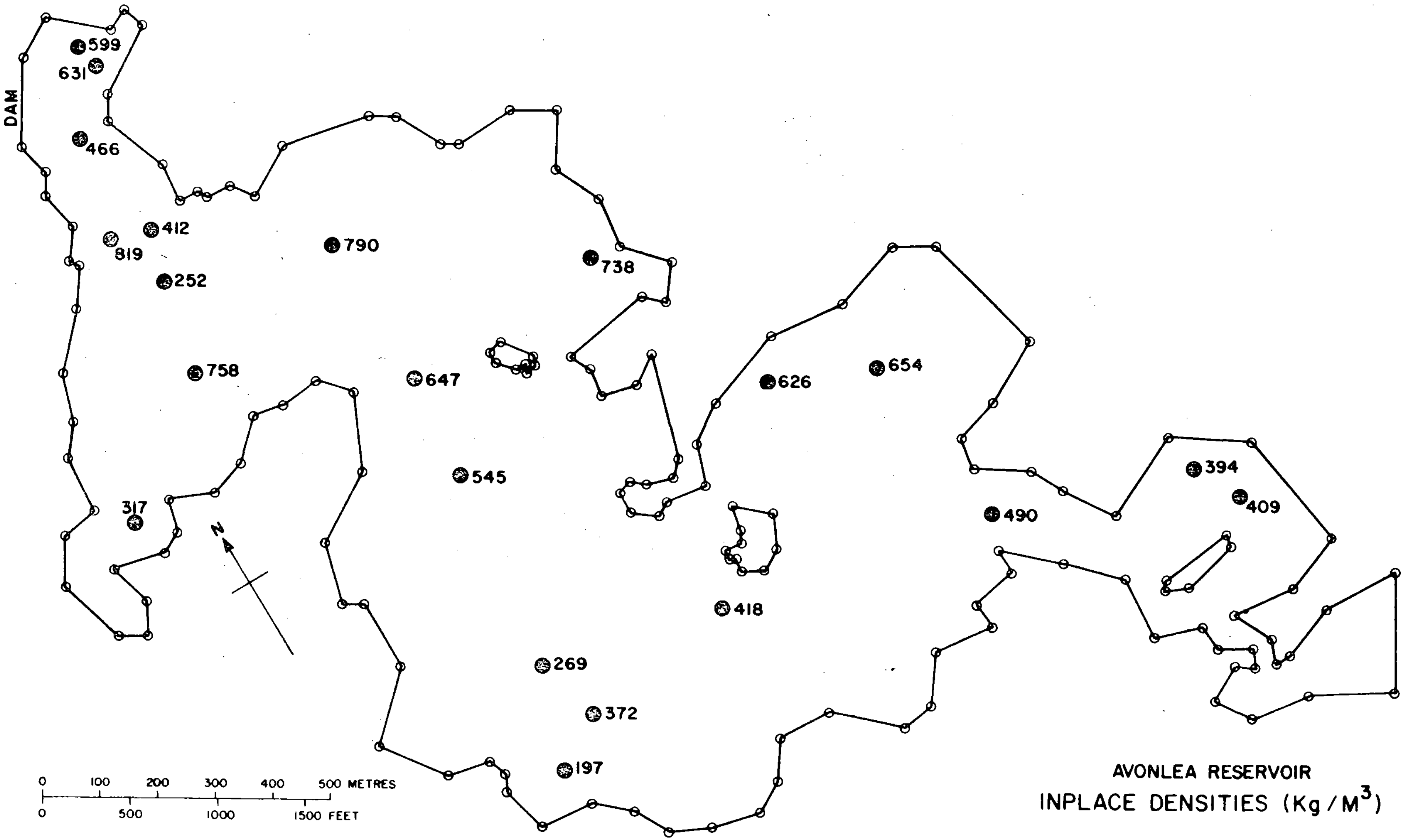
4.3 Bed Material Densities and Deposited Load

Inplace densities have been calculated from samples taken in different areas of the reservoir (Fig. 13). Densities range from 197 to 819 Kg/M^3, with an average value of 513 Kg/M^3 for the reservoir.

Therefore, with a total loss in storage capacity of 346 dam^3 (280 acre-ft.) and an average density of 513 Kg/M^3 the deposited load would be 145,675 tonnes. An annual trapped load would be 13,243 tonnes.

4.4 Trap Efficiency and Sediment Discharge

Discharge information was obtained from station No. 05JE005 located about 5Km downstream of the reservoir. The drainage area for this station includes that for Avonlea reservoir. Consequently flows from Avonlea reservoir were prorated from the station discharge. Prorated flows for the reservoir outflow are presented in Table 4.



AVONLEA RESERVOIR

INPLACE DENSITIES (Kg / M^3)

FIG. 13

Table 4

1969	24,784	dam^3
1970	32,272	dam^3
1971	19,827	dam^3
1972	17,612	dam^3
1973	381	dam^3
1974	53,470	dam^3
TOTAL	148,346	dam^3
MEAN	24,724	dam^3

Source: Historical Streamflow Summary, Saskatchewan, Water Survey of Canada.

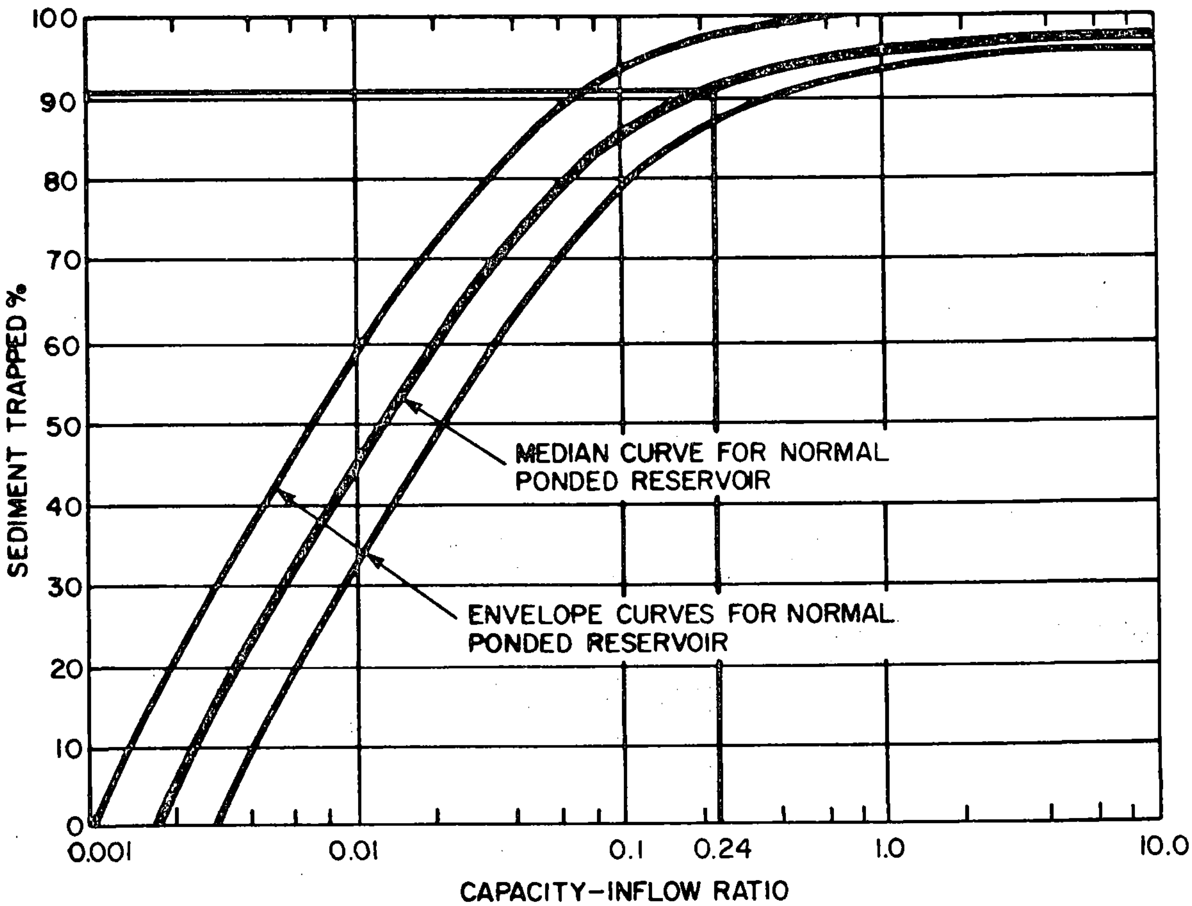
Trap efficiency is defined from a capacity-inflow ratio, which for Avonlea is 0.24. The assumption that annual outflow is equal to that of inflow and from the Fig. 14 (Brune, 1953) sediment trap efficiency for Avonlea reservoir is determined as 91%.

Since only about 90% of the sediment is trapped in the reservoir the total sediment discharge for the eleven-year period would be 160,000 tonnes, with a mean annual sediment discharge of approximately 14,500 tonnes.

4.5 Suspended and Bedload Contribution to Sediment Discharge

The location of samples taken to analyze bed material and suspended sediment are illustrated in Fig. 15.

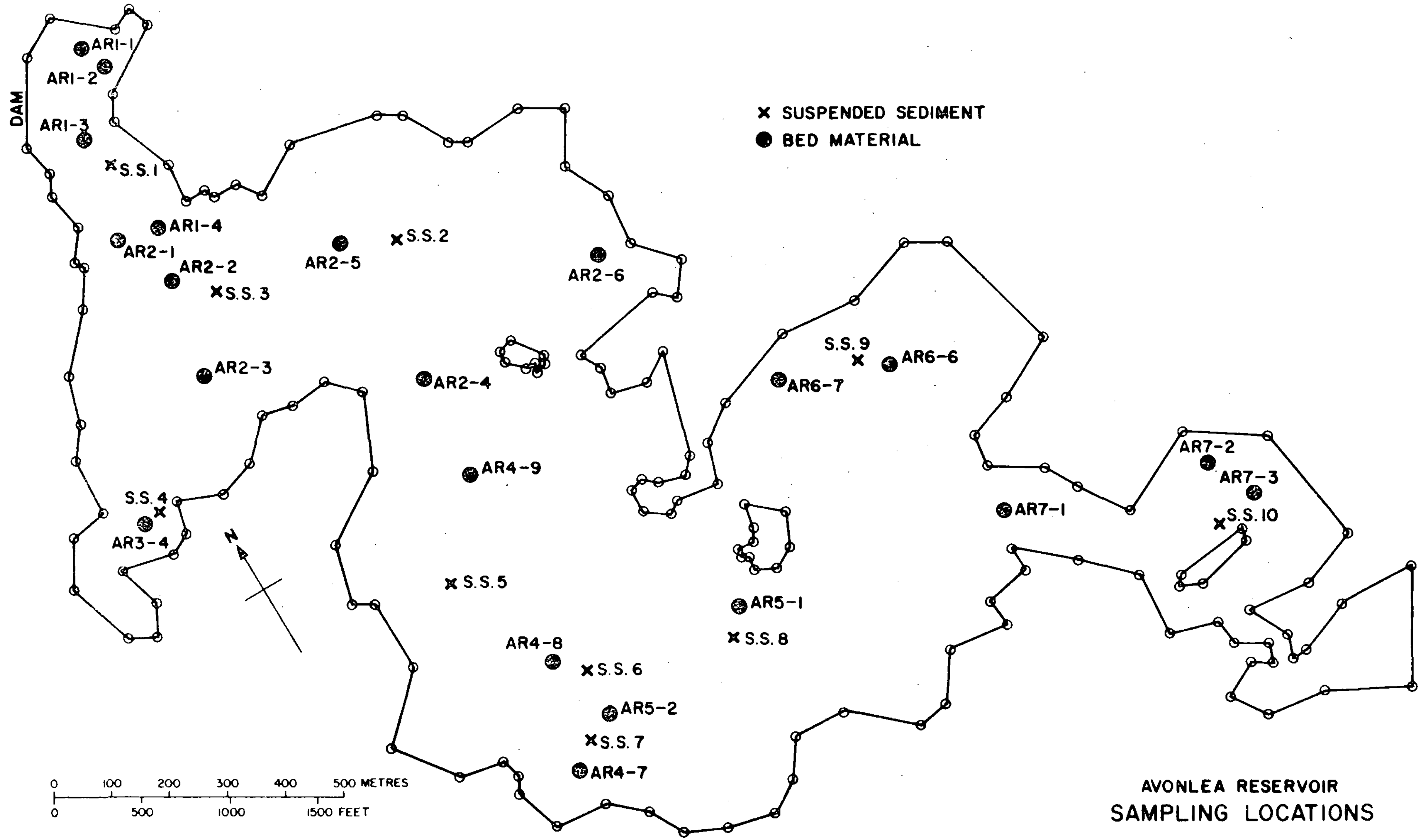
SEDIMENT TRAP EFFICIENCY



SOURCE: BRUNE, 1953

$$\frac{\text{CAPACITY}}{\text{INFLOW}} = \frac{6035}{24,724} = 0.24$$

FIG. 14



AVONLEA RESERVOIR
SAMPLING LOCATIONS

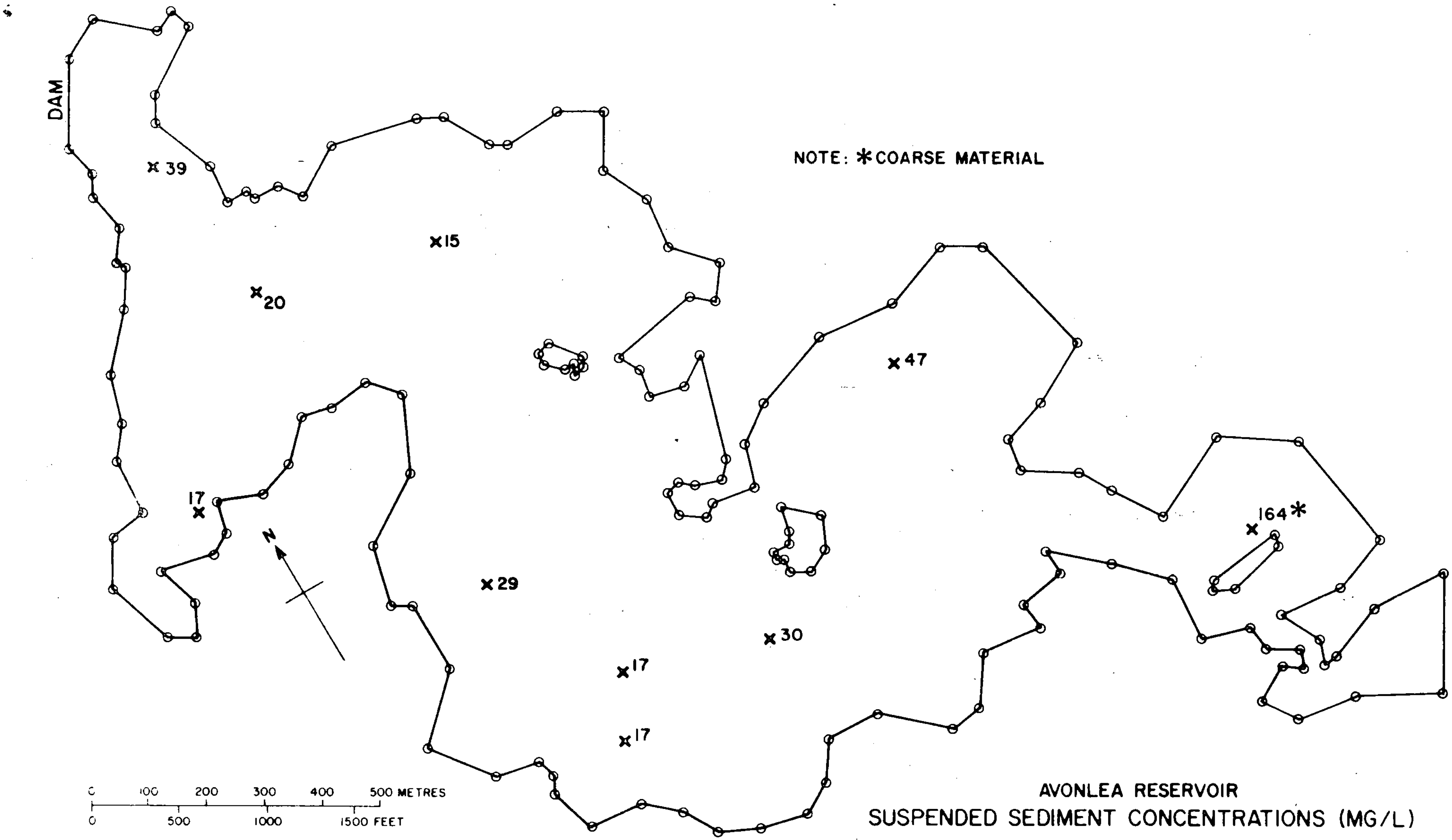
FIG.15

4.5.1 Suspended Sediment Analysis

Suspended sediment concentrations have been calculated at different locations in the reservoir (Fig. 16). The values range from 15 to 47 mg/l excluding the sample that appears to have trapped bed material. The average concentration for the reservoir is 26 mg/l. The reason the concentrations are low is that sampling was done in July, flows would be slower and suspended sediment would be due mostly to mild bank erosion. During spring runoff concentrations can be 10 to 50 times greater, by comparing data from other rivers in Saskatchewan in Sediment Data (1977).

4.5.2 Bed Material Analysis

To determine settling characteristics within the reservoir, bed material particle size has been related to thalweg distance from the dam. Usually in a reservoir the coarse material is the first to settle out in the upper reaches then there is a progression to finer material as one approaches the dam. This does not appear to be the case for Avonlea reservoir. The trend in Fig. 17 indicates an increase in particle size towards the dam. Reasons can be advanced to account for this. The first is that there is a tributary which enters the reservoir near the dam and explains the presence of the larger particles close to the dam. The second is that the reservoir is annually drawn down and mixing would occur when the low level reservoir was being filled by spring runoff. Therefore, the result is that the particle size is fairly uniform but increasing towards the dam. Particle size distributions for the individual samples are presented in Appendix B.



AVONLEA RESERVOIR
SUSPENDED SEDIMENT CONCENTRATIONS (MG/L)

FIG.16

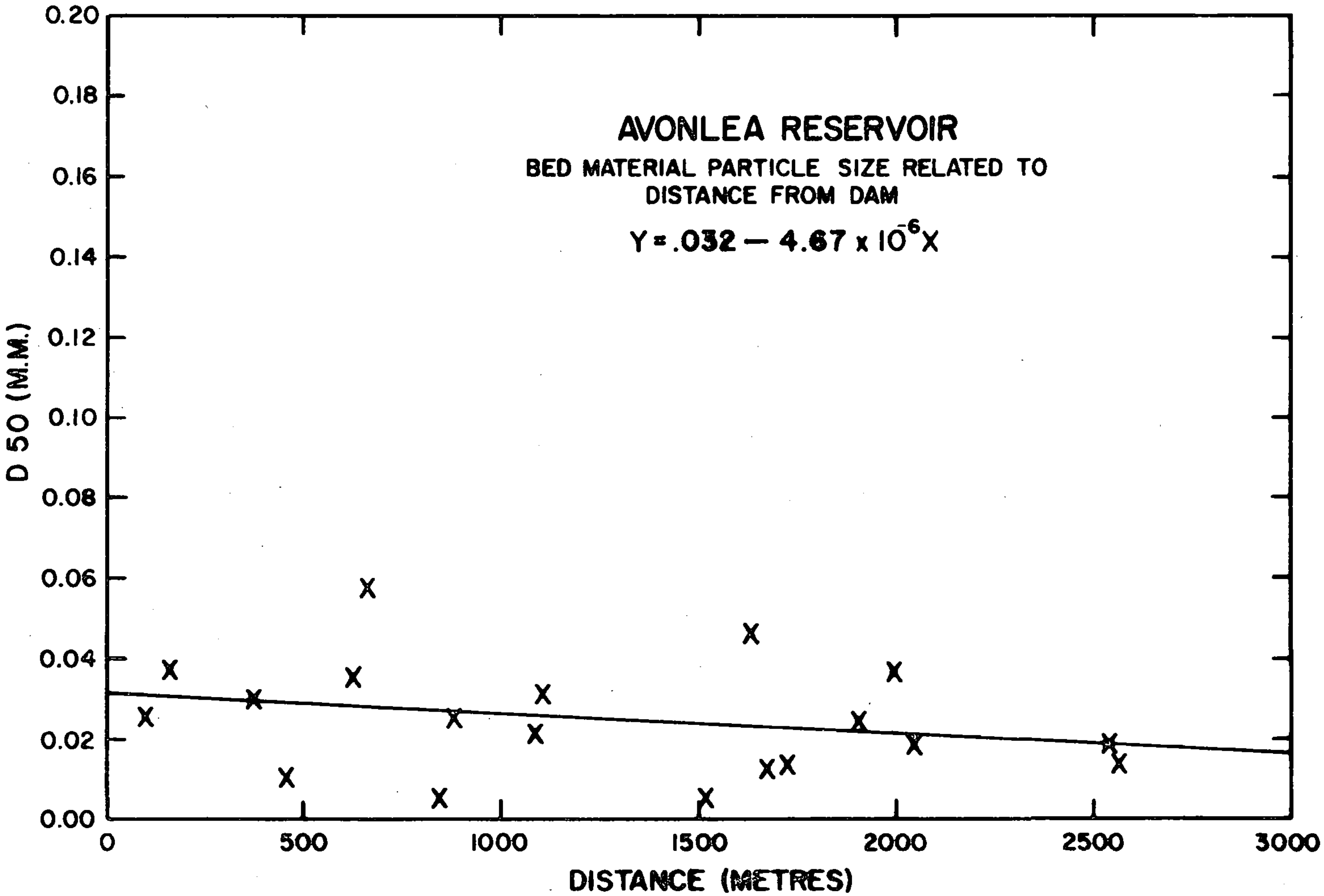

AVONLEA RESERVOIR
BED MATERIAL PARTICLE SIZE RELATED TO
DISTANCE FROM DAM
Y = .032 — 4.67 x 10^-6 X
D 50 (M.M.)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
500
1000
1500
2000
2500
3000
DISTANCE (METRES)

FIG.17

4.6 Bedload and Suspended Load Differentiation

To distinguish bedload from suspended load a few assumptions must be made. The first is that all the bedload will be trapped in the reservoir. Also because there is no information on velocities, one must distinguish what particle sizes would make up the bedload. There has been little work that has been completed that has tried to differentiate bedload from suspended load from reservoir data. A minimum particle size of 0.250 mm, very fine gravel (Chow, 1964) was chosen to be the smallest bedload material. This again is assuming average annual flow conditions. The average calculated from the twenty-one samples (Appendix B) shows that approximately 10% of the total load would be considered bedload. This value falls within the range 5 to 20% determined by Stichling (1973) for most prairie streams.

Therefore, the annual bedload entering the reservoir would be in the order of 1,500 tonnes.

The suspended load would be the difference between the total sediment load and the bedload, 13,000 tonnes per annum.

4.7 Suspended Sediment Yield

Equations and formulae have been developed to predict sediment yields using different variables. The results from these are compared to the value of 15.8 tonnes/Km^2/yr. obtained from this study.

There have been many maps produced that depict sediment yields for different regions. Gregory and Walling (1973) illustrate Strakov's (1967) map, from this map the Avonlea area should have a sediment yield up to 10 tonnes/Km^2/yr. Stichling (1969) determined sediment yield from regional sediment concentration data and shows the Avonlea area having a sediment yield in the order of 2.0 tonnes/Km^2/yr.

Fournier (1960) classified drainage basins according to relief and climate into four categories and derived a regression equation for each category. A precipitation concentration variable is used, p^2/P where p is the month with the greatest precipitation and P is mean annual precipitation. It would appear one should use the regression equation corresponding to class 1b low relief, semi-arid climate. However, an unrealistic negative value is obtained. If the regression equation from class 1a low relief, temperate climate is used a value of 15 tonnes/Km^2/yr. is calculated. It would appear that the semi-arid climate Fournier is referring to is associated with a tropical or subtropical environment with strong seasonal precipitation characteristics. Avonlea has precipitation year-round.

Fleming (1969) developed regression equations for four classes of vegetation cover. Using mean yearly discharge as the variable the total annual sediment load is obtained. The regression equation developed for the short grassland and scrub produced a sediment yield of 270 tonnes/Km^2/yr. using Avonlea's mean annual discharge of 1.16 m^3/S. The data used to derive these regression equations was taken from areas in the United States and is reliable supposedly for universal use.

Effective mean annual precipitation was determined by Langbein and Schumm (1958) to determine sediment yields. Effective precipitation is the amount of precipitation required to produce a known amount of runoff under specified temperature conditions. A mean annual runoff of 30 mm/yr. was calculated for the drainage basin. Mean annual temperature curves in Schumm (1965) allows the effective precipitation to be obtained using the known runoff value. The effective precipitation would be 250 mm per annum by extrapolation from this relationship using Avonlea's mean annual temperature of 2.5°C. Using effective precipitation in the formula developed from stream data produces a value of 300 tonnes/Km/yr. while, the formula derived from reservoir data produced a sediment yield of 600 tonnes/Km^2/yr. These formulae have been developed in the Southwestern U.S.A. in a region of very high accelerated erosion and explains the high values.

Douglas (1967) derived a formula using effective precipitation as the variable, but used data from a selection of rivers so as to correct for overly high values. A sediment yield of 135 m^3/Km^2/yr. was calculated for Avonlea and using the determined average density of 513 Kg/m^3, a yield of 68 tonnes/Km^2/yr. should be produced.

Even though the actual sediment yield was determined from only eleven years it is highly unlikely that long-term average yields would increase to a magnitude such as these equations suggest.

4.8 Life Expectancy of Reservoir

A sedimentation rate of 31.5 dam^3/yr. (25.5 acre-ft/yr.) was calculated with a mean annual flow of 24,724 dam^3. At this rate it would require a further 180 years to completely fill the reservoir. More than half of the dead storage has been filled in within the first eleven years and will be totally filled in within the next ten years.

That means from this point on there will be diminishing returns and once the reservoir is no longer able to meet the water supply needs marks the end of its useful life. Therefore, assuming that the critical point is reached once half of the storage capacity is filled in would reduce the useful life of this reservoir to approximately 90 years.

Factors such as reduced trapping efficiency and compacting of sediment could slightly reduce the impact of sedimentation, but not by any considerable amount.

In a report prepared by Mahood (1969) flows for Avonlea Creek were reconstructed for 1911-64 inclusive and return periods determined. Based on Mahood the maximum flow experienced in the period 1969-74 would have a return period of 25 years. Comparing the Moose Jaw Creek flows for 1963-69 indicates that this 25 year flood in Avonlea Creek for 1969-74 was probably not exceeded in the period 1963-69. Floods with return periods of 50 years or 100 years would greatly increase the sediment delivered to the reservoir, rapidly reducing the useful life of the reservoir.

Chapter 5 Summary and Conclusions

The Hydac-100 system was used to measure accurately capacity changes in Avonlea reservoir. It was found that there has been a loss in storage of 346 dam^3 (280 acre-ft.) during the period from 1963 to 1974. This gives a sedimentation rate of 31.5 dam^3/yr. (25.5 acre-ft./yr.) for the reservoir.

Sampling of bed material allowed an average density of 513 Kg/M^3 to be determined for the sediment. This value was used to determine the annual trapped load of 13,243 tonnes. The trap efficiency of the reservoir was determined so that the mean annual discharge of sediment could be estimated. It was found to be in the order of 14,500 tonnes. An estimation that the bed load comprised 10% of the total sediment load enabled a suspended sediment yield of 15.8 tonnes/Km^2/yr. to be calculated for the 825 Km^2 drainage basin.

This result was compared with values obtained from empirical formulae. It was found that most of the formulae produced results that did not compare well with the actual measured value.

Under past flow conditions Avonlea reservoir is estimated to have a useful life expectancy in the order of 90 years.

There was concern shown that accelerated sedimentation was accounting for the rapid loss in storage capacity. Computations revealed that the original capacity was incorrectly calculated and that Avonlea reservoir is filling in at a moderate rate, normal for its environmental and drainage basin characteristics. If one used the original capacity figure for Avonlea reservoir a sedimentation rate of 154 dam^3 (125 acre-ft./yr.) would be calculated and the useful life of the reservoir would only be 20 years which would not seem possible.

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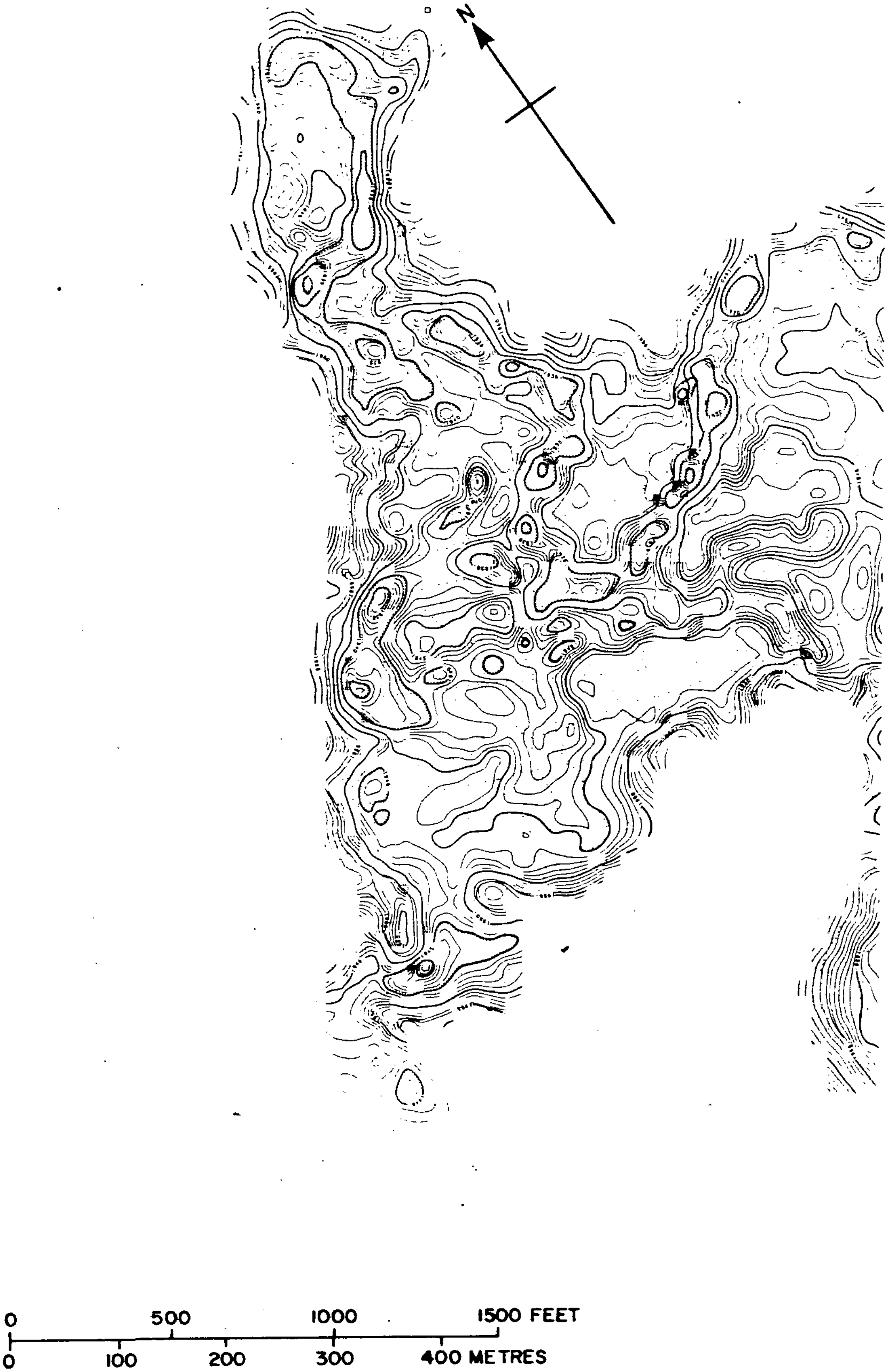
APPENDIX A

Includes for Individual Modules:

i) Contour Map

ii) Elevation Capacity Table

iii) Capacity Curve



CONTOUR INTERVAL = 1 FOOT

AVONLEA RESERVOIR
MODULE I
MORPHOLOGICAL SURVEY
1974

SEDIMENT SURVEY SECTION
OTTAWA, ONT.
AUGUST, 1976

AVONLEA RESERVOIR 1974 (MODULE 1)

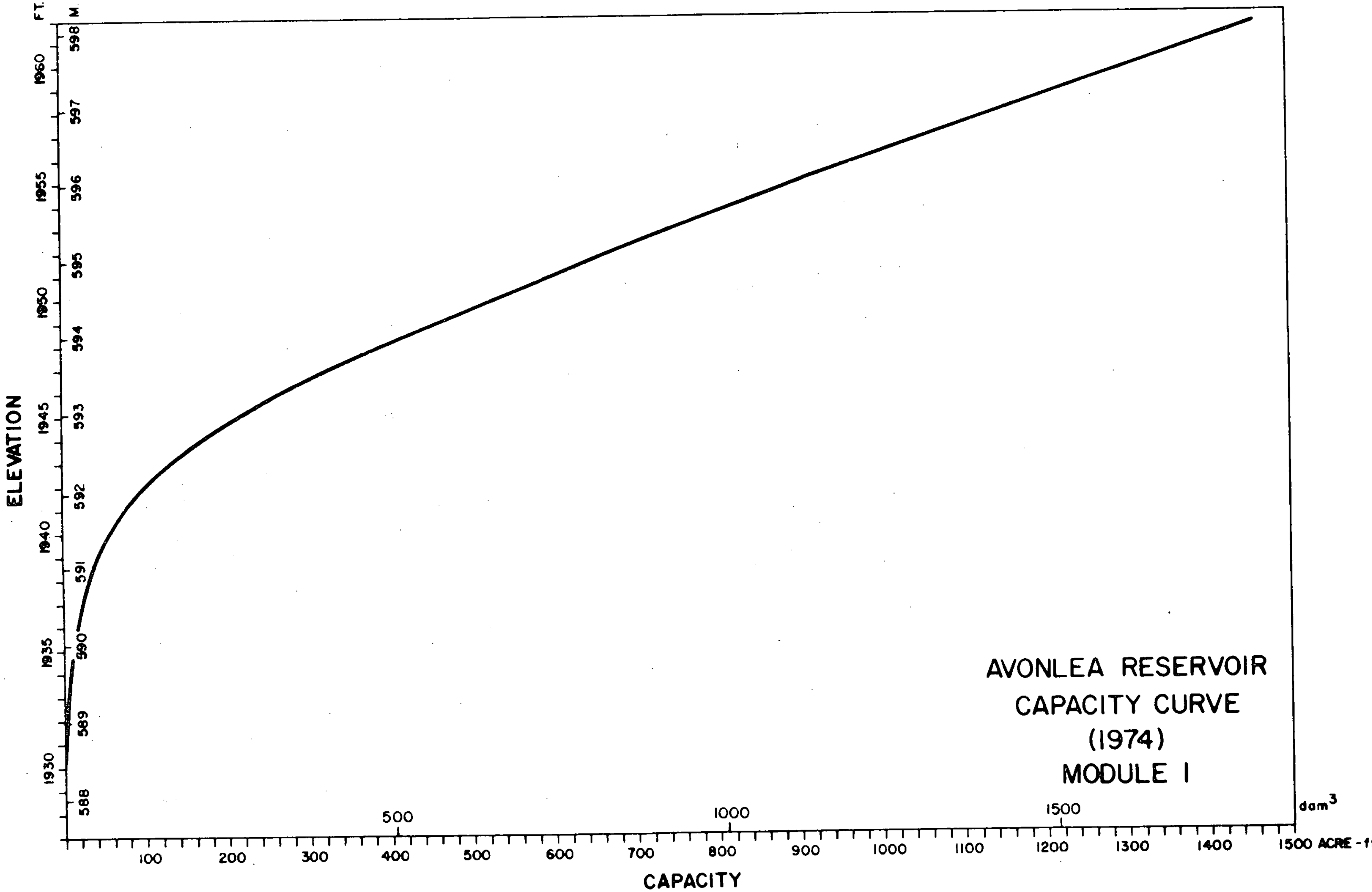
ELEVATION - CAPACITY TABLE

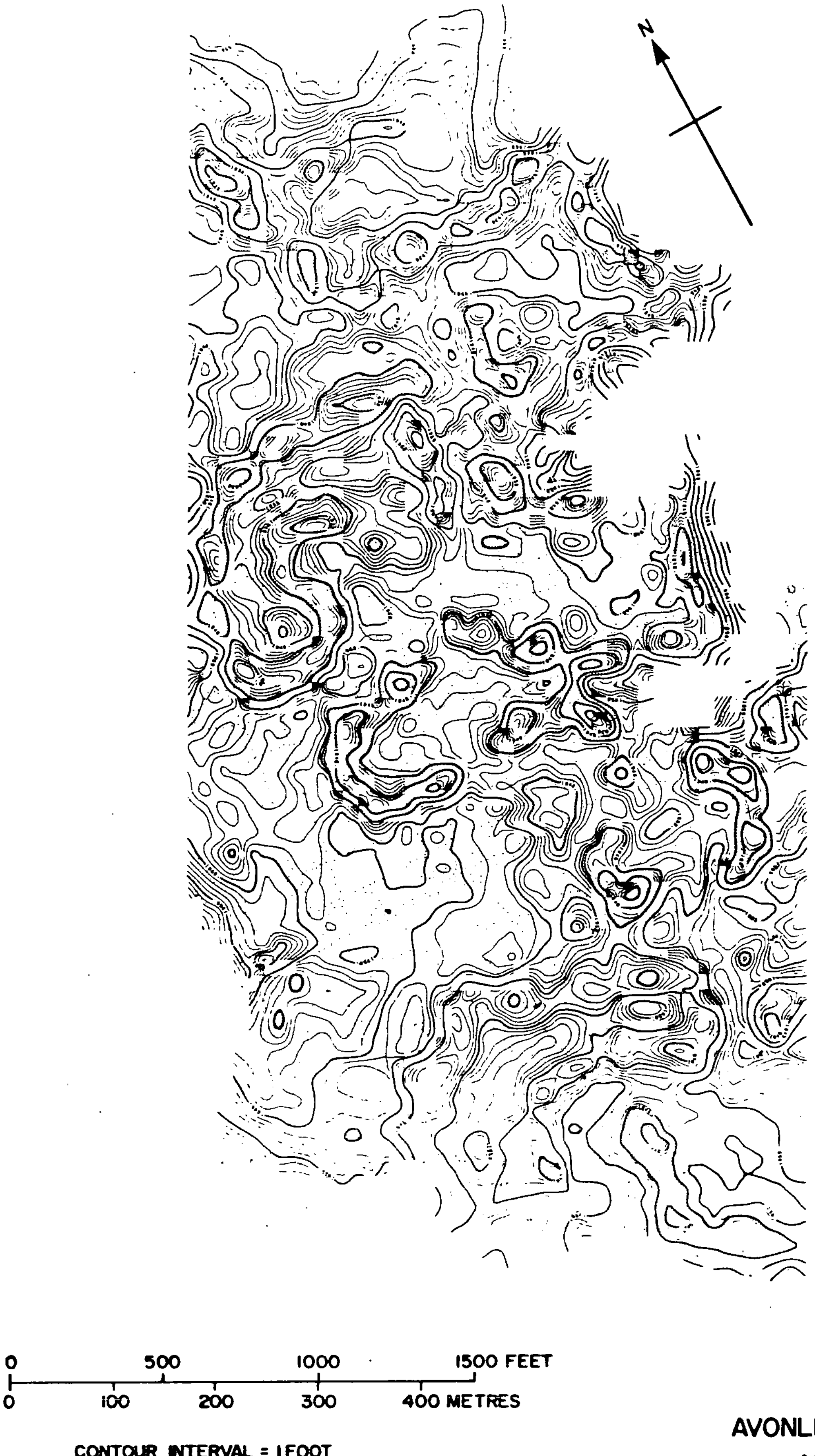
ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)
1927.50	.0	1940.00	49.3	1952.50	683.3		
1928.00	.1	1940.50	56.8	1953.00	721.0		
1928.50	.2	1941.00	65.4	1953.50	759.0		
1929.00	.3	1941.50	75.5	1954.00	797.3		
1929.50	.5	1942.00	87.1	1954.50	836.1		
1930.00	.7	1942.50	100.7	1955.00	875.3		
1930.50	1.0	1943.00	116.0	1955.50	915.0		
1931.00	1.4	1943.50	133.0	1956.00	955.1		
1931.50	1.8	1944.00	151.6	1956.50	995.7		
1932.00	2.4	1944.50	171.7	1957.00	1036.7		
1932.50	3.2	1945.00	193.3	1957.50	1078.3		
1933.00	4.2	1945.50	216.7	1958.00	1120.3		
1933.50	5.3	1946.00	242.2	1958.50	1162.6		
1934.00	6.8	1946.50	269.6	1959.00	1205.1		
1934.50	8.4	1947.00	299.0	1959.50	1247.7		
1935.00	10.2	1947.50	330.2	1960.00	1290.3		
1935.50	12.1	1948.00	362.6	1960.50	1333.1		
1936.00	14.3	1948.50	396.6	1961.00	1376.0		
1936.50	16.7	1949.00	430.4	1961.50	1418.9		
1937.00	19.6	1949.50	465.3	1962.00	1461.9		
1937.50	23.0	1950.00	500.7				
1938.00	27.0	1950.50	536.5				
1938.50	31.6	1951.00	572.6				
1939.00	36.8	1951.50	609.1				
1939.50	42.7	1952.00	646.0				

CONVERSION

ACRE-FEET X 1.2335 = CUBIC DECAMETRES (dam^3)

FEET X .3048 = METRES (M)


AVONLEA RESERVOIR
CAPACITY CURVE
(1974)
MODULE I
ELEVATION
FT.
M
1930
1935
1940
1945
1950
1955
1960
588
589
590
591
592
593
594
595
596
597
598
CAPACITY
500
1000
1500
dam^3
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500 ACRE - ft



AVONLEA RESERVOIR
MODULE 2
MORPHOLOGICAL SURVEY
1974

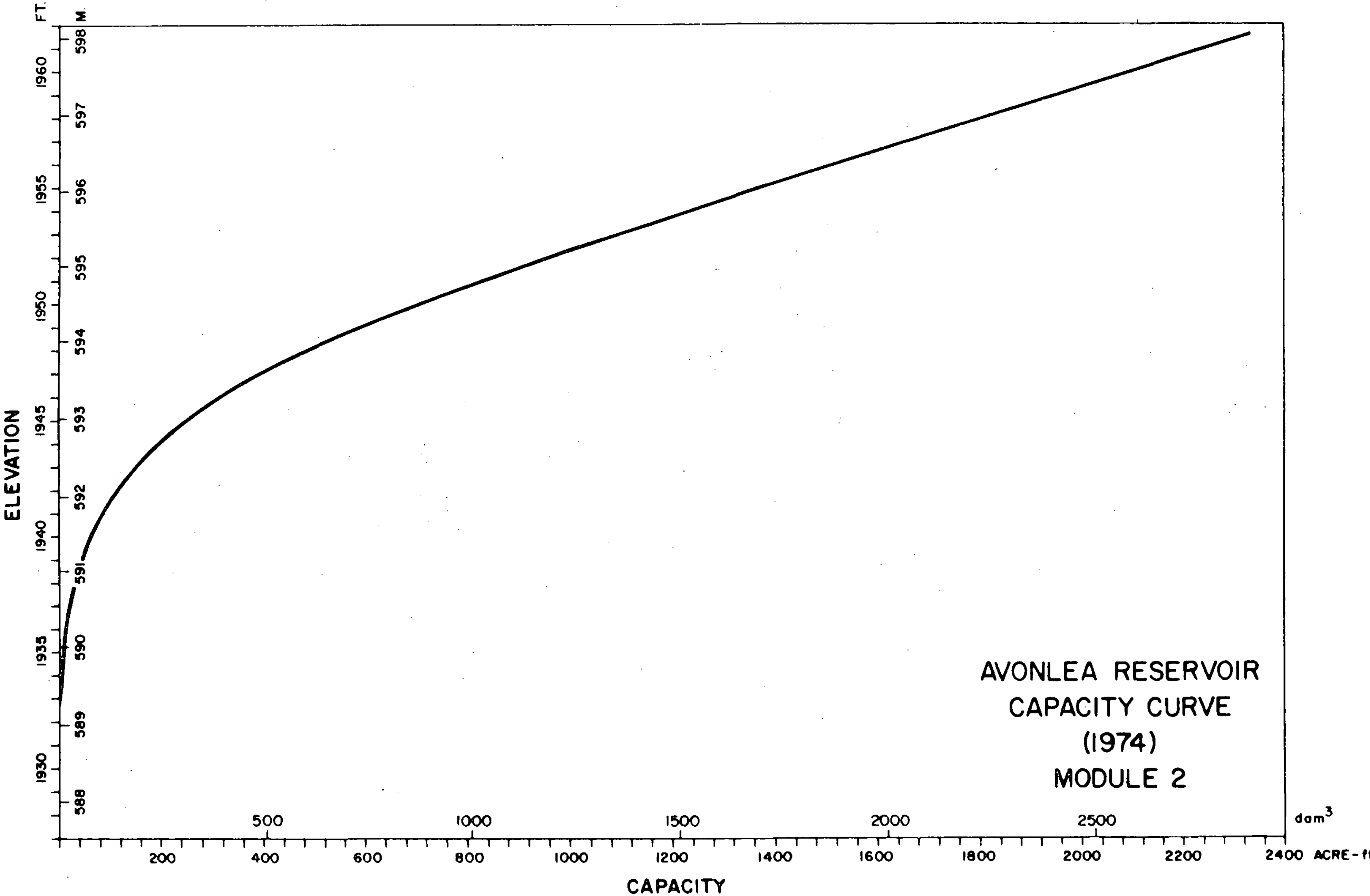
* ELEVATION - CAPACITY TABLE *

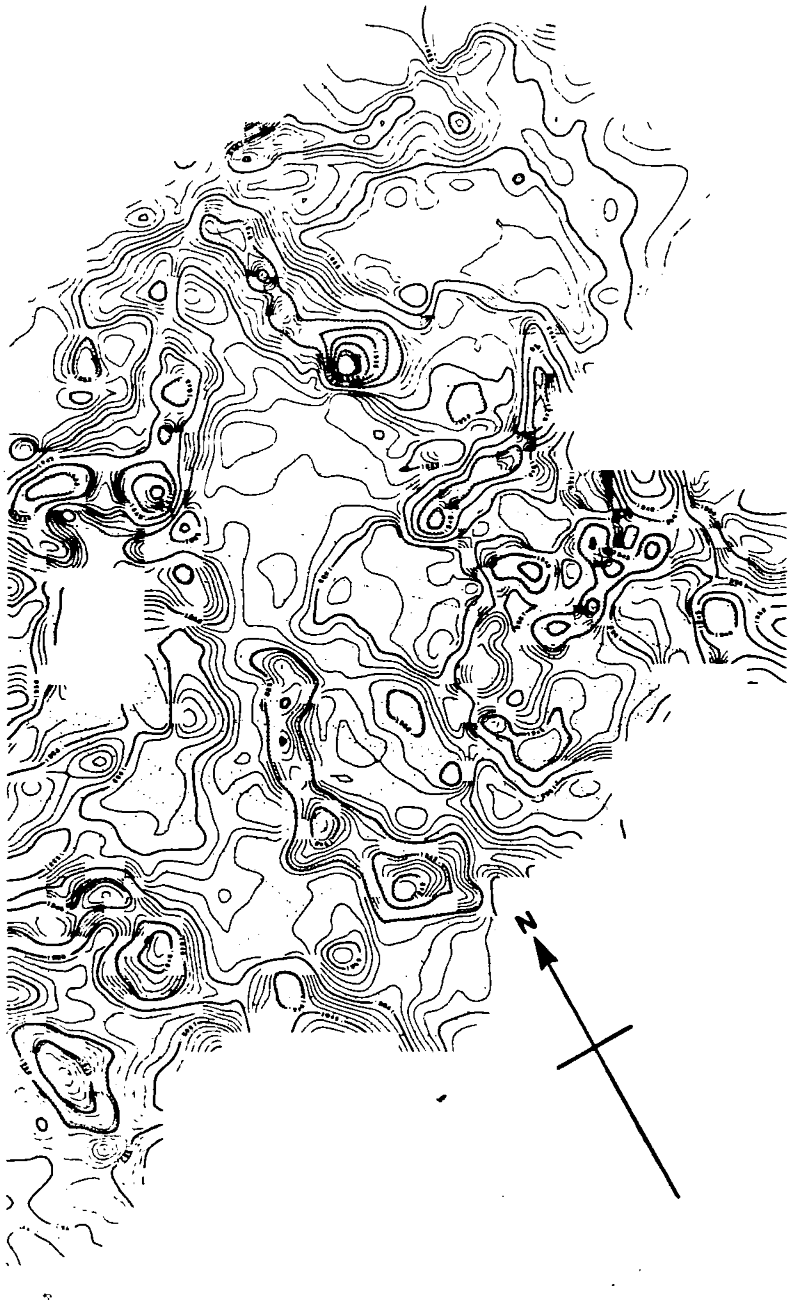
ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)
1929.00	.0	1941.50	85.4	1954.00	1167.5		
1929.50	.0	1942.00	99.0	1954.50	1237.7		
1930.00	.1	1942.50	114.3	1955.00	1308.6		
1930.50	.3	1943.00	131.4	1955.50	1380.1		
1931.00	.5	1943.50	150.4	1956.00	1452.1		
1931.50	.8	1944.00	171.4	1956.50	1524.6		
1932.00	1.2	1944.50	194.8	1957.00	1597.4		
1932.50	1.6	1945.00	220.9	1957.50	1670.7		
1933.00	2.2	1945.50	250.0	1958.00	1744.1		
1933.50	2.8	1946.00	282.2	1958.50	1817.8		
1934.00	3.6	1946.50	316.9	1959.00	1891.6		
1934.50	4.8	1947.00	354.3	1959.50	1965.6		
1935.00	6.6	1947.50	394.6	1960.00	2039.5		
1935.50	8.4	1948.00	437.7	1960.50	2113.5		
1936.00	11.0	1948.50	483.7	1961.00	2187.6		
1936.50	14.2	1949.00	532.9	1961.50	2261.6		
1937.00	18.0	1949.50	585.7	1962.00	2335.7		
1937.50	22.2	1950.00	642.4				
1938.00	26.9	1950.50	702.1				
1938.50	32.4	1951.00	764.0				
1939.00	38.7	1951.50	827.9				
1939.50	45.8	1952.00	893.7				
1940.00	53.9	1952.50	960.9				
1940.50	63.0	1953.00	1029.0				
1941.00	73.5	1953.50	1097.9				

CONVERSION

ACRE-FEET X 1.2335 = CUBIC DECAMETRES (dam^3)

FEET X .3048 = METRES (M)


ELEVATION
FT.
M.
1930
1935
1940
1945
1950
1955
1960
588
589
590
591
592
593
594
595
596
597
598
CAPACITY
dam3
500
1000
1500
2000
2500
ACRE-ft
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
AVONLEA RESERVOIR
CAPACITY CURVE
(1974)
MODULE 2



0 500 1000 1500 FEET

0 100 200 300 400 METRES

CONTOUR INTERVAL = 1 FOOT

AVONLEA RESERVOIR
MODULE 3
MORPHOLOGICAL SURVEY
1974

SEDIMENT SURVEY SECTION
OTTAWA, ONT.
AUGUST, 1976

AVONLEA RESERVOIR 1974 (MODULE 3)

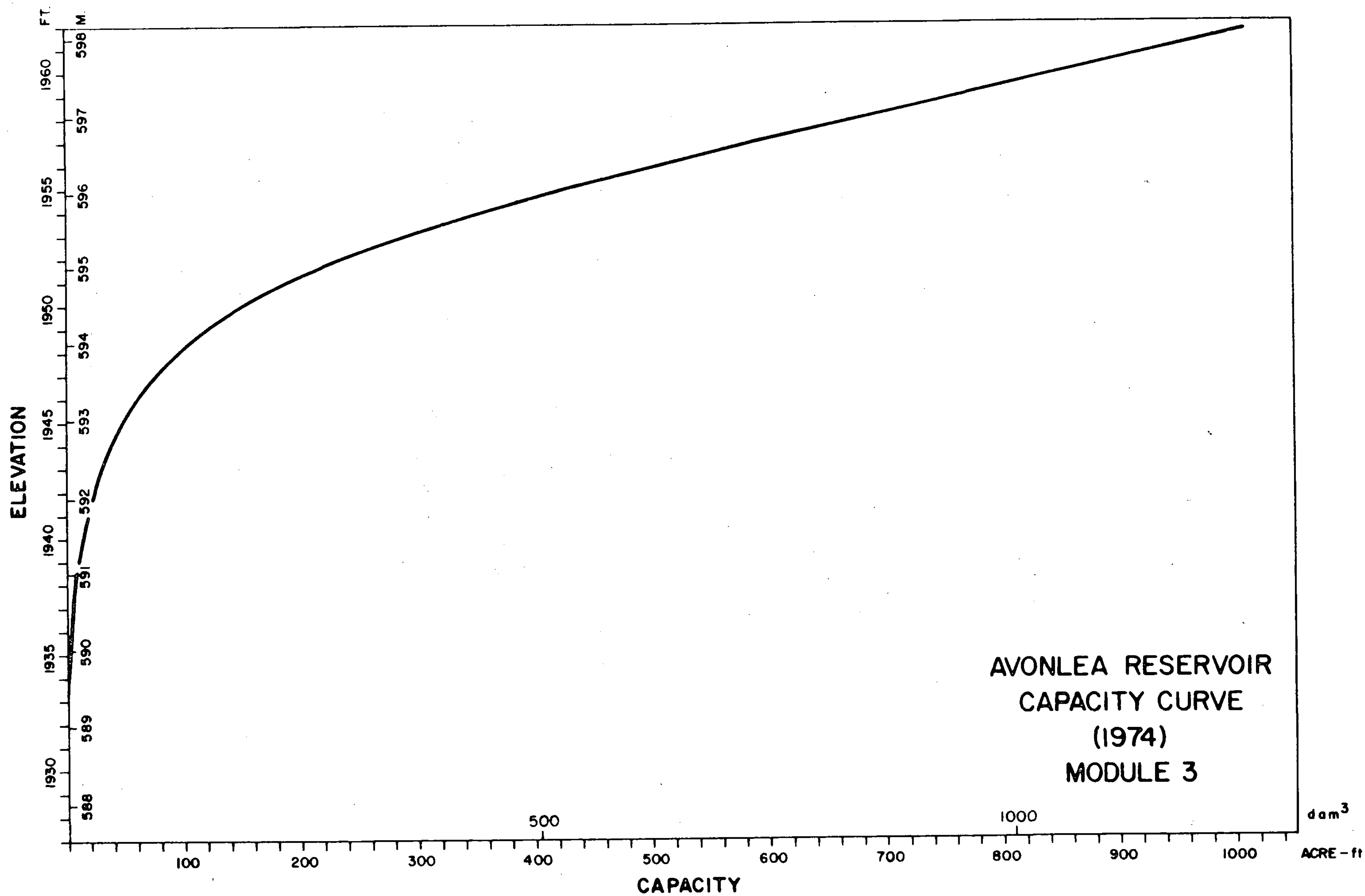
ELEVATION - CAPACITY TABLE

ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)
1928.00	.0	1940.50	14.9	1953.00	265.2		
1928.50	.0	1941.00	17.0	1953.50	294.9		
1929.00	.1	1941.50	19.2	1954.00	327.0		
1929.50	.1	1942.00	21.5	1954.50	361.4		
1930.00	.2	1942.50	24.1	1955.00	397.6		
1930.50	.3	1943.00	27.0	1955.50	435.2		
1931.00	.4	1943.50	30.4	1956.00	474.4		
1931.50	.5	1944.00	34.1	1956.50	515.6		
1932.00	.6	1944.50	38.3	1957.00	558.7		
1932.50	.8	1945.00	43.1	1957.50	602.8		
1933.00	1.0	1945.50	48.6	1958.00	647.6		
1933.50	1.3	1946.00	54.7	1958.50	692.7		
1934.00	1.5	1946.50	61.4	1959.00	738.1		
1934.50	1.8	1947.00	69.0	1959.50	783.7		
1935.00	2.2	1947.50	77.3	1960.00	829.2		
1935.50	2.7	1948.00	86.7	1960.50	874.8		
1936.00	3.3	1948.50	97.3	1961.00	920.4		
1936.50	3.9	1949.00	108.9	1961.50	966.0		
1937.00	4.7	1949.50	121.9	1962.00	1011.6		
1937.50	5.6	1950.00	136.5				
1938.00	6.8	1950.50	152.6				
1938.50	8.1	1951.00	170.7				
1939.00	9.5	1951.50	190.7				
1939.50	11.2	1952.00	213.1				
1940.00	12.9	1952.50	237.9				

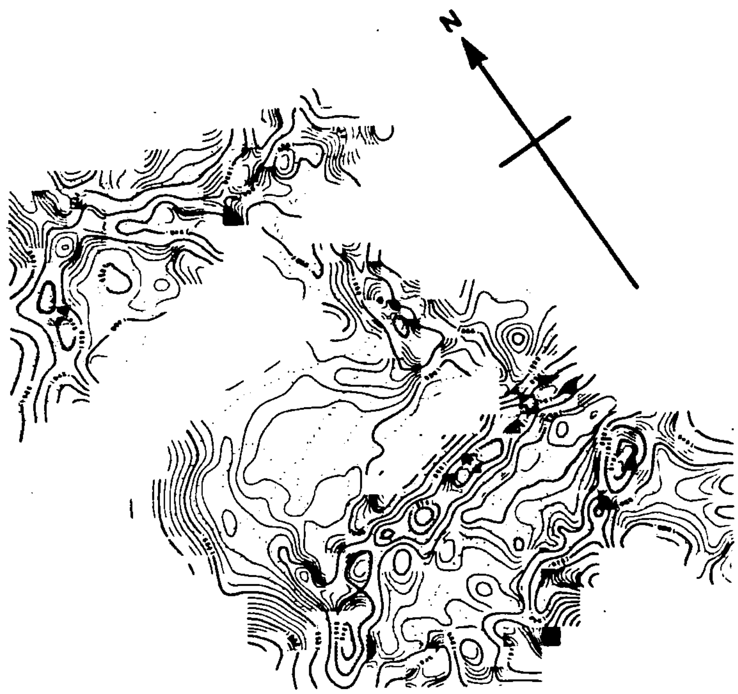
CONVERSION

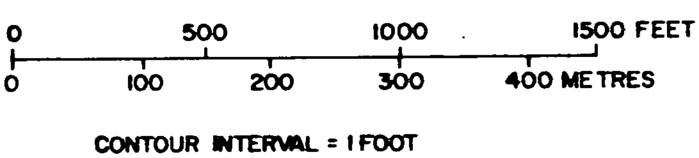
ACRE-FEET X 1.2335 = CUBIC DECAMETRES (dam^3)

FEET X .3048 = METRES (M)



AVONLEA RESERVOIR
CAPACITY CURVE
(1974)
MODULE 3
ELEVATION
FT.
M.
1930
1935
1940
1945
1950
1955
1960
588
589
590
591
592
593
594
595
596
597
598
CAPACITY
dam³
500
1000
ACRE - ft
100
200
300
400
500
600
700
800
900
1000





AVONLEA RESERVOIR
MODULE 4
MORPHOLOGICAL SURVEY
1974

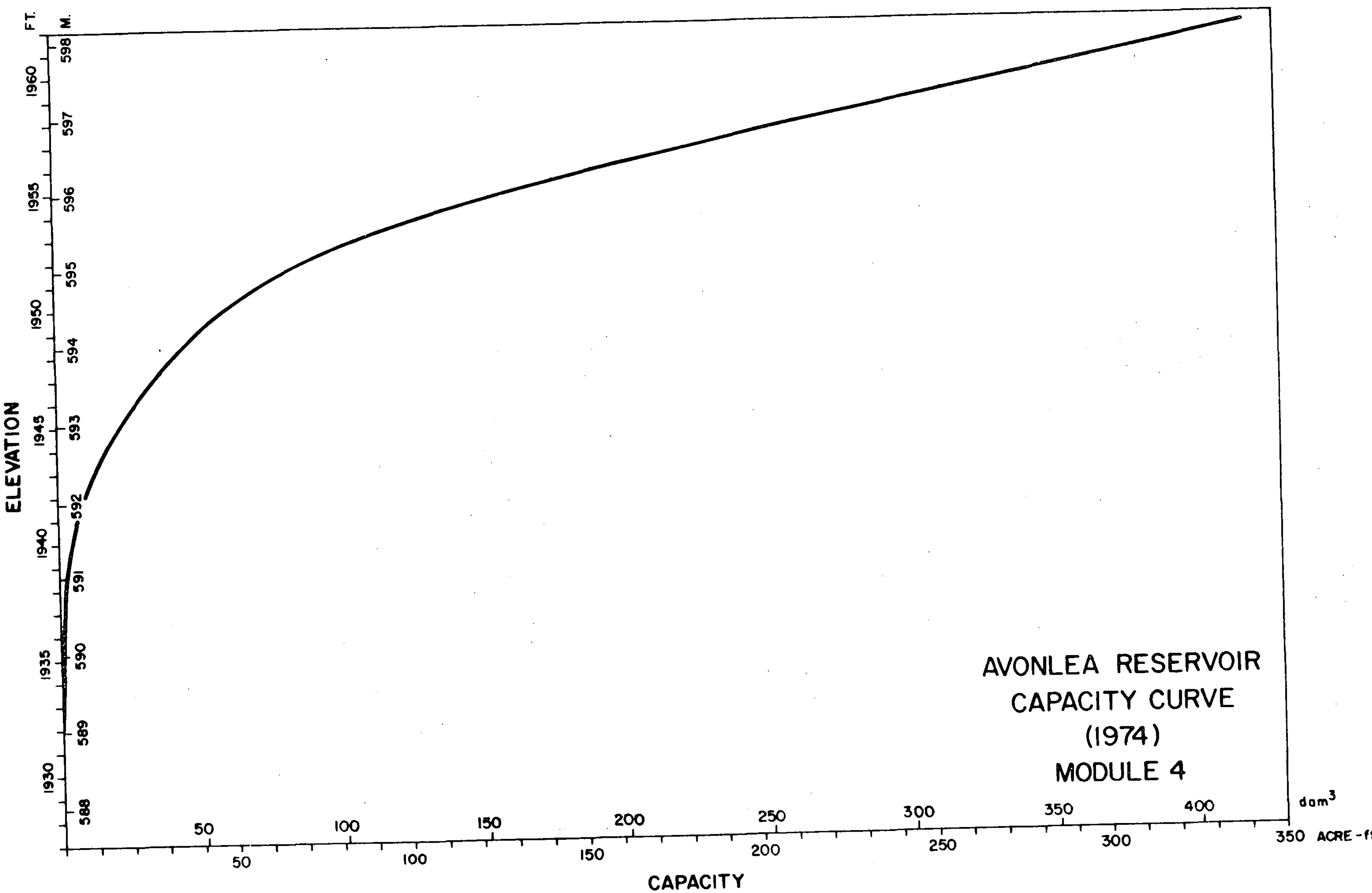
* ELEVATION - CAPACITY TABLE *

ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)	ELEVATION (FT)	ACC. VOLUME (ACRE-FT)
1929.00	.0	1941.50	5.9	1954.00	99.3		
1929.50	.0	1942.00	6.8	1954.50	110.3		
1930.00	.0	1942.50	7.9	1955.00	122.5		
1930.50	.1	1943.00	9.2	1955.50	135.7		
1931.00	.1	1943.50	10.7	1956.00	149.6		
1931.50	.2	1944.00	12.3	1956.50	164.0		
1932.00	.2	1944.50	14.1	1957.00	178.8		
1932.50	.3	1945.00	16.1	1957.50	194.1		
1933.00	.4	1945.50	18.2	1958.00	209.9		
1933.50	.5	1946.00	20.5	1958.50	225.8		
1934.00	.6	1946.50	22.9	1959.00	241.8		
1934.50	.7	1947.00	25.5	1959.50	258.1		
1935.00	.8	1947.50	28.3	1960.00	274.4		
1935.50	.9	1948.00	31.1	1960.50	290.9		
1936.00	1.0	1948.50	34.1	1961.00	307.4		
1936.50	1.2	1949.00	37.4	1961.50	323.9		
1937.00	1.3	1949.50	40.9	1962.00	340.4		
1937.50	1.5	1950.00	44.9				
1938.00	1.8	1950.50	49.2				
1938.50	2.1	1951.00	54.0				
1939.00	2.6	1951.50	59.5				
1939.50	3.1	1952.00	65.9				
1940.00	3.6	1952.50	73.2				
1940.50	4.3	1953.00	81.0				
1941.00	5.0	1953.50	89.7				

CONVERSION

ACRE-FEET X 1.2335 = CUBIC DECAMETRES (dam^3)

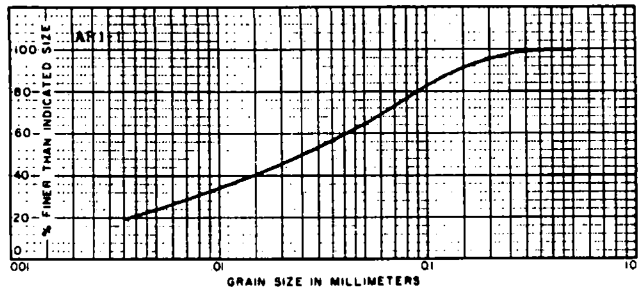
FEET X .3048 = METRES (M)

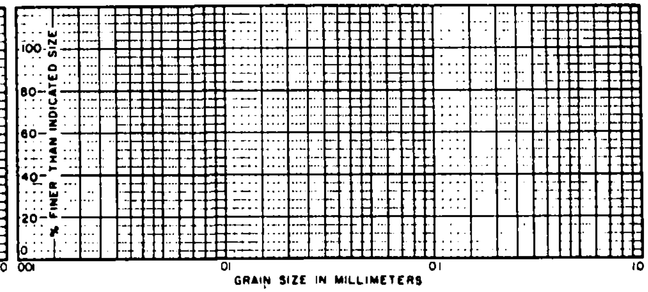

ELEVATION
FT.
M.
1930
1935
1940
1945
1950
1955
1960
588
589
590
591
592
593
594
595
596
597
598
CAPACITY
dam3
50
100
150
200
250
300
350
400
ACRE-ft
AVONLEA RESERVOIR
CAPACITY CURVE
(1974)
MODULE 4

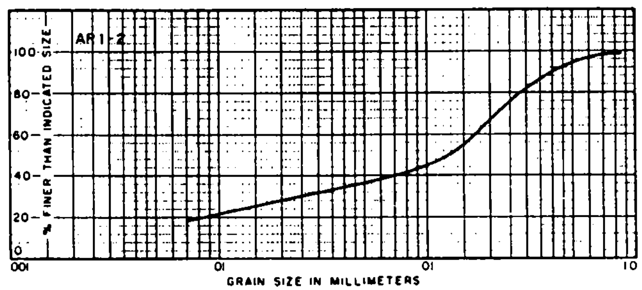
APPENDIX B

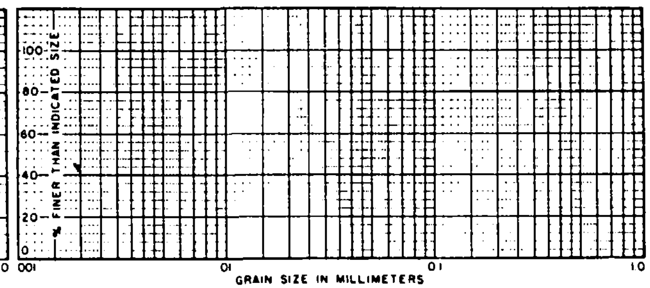
Particle Size Distribution for Individual Samples

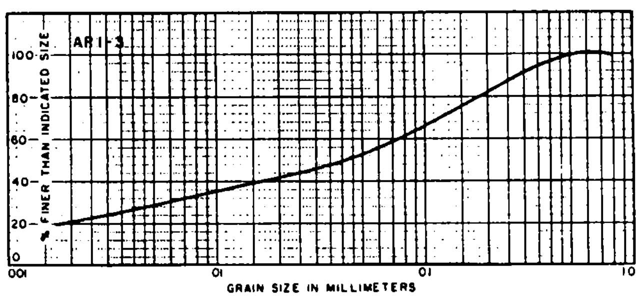
SAMPLE LOCATION	DATE	NO OF SAMPLE	PERCENTAGE FINER THAN INDICATED SIZE M.M.								% SILT 0062 - 0005 MM	% CLAY < 0005 MM
			8000	4000	2000	1000	0500	0250	0125	0062		
AR I	18/73 JULY	1					100	96	89	69	46	23
AR I	18/73 JULY	2		100	99	98	95	74	50	37	19	18
AR I	18/73 JULY	3				100	98	85	67	56	26	30
AR I	18/73 JULY	4				100	98	92	81	65	40	25

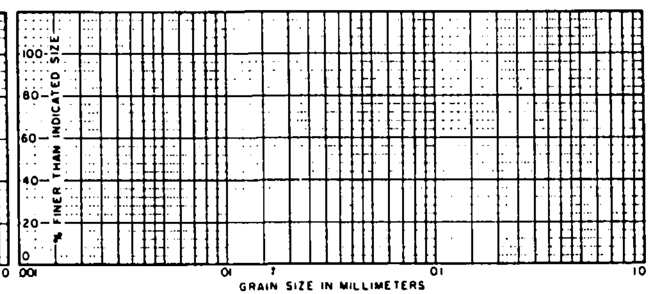


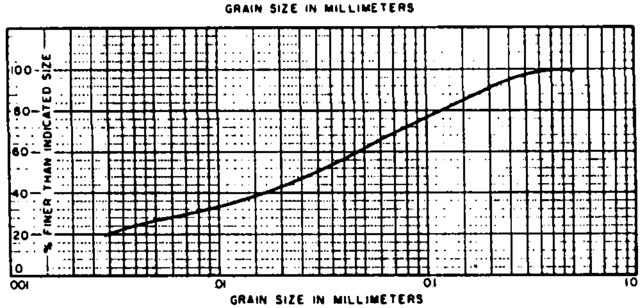












WATER RESOURCES BRANCH

DEPARTMENT OF THE ENVIRONMENT

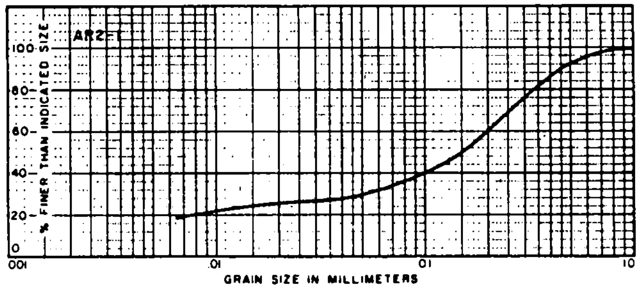
SEDIMENTATION STUDY

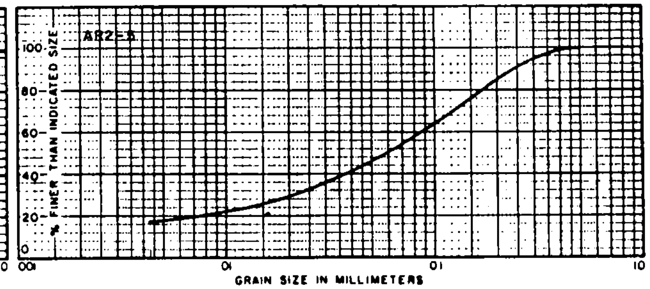
AVONLEA RESERVOIR

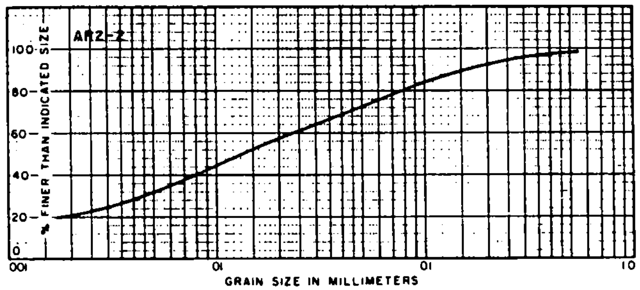
BED MATERIAL PARTICLE SIZE DISTRIBUTION

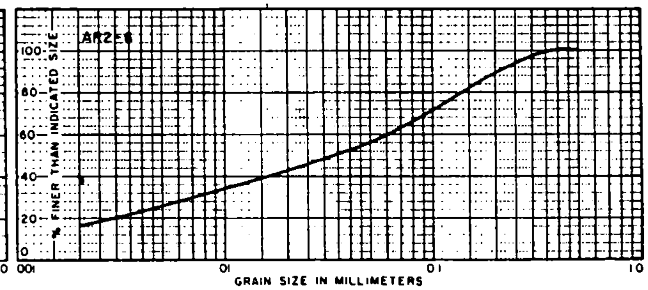
DATE 1973		FIG

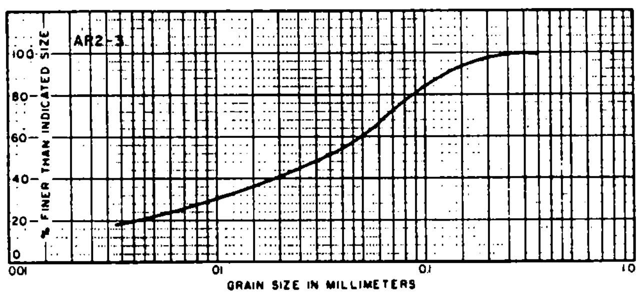
SAMPLE LOCATION	DATE	NO OF SAMPLE	PERCENTAGE FINER THAN INDICATED SIZE M.M.								% SILT 0062 - 0005 MM	% CLAY < 0005 MM
			8000	4000	2000	1000	0500	0250	0125	0062		
AR2	19/73 JULY	1		99	98	97	93	63	43	32	15	17
AR2	19/73 JULY	2				100	98	93	88	73	32	41
AR2	19/73 JULY	3					100	98	90	69	46	23
AR2	19/73 JULY	4					100	99	94	71	47	24
AR2	19/73 JULY	5					100	90	69	51	33	18
AR2	19/73 JULY	6					100	94	77	62	35	27

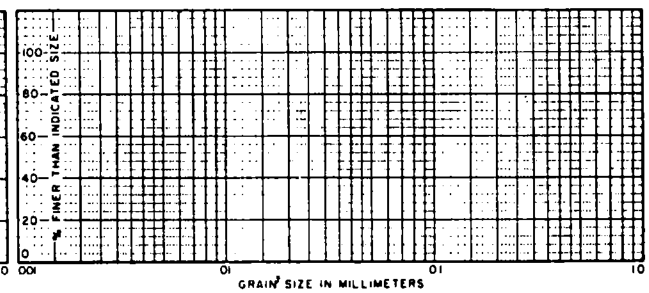


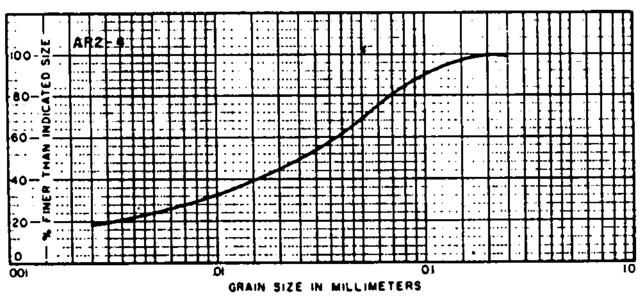












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DEPARTMENT OF THE ENVIRONMENT

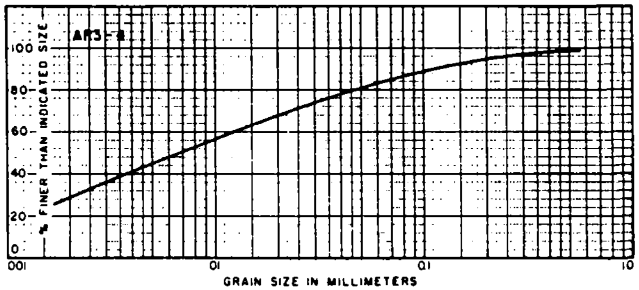
SEDIMENTATION STUDY

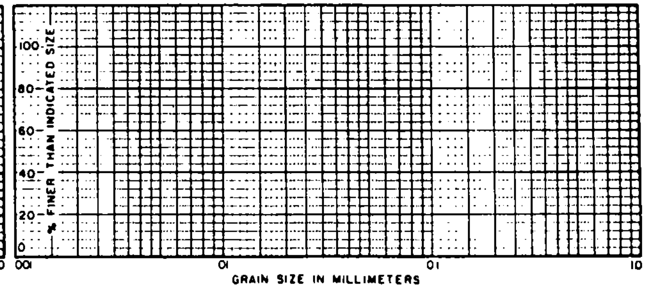
AVONLEA RESERVOIR

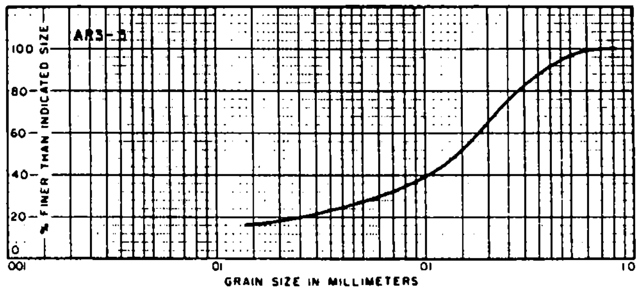
BED MATERIAL PARTICLE SIZE DISTRIBUTION

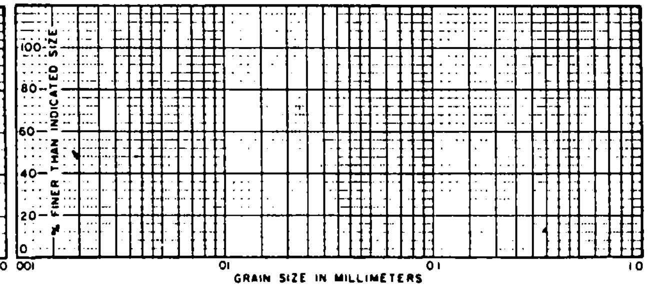
DATE 1973 | FIG

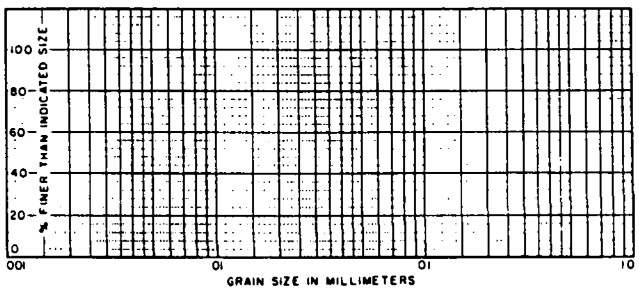
SAMPLE LOCATION	DATE	NO OF SAMPLE	PERCENTAGE FINER THAN INDICATED SIZE M M.								% SILT 0062 - 0005 MM	% CLAY < 0005 MM
			8000	4000	2000	1000	0500	0250	0125	0062		
AR3	19/73 JULY	4				100	97	94	92	83	37	46
AR3	19/73 JULY	6		99	99	99	97	72	43	32	22	10
AR3	19/73 JULY	5	- DISTURBED SAMPLE									

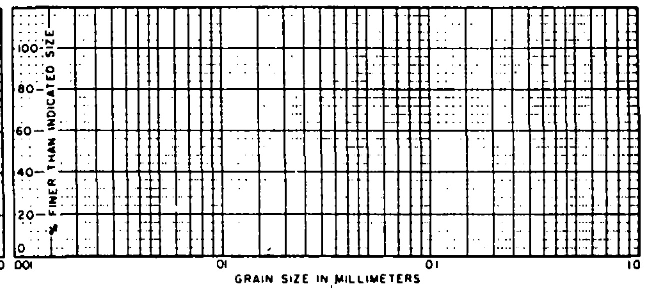


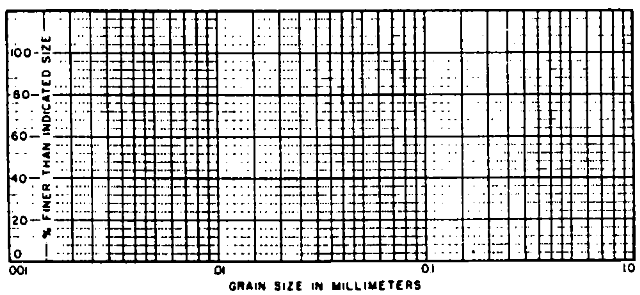












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DEPARTMENT OF THE ENVIRONMENT

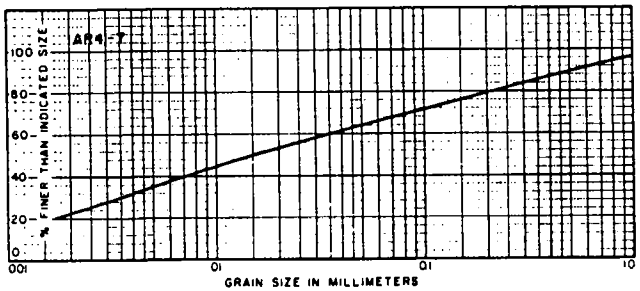
SEDIMENTATION STUDY

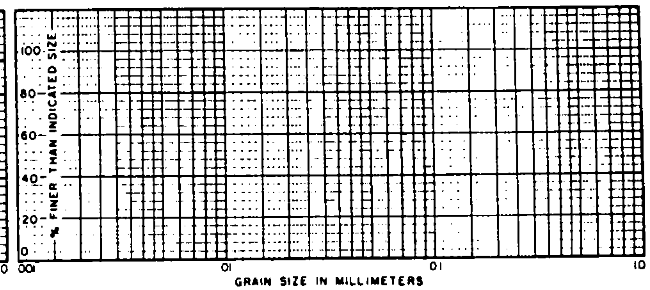
AVONLEA RESERVOIR

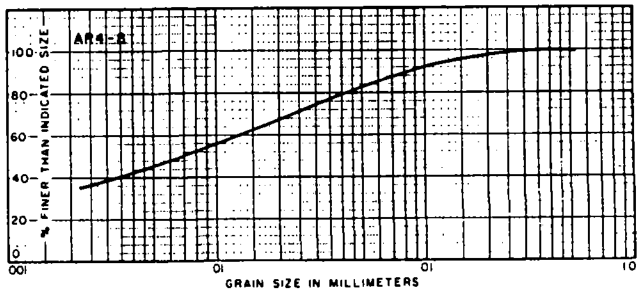
BED MATERIAL PARTICLE SIZE DISTRIBUTION

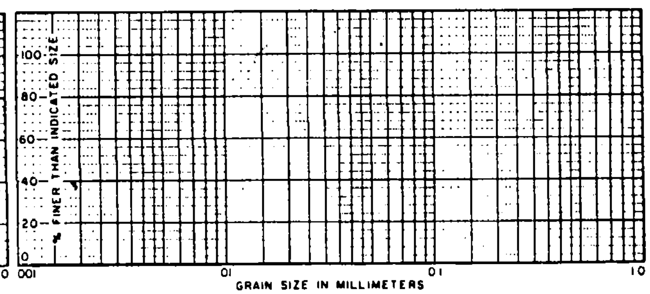
DATE 1973 | | FIG

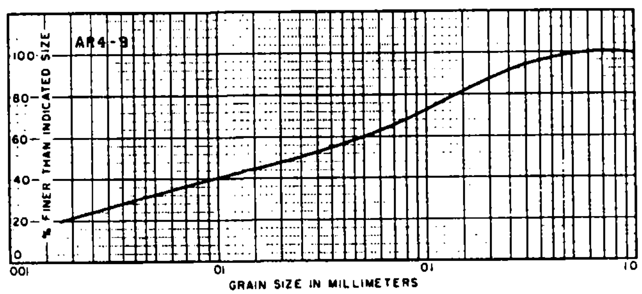
SAMPLE LOCATION	DATE	NO OF SAMPLE	PERCENTAGE FINER THAN INDICATED SIZE MM 8.000	4.000	2.000	1.000	0.500	0.250	0.125	0.062	% SILT 0.062 - 0.005 MM	% CLAY < 0.005 MM
AR4	27/73 JULY	7			100	96	85	78	74	67	31	36
AR4	27/73 JULY	8				100	99	97	95	83	36	47
AR4	27/73 JULY	9				100	98	92	77	63	30	33

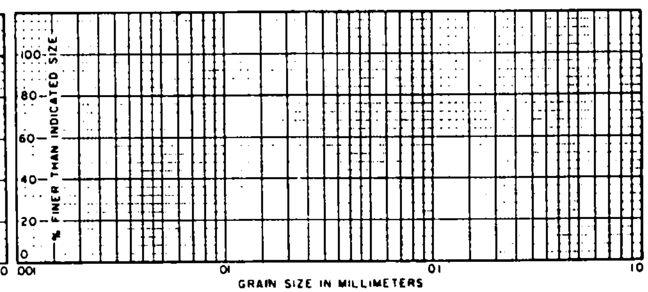


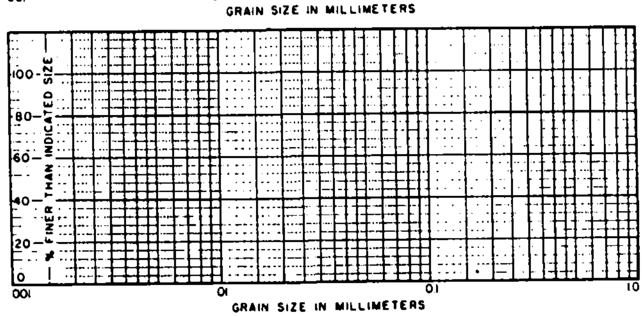












WATER RESOURCES BRANCH
DEPARTMENT OF THE ENVIRONMENT

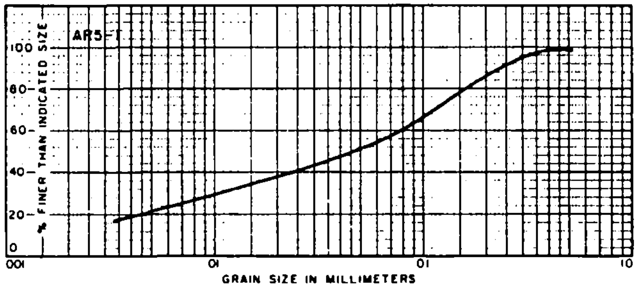
SEDIMENTATION STUDY

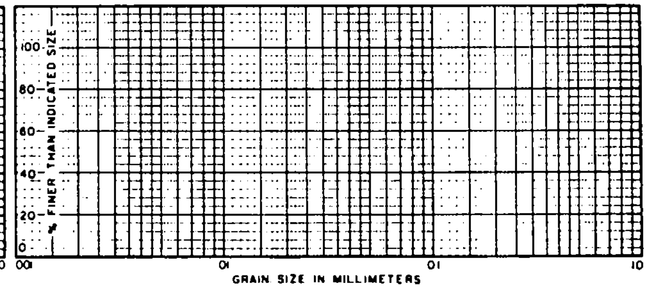
AVONLEA RESERVOIR

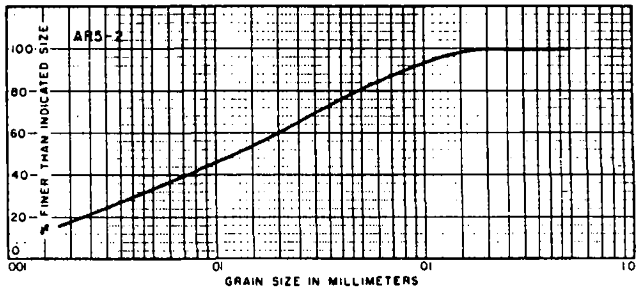
BED MATERIAL PARTICLE SIZE DISTRIBUTION

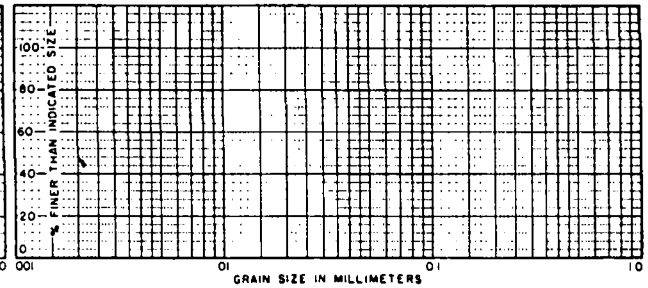
DATE 1973 | FIG

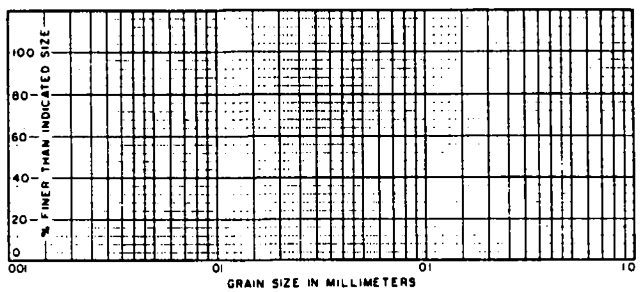
SAMPLE LOCATION	DATE	NO OF SAMPLE	PERCENTAGE FINER THAN INDICATED SIZE M.M. 8.000	4.000	2.000	1.000	0.500	0.250	0.125	0.062	% SILT 0.062 - 0.005 MM	% CLAY < 0.005 MM
AR5	27/73 JULY	1				100	98	90	72	56	35	21
AR5	27/73 JULY	2					100	99	97	84	48	36

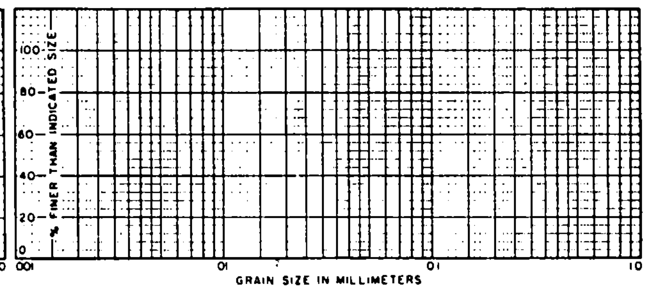


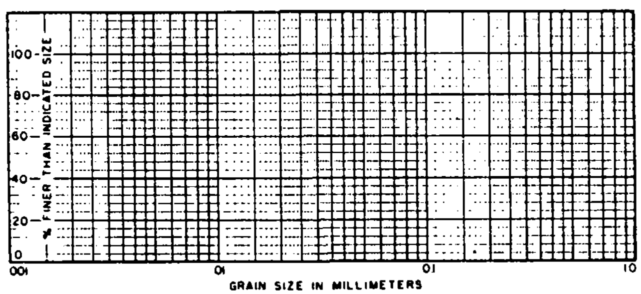












WATER RESOURCES BRANCH
DEPARTMENT OF THE ENVIRONMENT

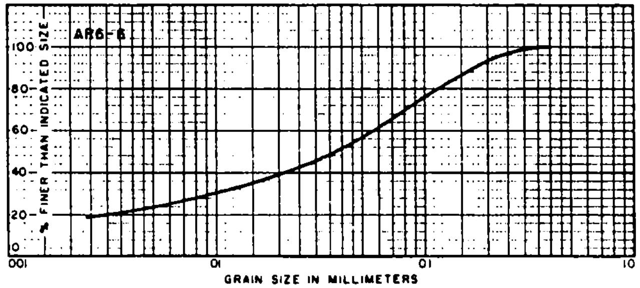
SEDIMENTATION STUDY

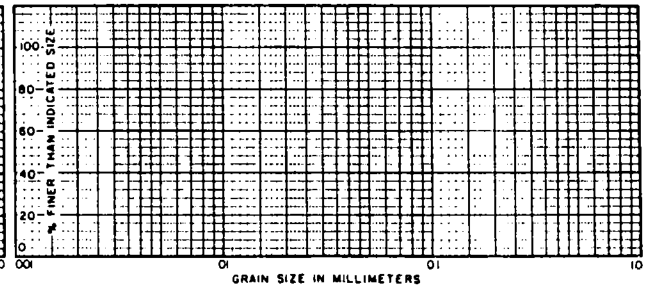
AVONLEA RESERVOIR

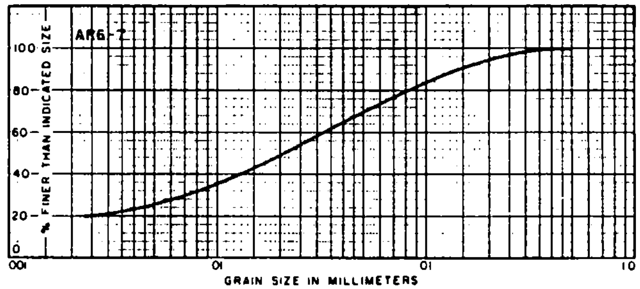
BED MATERIAL PARTICLE SIZE DISTRIBUTION

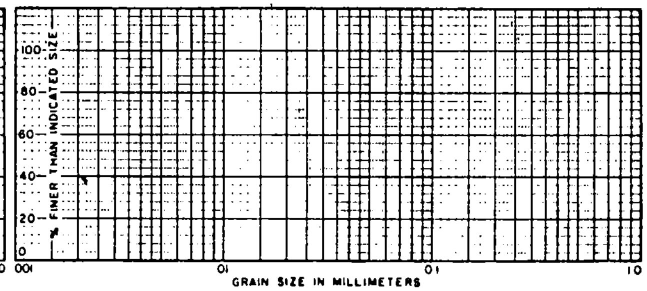
DATE 1973		FIG

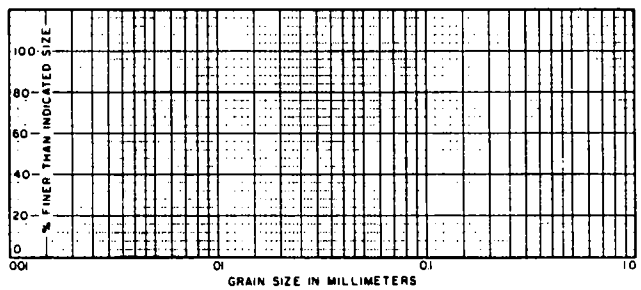
SAMPLE LOCATION	DATE	NO OF SAMPLE	PERCENTAGE FINER THAN INDICATED SIZE M.M								% SILT 0062 - 0005 MM	% CLAY < 0005 MM
			8000	4000	2000	1000	0500	0250	0125	0062		
AR6	26/73 JULY	6				100	99	96	80	62	37	25
AR6	26/73 JULY	7				100	99	96	88	69	41	28

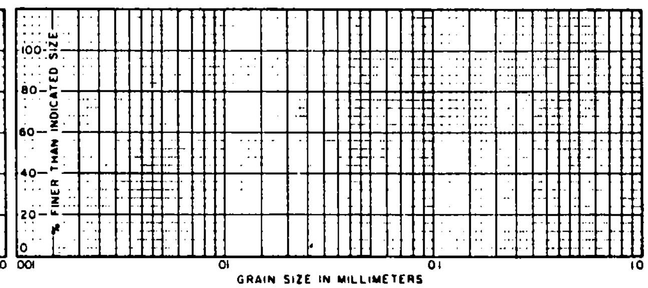


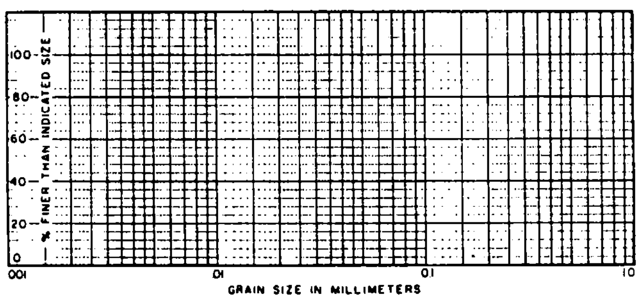












WATER RESOURCES BRANCH
DEPARTMENT OF THE ENVIRONMENT

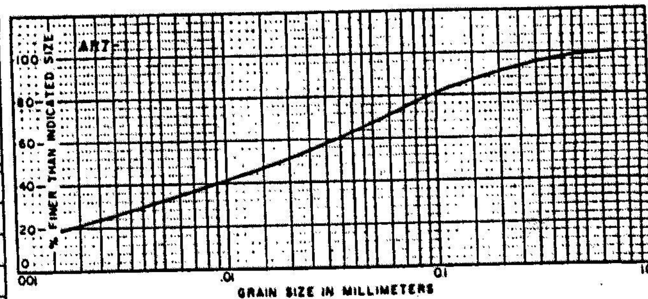
SEDIMENTATION STUDY

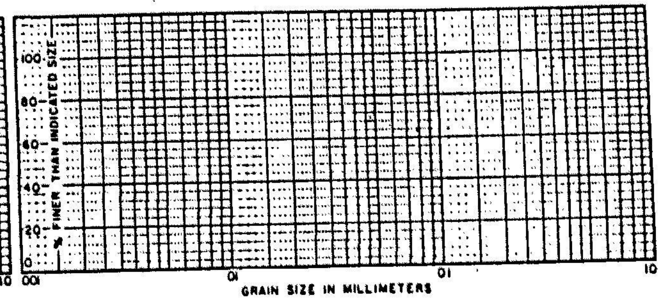
AVONLEA RESERVOIR

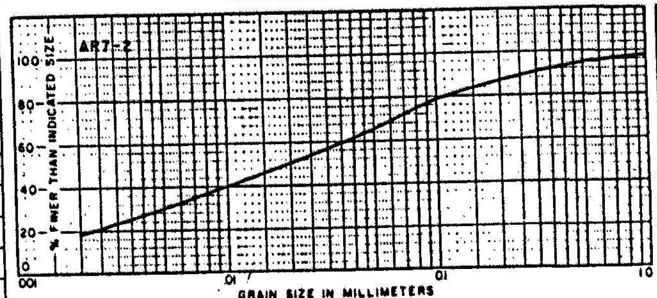
BED MATERIAL PARTICLE SIZE DISTRIBUTION

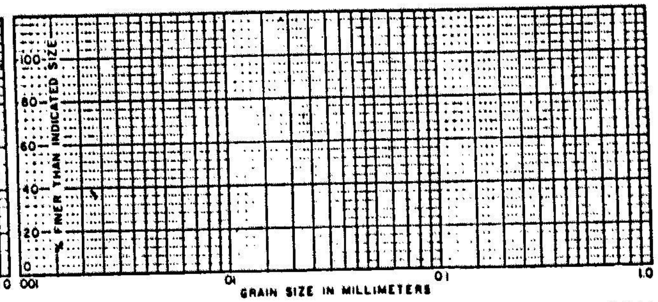
DATE 1973 | FIG

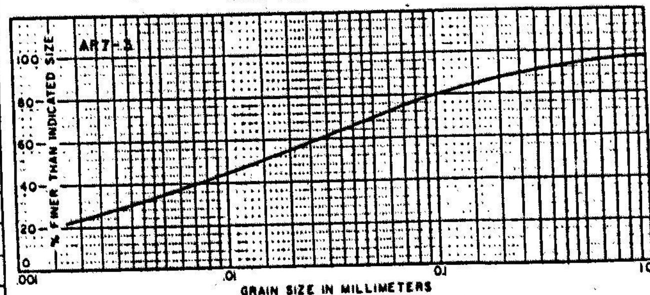
SAMPLE LOCATION	DATE	NO OF SAMPLE	PERCENTAGE FINER THAN INDICATED SIZE M.M. 8.000	4.000	2.000	1.000	0.500	0.250	0.125	0.062	% SILT 0.062 - 0.005 MM.	% CLAY < 0.005 MM.
AR7	26/73 JULY	1				100	97	94	87	72	41	31
AR7	26/73 JULY	2			100	98	93	88	84	70	38	32
AR7	26/73 JULY	3			100	98	91	87	84	74	39	35

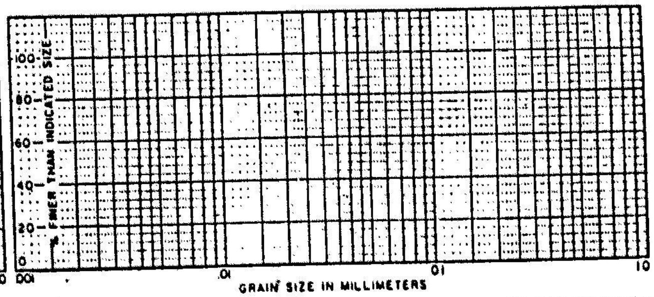


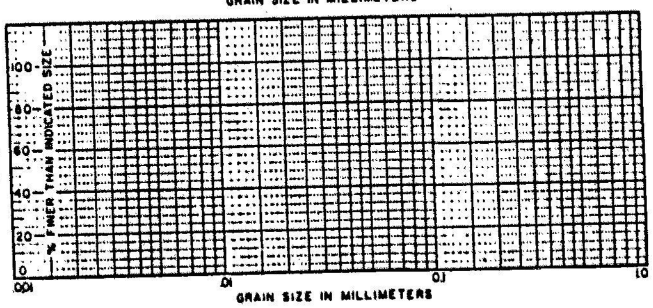












WATER RESOURCES BRANCH
DEPARTMENT OF THE ENVIRONMENT

SEDIMENTATION STUDY

AVONLEA RESERVOIR

BED MATERIAL PARTICLE SIZE DISTRIBUTION

DATE 1973		FIG