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GREGORY: DEWATERING STUDY FOR OPEN PIT MINE, LABRADOR

DEWATERING POTENTIAL STUDY

FOR AN

OPEN PIT MINE

IN

LABRADOR

CANADA

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ABSTRACT

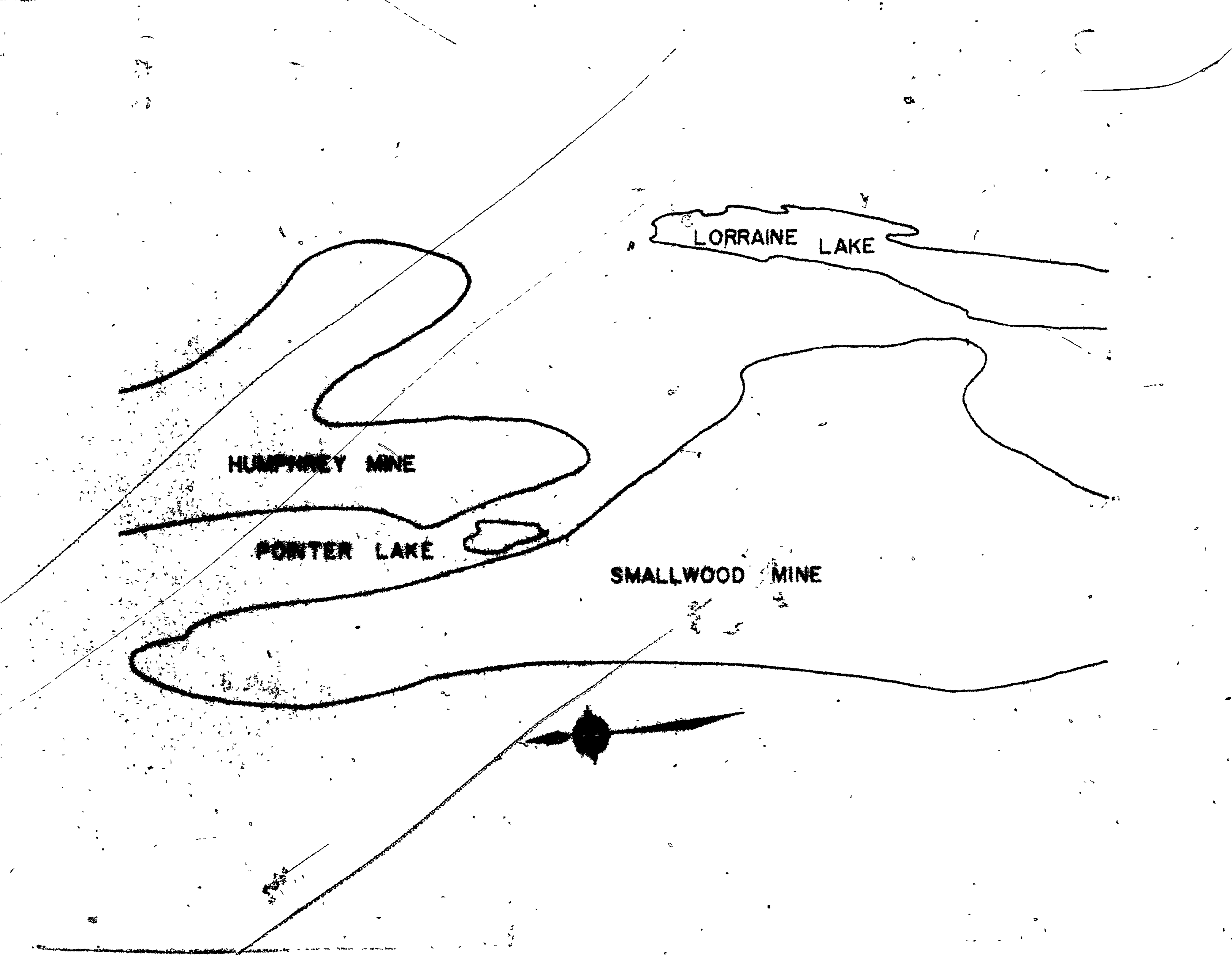
A study was carried ~~out to~~ investigate the factors relating to dewatering at the open pit mines of the Iron Ore Company of Canada in Labrador City, Labrador. Information was collected regarding climate, geology, surface water, ground water, vegetation and mining practices. The seasonal climatic features were defined with respect to water availability and dewatering requirements.

The area surrounding the pits was divided into a number of small, independent surface and sub-surface drainage basins, the limits of which were mapped in the field. A technique of water budgeting was devised in order to permit calculation of the dewatering requirements based upon data collected in the study. An analysis was made of the dewatering potential of one pit in the area using the water budgeting technique, and it was found to give results in close agreement with the actual requirements. The water budget analysis may be made in a conceptual form in advance of the mining so that the dewatering requirements can be predicted. It is believed that a study of the type described herein is certainly justifiable in economic terms and could serve very usefully to improve the dewatering activities required by open pit mining in this region of Canada.

SOMMAIRE

Ce travail a pour but d'étudier les facteurs influant sur l'évacuation des eaux aux mines à ciel ouvert de l'Iron Ore Company du Canada à Labrador City au Labrador. Nous avons recueilli des données sur le climat, la végetation et les techniques d'extraction. Les caracteristiques climatiques saisonnières ont été définies en termes de la disponabilité de l'eau et des besoins d'évacuation d'eau.

La région entourant les puits d'extraction a été divisée en un certain nombre de petits bassins de drainage independants, en surface et souterrains, dont les limites ont été cartographiées sur le terrain. Une méthode de comptabilité de l'eau basée sur les données recueillies lors de cette étude a été établie pour permettre les calcul des besoins en évacuation des eaux. Une analyse des besoins en evacuation des eaux de l'une des mines de cette region utilisant cette méthode a donné des résultants très voisins des besoins réels. La comptabilité de l'eau peut être établie avant les opérations minières, prévoyant les besoins en évacuation des eaux. Nous sommes certain qu'une telle étude est justifiable en terms économiques et pourrait être utilisées pour améliorer les activités d'évacuation des eaux requises par les mines à ciel ouvert de cette région du Canada.


LORRAINE LAKE
HUMPHREY MINE
POINTER LAKE
SMALLWOOD MINE

FRONTISPIECE

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CHAPTER 1 - INTRODUCTION

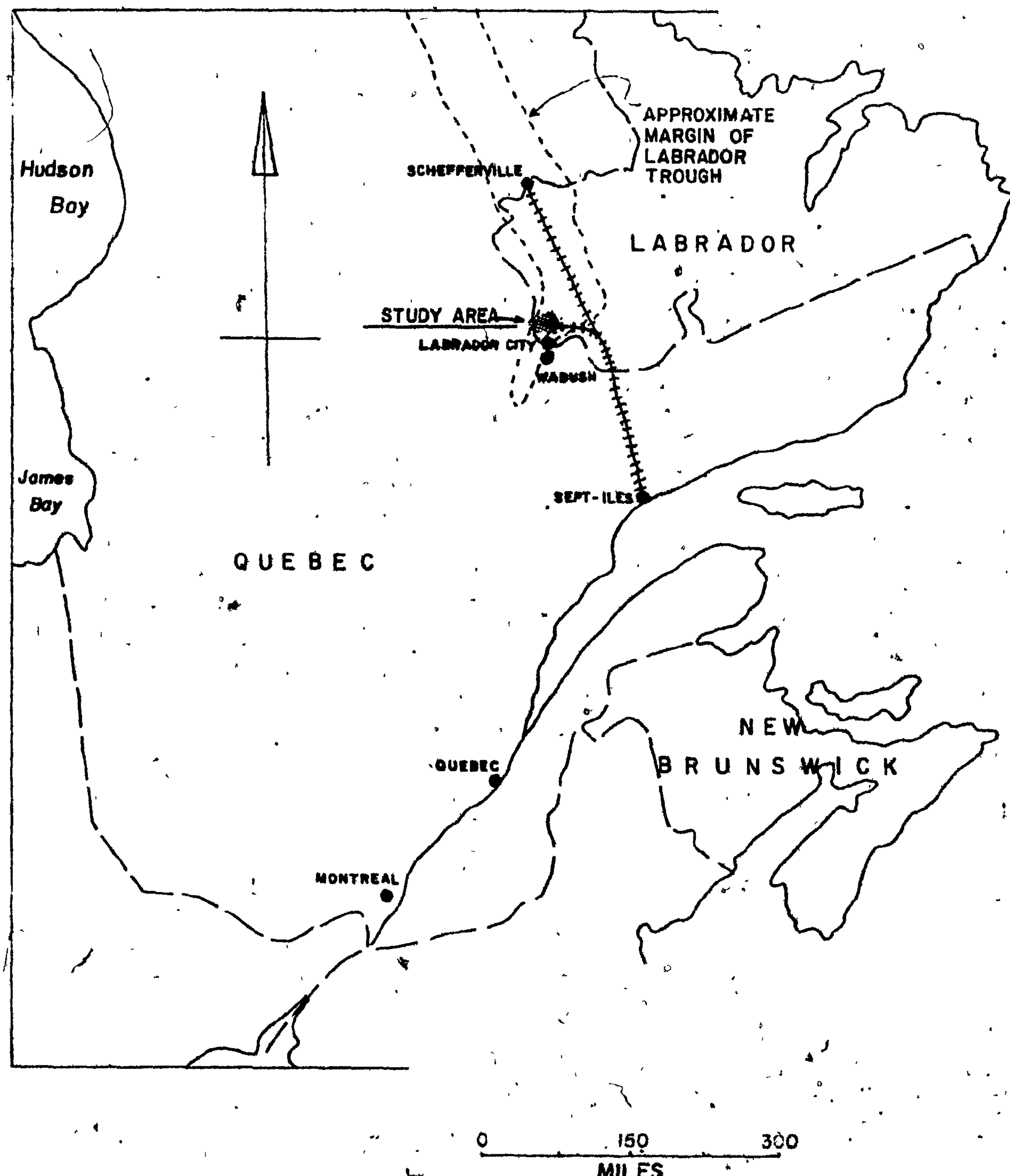
This thesis is presented in partial fulfillment of the M. Sc. degree requirements of McGill University, Montreal. It is based upon work carried out while the author was employed with the Iron Ore Company of Canada, during the field season of May/September, 1973. The location of the study area is shown in Figure 1A; Figure 1B is a plan of the area, identifying the lakes and the open pits. The mining area is approximately five miles in length, and three miles wide. It contains several pits in various stages of development, ranging in size up to 10,000 feet long, 2000 feet wide, and 300 feet deep, these being the approximate dimensions of the Smallwood Pit.

The Iron Ore Company has actively mined the area for over ten years. Initial work was begun on the Smallwood deposit and subsequently expanded as production increased. The company decided to initiate a dewatering potential study, to be carried out by the Technical Services Branch of its Geotechnical Department, for two main reasons:

(1) Successive deepening and enlargement of Smallwood, and to a lesser extent Humphrey, Mines has increased and continues to increase their water catchment

FIGURE 1A

LOCATION OF STUDY AREA



potentials from both surface and sub-surface sources. The present system of dewatering with pit floor sumps is becoming less efficient as the quantity of water to be handled increases.

(2) The latest lowering of the floor of Smallwood Mine reduces it to almost the same level as the surface of Luce Lake. The projected ultimate depth of the pit is some 500 feet below this level. The proximity and size of the lake require that its possible role as a ground water recharge source be evaluated.

There are two additional, specific reasons why pit floor sump dewatering is unsuitable in the mines of the study area;

(1) Following large blasts, fly rock, of boulders up to several tons in weight, offers the likelihood of serious damage to dewatering equipment, especially when these are situated at lower levels within the pit. In consequence, the present dewatering system must be disassembled prior to each blast (an inconvenience to be suffered on average every second day).

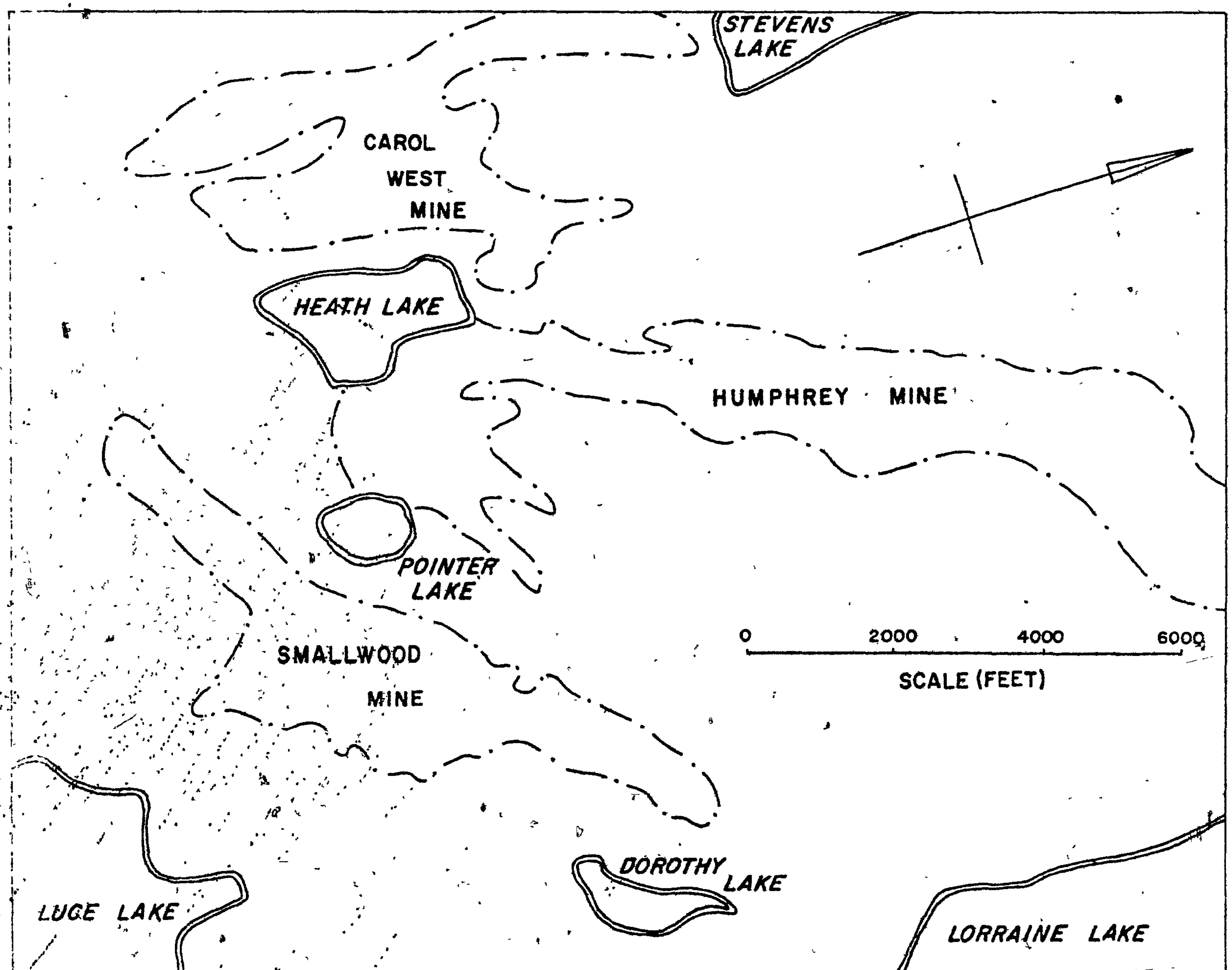


FIGURE 1B

PLAN OF STUDY AREA

(2) In early winter, before the ground becomes entirely frozen, water seepage from rock faces cause icing over large areas of the mines. Serious disruption of the mining work may result from this, depending upon the quantity of water flow and the thickness of ice that develops.

Dewatering by a number of shallow or medium depth wells, peripheral to each mine is seen as a partial solution to the problems. This system is also favoured because it has been observed that most of the ground water seeping into the pits does so in localised regions, which have been correlated with fracture zones, and would be ideally suited for the siting of wells around the pit margin.

The work for this project is the first of its kind in the area, so that with the exception of occasional comments in drillers' and engineers' reports, no background information could be found. The author was also unsuccessful in a literature search for any previous studies carried out in other areas with similar hydrogeological and climatological conditions. Within the study area, abundant geological information is available, having been produced in the course of the surface mapping and drilling programmes of the company (see Chapter 2). Reference was also made to the aerial photographs of the area, in the planning stages of the project, but these were of little use in detailed work since they predate the mining operation. However, they do serve as a reference to show the changes in the geomorphology that have occurred as a result of the Iron Ore Company's activities.

In view of the poor state of knowledge of any part of the hydrological regime, the field activities in the study area were designed to cover as many different aspects as possible within the time allowed. Thus, the scope of the thesis is rather wide, but it is hoped that the comprehensive nature of the content will compensate for any paucity of specific detail. Moreover, the thesis is intended to describe a practical approach to water budget and dewatering analysis, given limited manpower and resources. Indeed, this type of approach is, by necessity, normally the only acceptable method within the field of applied hydrology. The economics of data collecting and analysing are a very major factor, particularly with respect to information about sub-surface conditions. Thus for a study to be worthwhile in an area such as mining, it must be justifiable in a cost-benefit sense. It is hoped, therefore, that this paper will show how solutions to various hydrologic problems may be approximated within acceptable budget restrictions.

The primary aim of the thesis is to report the author's findings in the area of research, and to show how they may be applied in the formulation of a mine dewatering programme. Some discussion is also included of the various advantages and disadvantages associated with working on a hydrological study in an area of active mining operations. Within this broad, practically orientated context, the thesis follows four major roads of enquiry:

(1) Identification and delineation of the drainage network of the area.

(2) Description and appraisal of the sub-surface water conditions.

(3) Quantitative assessment of the hydrology in the form of a water budget study.

(4) Interpretation of the information from a dewatering viewpoint.

The author is entirely responsible for the conclusions of the thesis. Any opinions stated herein are not necessarily

shared by the Iron Ore Company of Canada, or by any of its employees.

The author is very grateful to the Iron Ore Company of Canada, for their generous assistance and co-operation, without which this thesis would not have been possible. In particular, the author is indebted to Mr. P. Stacey, and Mr. F. Khan, Head of the Geotechnical Services Branch, and company Hydrogeologist, respectively, for their extensive support.

The author must also express his gratitude to the staff members of the Department of Geological Science at McGill University for their encouragement. Dr. R. H. Grice and Dr. R. Bowen are especially thanked for their stimulating comments and particular assistance during editing and final preparation of the thesis.

CHAPTER 2 - BACKGROUND INFORMATION

2.1 General Geology

The study area is located in the extreme southwest of the Labrador Trough (Figure 1A), a belt of late Pre-cambrian igneous and sedimentary rocks. The sequence within the trough is separated from the underlying Ashuanipi basement complex by an unconformity and large faults. More recent, Montagnais intrusives are found throughout the trough, but comprise a very minor part of the rock outcrop of the study area.

The margins of the trough are far enough removed from the study area that none of the Archean basement complex is exposed within it; nor have they been penetrated during drilling. Thus, for the purpose of the study, only the Proterozoic rocks, shown in Table 2A need be considered in detail. This stratigraphic sequence (modified after Cambell, 1962), includes sufficient mineralogical and petrographical information for identification purposes. A more pertinent classification of geohydrological rock units is presented in Chapter 4.

The sediments of the study area are believed to have been laid down as shallow basin deposits on an irregular basement surface. Composition changes are mainly stratigraphically controlled within the study area, but may be partly due to lateral facies variations. The detrital input was mostly arenaceous with minor argillites. Clean quartz sandstones are intercalated with greywacke, limestone, chert, and chemically precipitated ferrous oxide.

Regional metamorphism of Grenville age, produced the massive quartzites and schistose units of the present stratigraphic sequence. Quite extensive ion migration accompanied the metamorphism, particularly with regard to the iron precipitates, which are now found as magnetite, haematite, martite, and siderite. The average grade of the metamorphism is almandine/amphibolite, and the intensity of the schistosity varies markedly with composition and structural position.

The rocks of the area were tightly folded during the Grenville orogeny and two main systems are now observable, one with its axis N - S ± 20 degrees, the other N 75 degrees E ± 15 degrees. The former system is best developed, producing long parallel folds, usually overturned to the west. The degree of folding is closely related to the competency of the rocks, with quite complex, local

TABLE 2A

FORMATION		COMPOSITION	
		Quartz Specularite	
		Specularite	
		Specularite-Magnetite	
	UPPER	Magnetite-Specularite	
		Magnetite	
		Quartz-Magnetite	
WABUSH		Gradational Contact	
		Quartz - Carbonate-Magnetite (Specularite)	
	LOWER	Quartz - Carbonate-Grunerite - Amphibole	Geothite-Limonite Alteration Common
		Quartz - Carbonate-Grunerite - Ankerite-Siderite	
	UPPER	Impure Quartzite, Iron Oxides Common	
CAROL	MIDDLE	Massive crystalline Quartzite	
	LOWER	Massive Quartzite with Shaley Bands	
KATSAÓ		Garnet, Cyanite, Biotite, and Hornblende Schists and Gneisses	

STRATIGRAPHIC SEQUENCE

distortions appearing in the weaker units, particularly at sites of interaction of the two fold systems.

Generally however, regular folds of the main system predominate, having anticlines rather tighter than the synclines and an average wavelength of about 2000 feet. The outcrop pattern of the major units of Table 2A and the main structural features are shown on the geological map which forms Sheet 1 (in pocket). One important feature to note on this map is an outcrop of hornblende schist in the central part of the study area lying parallel with the edge of the Smallwood ore deposit and partly underlying Pointer Lake. It is not known whether this unit is a displaced member of the Katsao Schist group, or whether it is an isolated unit, perhaps the metamorphic product of a small igneous intrusion. However, because of this unit's important role hydrogeologically, it is termed the Hornblende Schist, and referred to as such throughout the text.

Jointing and fracturing is commonly observed in the rocks of the study area. Within the pit limits, the fractures are usually open and closely spaced. This appearance is primarily a result of blasting however, and, in the author's opinion, does not truly represent the natural state of the materials. Detailed observation of in-situ rocks, away from the mining areas, both at and below the ground surface, shows joints and fractures tightly closed in general, and far less abundant. Inspection of drill core from many parts of the study area seems to corroborate these observations. Secondary carbonate, haematite, and quartz-fill is often present along larger fracture planes.

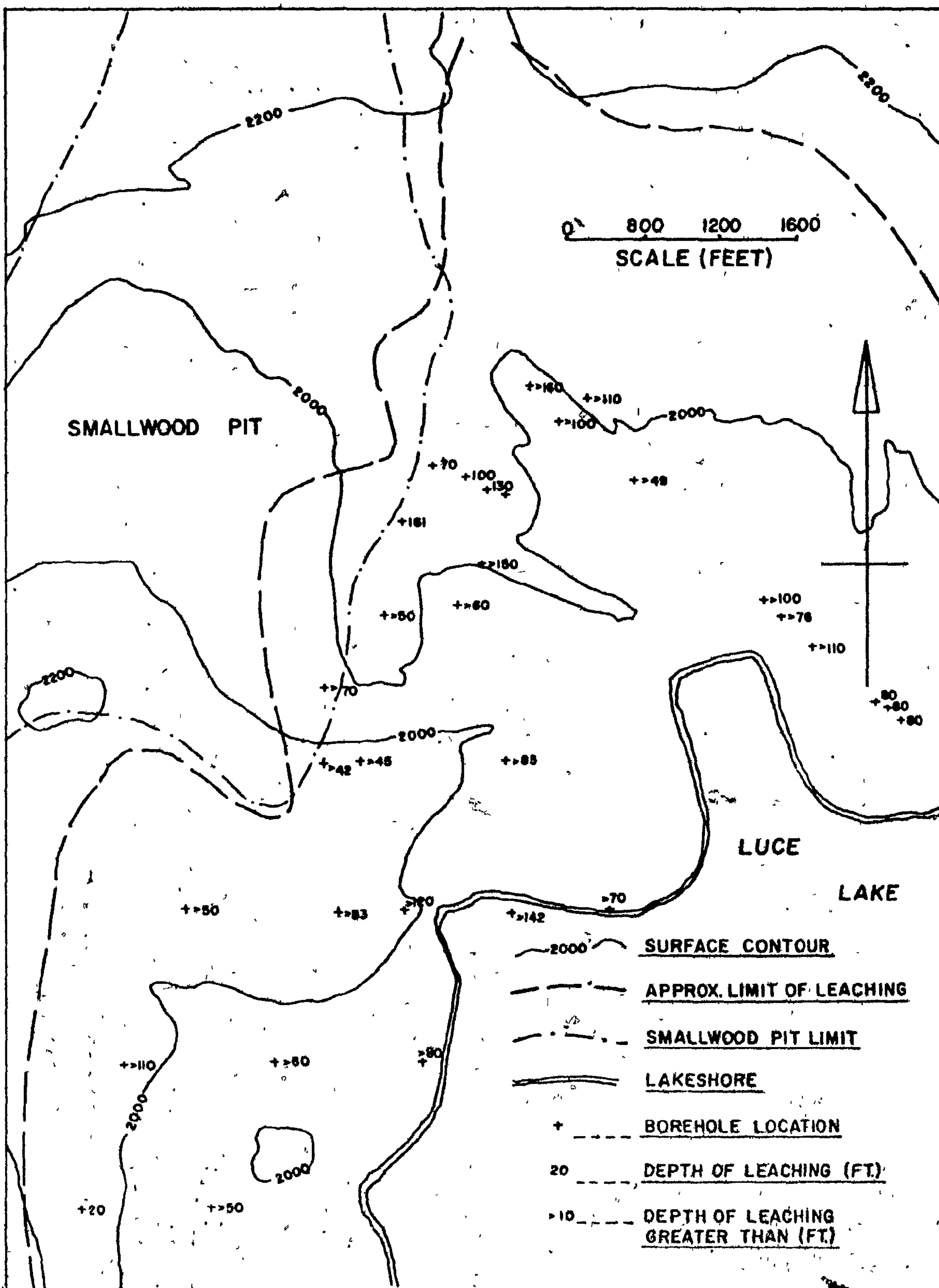
A few seemingly localised zones of open fractures do occur, and are easily identified where they intersect a part of a pit wall. They are probably related to faulting within the area and may also show leaching effects. These fracture zones are quite significant hydrologically, and may warrant dewatering on an individual basis where they are observed discharging water at their intersection with the pit margin. This dewatering could be effected by shallow to medium depth wells penetrating the fracture zones outside the pit limit. These wells would form a part of the peripheral well system, which is discussed more fully later in the thesis.

The carbonate members of the Lower and transitional Lower/-Upper, Wabush Formation are composed of a variety of schistose units. The minerals occur in crystalline bands from a few millimeters to several centimeters thick and they may be composed of single minerals or two or more minerals growing together. Quartz, coarse grained ferruginous carbonate, ankerite and siderite are common, along with magnetite, grunerite, cummingtonite, anthophyllite, hypersthene, actinolite and diopside. The amphiboles often occur as long lath-shaped crystals which give the rock a fibrous texture. Some parts of these carbonate rocks have suffered very heavy leaching. In extreme cases, the whole rock is reduced to a highly incompetent, sugary sand of a very friable and porous nature. Elsewhere, bands and pods of leached material are found within the unaltered rock. In good exposures the leaching can be seen to follow the jointing system, and to spread out into the adjacent rock mass. Typically, core recovery from holes drilled in the more heavily leached material is very poor. The amount of leaching usually decreases quite rapidly with depth below the present land surface. However, within the area shown (Figure 2A), a very thick zone of leached material is present, probably greater than 250 feet at its maximum.

Overlying the ancient rocks of the area is a sparse and patchy layer of Pleistocene to recent, surficial material. The ridge crests and hill slopes rarely shoulder more than two or three feet of cover and are often bare-rocked.

FIGURE 2A

MAIN EXTENT OF LEACHED CARBONATE



Only in lake bottoms or on valley floors is soil found in any appreciable quantity, and then it is rarely developed to a depth of more than 30 feet. Fluvio-glacial and lacustrine silts and clays are most common, often with a high organic content. Coarser sands and fine gravels occur very sparingly in circumlacustrine beaches, small river deposits, and esker remnants.

In general, the presence of a reasonably thick soil cover tends to increase run-off and reduce infiltration to the underlying rock body. Also, water that does infiltrate tends to be held in the porous but poorly permeable soil and does not migrate freely into the underlying rock. Often these areas become quite swampy following heavy rainfall.

Soil cover is absent within most of the area of active mine work, since it is standard practice to strip off all the superficial material. One negative aspect of exposing the bedrock surface in this way is the resulting increase in infiltration and recharge to the ground water system. The approximate extent of this denudation is shown on Sheet 2 (in pocket), by an outer-limit line.

2.2 Physiography

The total relief of the study area varies between a low of 1910 feet at the surface of Luce Lake and a high of 2955 feet at Wabush Signal (see Sheet 2). Locally, adjacent hills and valleys rarely differ in elevation by more than 300 - 400 feet. The topography has been very significantly modified over the last 15 years by the mining activities, which have removed or redistributed several hundred million tons of the rocks of the area. The Frontispiece to the thesis shows an aerial view of part of the mining area, including Smallwood mine, and shows the scale of this modification.

The natural landscape is primarily of an erosional type and mostly dates back to the Pleistocene glacial period. The present day rate of natural weathering is very slow and mainly effected by freeze-thaw mechanisms. In keeping with this, the sediment transport system is mostly ineffective and barely suffices to move material off slopes into lake bottoms. Valleys have gently rounded or flat bottoms, and hill slopes and crests are well-smoothed.

The topographic expression is closely controlled by the geology of the area. High land is composed of the more resistant Carol, Katsao and Upper Wabush formations, while valleys tend to be restricted to Lower Wabush outcrop areas. Since the positions of these units are determined by the fold systems of the area, a definite correlation can be traced between the axes of the structural trends and the topographic grain.

2.3 Climate

The study area is located about 20 miles from the Wabush Airport meteorological station of the Canadian Atmospheric Environment Service. The station was established in November 1960, and has been recording climatic conditions on a daily basis since that date. Appendix 1 includes tables of total monthly and mean monthly precipitation, and mean monthly temperatures, over a ten year period from 1961 to 1972. The daily temperature and precipitation information for the period of the 1973 field season is also presented.

The general climatic picture in this part of Labrador/Quebec approaches extreme continental conditions, with an average annual temperature range of about 125 degrees Fahrenheit. The average yearly precipitation is approximately 35 inches, of which a greater part falls in the second half of the year. In an average year, the mean daily maximum temperature remains below freezing point between mid-November and late-April. Taken throughout the year the mean daily temperature is approximately 25 degrees Fahrenheit.

It is expected that the micro-climate of the study area is strongly influenced by the physiography, particularly with respect to wind velocity and precipitation. Daily precipitation during the field season, measured adjacent to Heath Lake with a ten square inch standard copper rain gauge (Appendix 1, Table A5), can be compared with the Wabush Airport data.

2.4 Vegetation

The study area may be sub-divided into two major and one minor floral provinces, which result from variations of the soil characteristics and the topography. The most important of these has been termed the "close-forest type", by Hare (1950). Black Spruce is the main species, with secondary Larch, Balsam and White Birch. The ground between the closely spaced trees carries a thick carpet of mosses (Sphagnum), lichens (Cladonia), bunch-berry, wood-sorrel, and many other small shrubs.

At higher elevations, on ridge crests and steep slopes, where there is poor soil cover, good drainage, and very open exposure to severe climatic factors, the second major province is found. Trees are rare and usually stunted. Grasses, mosses, and lichens abound along with many species of shrubs, especially Labrador tea and blueberry.

Lastly, in a few low-relief areas are patches of muskeg or swampy ground. These areas are generally underlain by past lake sediments and are poorly drained. Mosses, shrubs and marsh grasses predominate, though a few scattered and poorly developed trees may be present.

Potential evapo-transpiration (P.E.) values have been calculated for different boreal forest assemblages and are tabulated in Hare's paper. These values vary with climatic conditions and geographic distribution. Abstracting his proposals, for the combination of floral provinces found in the study area, a potential evapo-transpiration in the order of 12 - 15 inches per year can be expected. This is approximately equivalent to one third of the total yearly precipitation.

CHAPTER 3 - SURFACE HYDROLOGY

3.1 Introduction

The essential prerequisite for a drainage basin study is a topographic map showing the waterways and watersheds of the region. Several problems arise when this base map includes an area of large scale open-pit mining. Firstly, the present land surface bears little relation to the published maps of the National Topographic Survey. Secondly, the topography cannot be considered fixed or constant for it is in a state of flux changing from day to day as mining operations proceed.

The positions of watershed and stream lines can be moved, broken or created by the mining activities. However, these changes will only be made in the course of lateral expansion of a pit. Once the ultimate pit limit, the edge of the ore-body, has been reached, the topography regains its stability with respect to surface drainage. Continued mining within this pit limit will, of course, continue to modify the sub-surface drainage pattern.

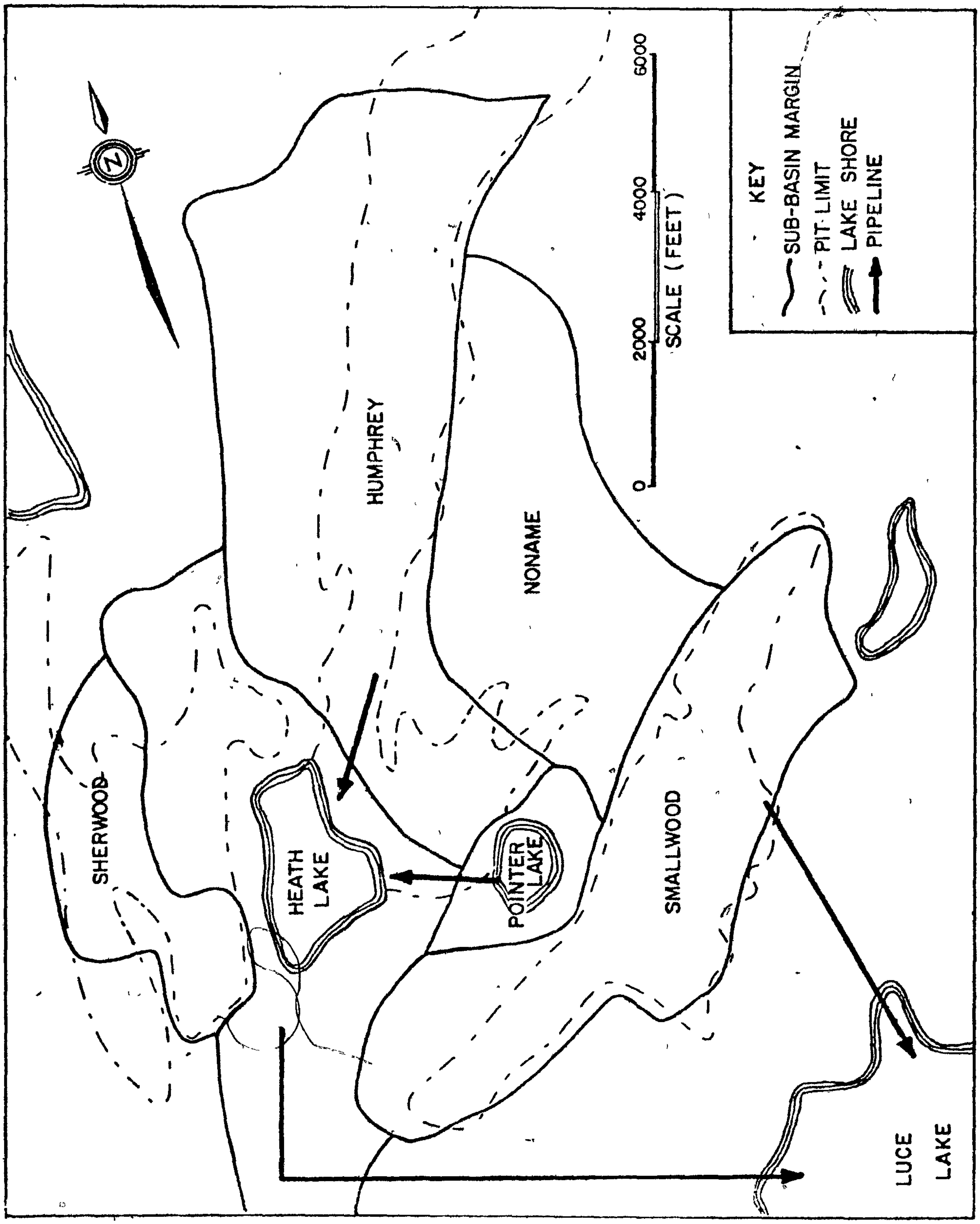
The base map used in this study (Sheet 2) is a composite of the original topographic survey and re-contoured spot heights abstracted from the mine surveyors' log. The map is an accurate record of the shape of the land surface during August, 1973. Once established, the base map can be easily up-dated to keep pace with the mining activities. Proposed future expansions of the mining may also be superimposed upon the base map in advance, to permit long term planning of the dewatering system and to afford a precognizance of the changes to the hydrology of the area.

All the surface drainage data, the positions of lake shorelines and streams, were checked in the field by traverse mapping. The traverse survey along 200 feet and 400 feet parallels was also a source of extensive background information on the study area. It allowed close observation of the rock types and their physiographic expression and provided an overall picture of the surface/sub-surface, recharge/discharge characteristics. In addition, it furnished the opportunity to collect water-table information from a number of abandoned diamond drill holes scattered about the study area (see Chapter 4).

It is convenient to define, for the purposes of this study, a <u>drainage sub-basin</u>. This is a synthetic area of internal surface drainage which has been isolated from

FIGURE 3A

APPROXIMATE LOCATIONS OF SURFACE DRAINAGE SUB-BASINS



the natural drainage system by the mining operation. Water from a sub-basin may be removed by pump and pipeline into an adjacent sub-basin, or alternatively, into some part of the natural drainage network and thence out of the study area. This sub-basin concept is very useful since it allows a quantitative breakdown of the surface water budget into areas which relate to individual open-pits.

There are six drainage sub-basins within the study area. These are shown approximately in Figure 3A which includes a schematic representation of the pump and pipeline flow system. Figures 3B to 3G show the sub-basins in detail, including the relevant physical data of each. The boundaries of the sub-basins are also shown on the hydrogeological base map, Sheet 2.

The Sherwood sub-basin has been extended to incorporate a small, isolated mining area immediately adjacent to it. This is done for convenience, for the area is too small to be considered significant in itself. Moreover, since the mining of this area is actively progressing in the direction of Sherwood Pond, the two areas will coalesce in the near future, if they have not already done so at the time of writing.

FIGURE 3B

SHERWOOD SUB-BASIN

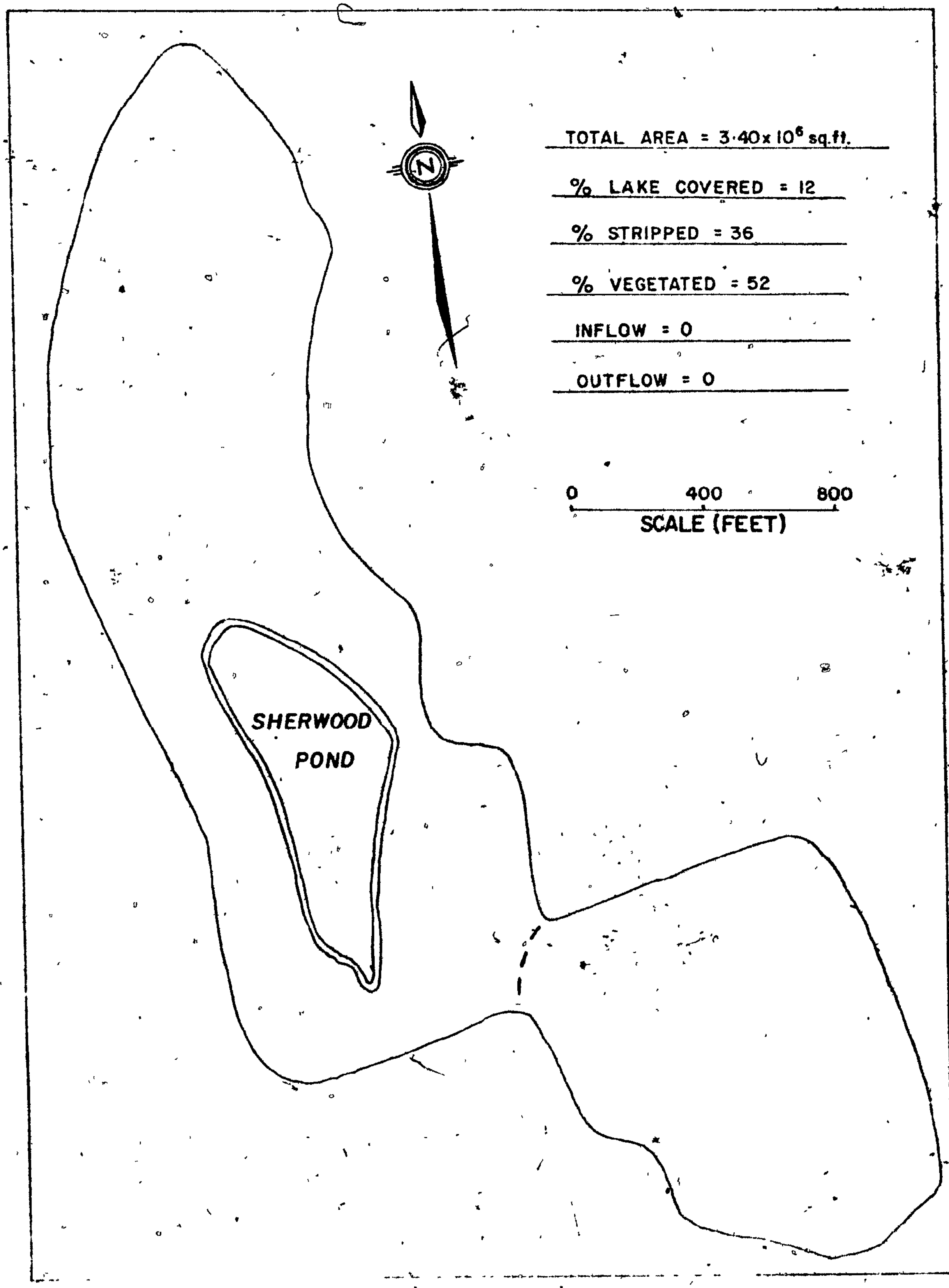


FIGURE 3C

NONAME SUB-BASIN

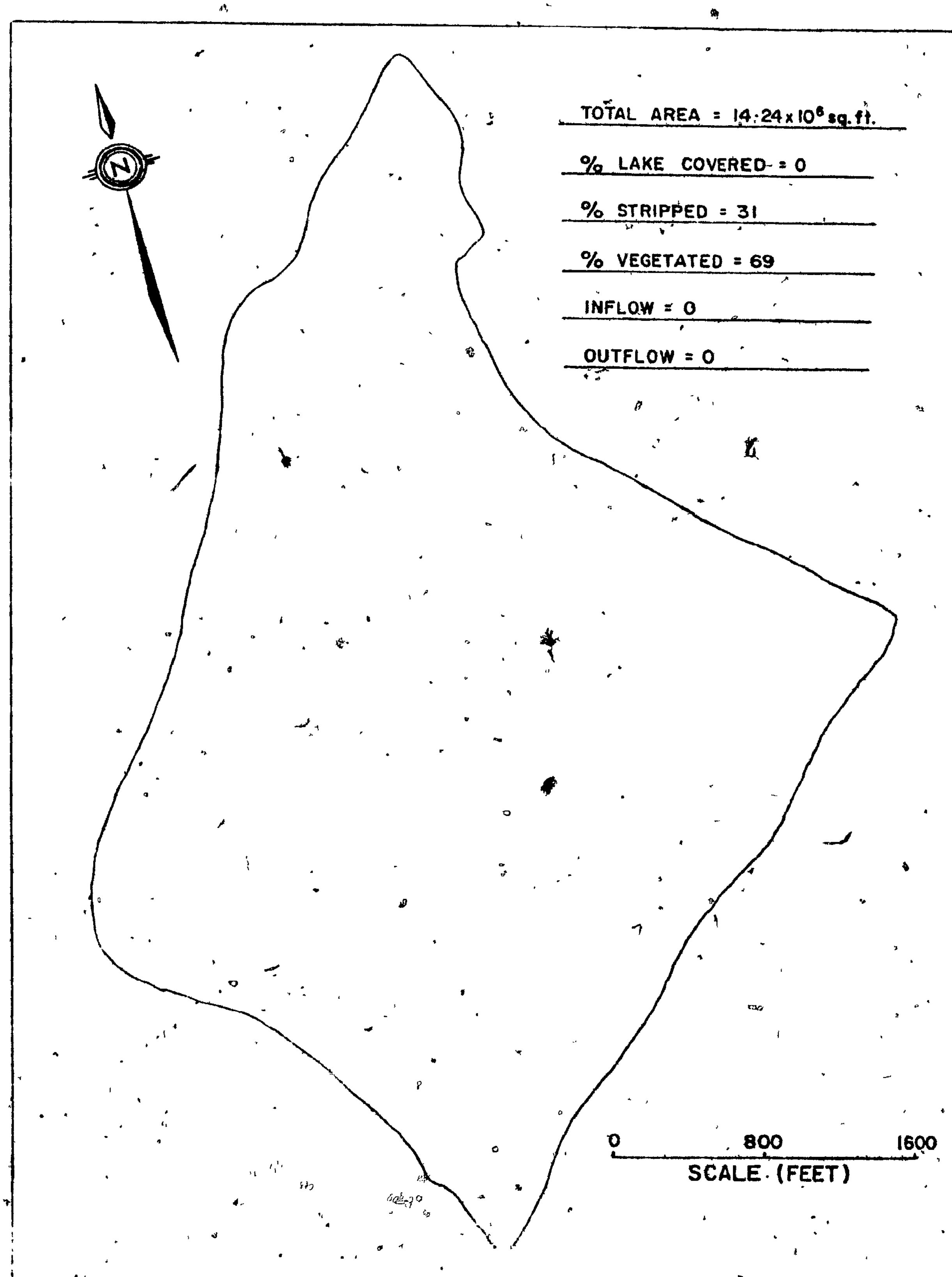


FIGURE 3D

POINTER SUB-BASIN

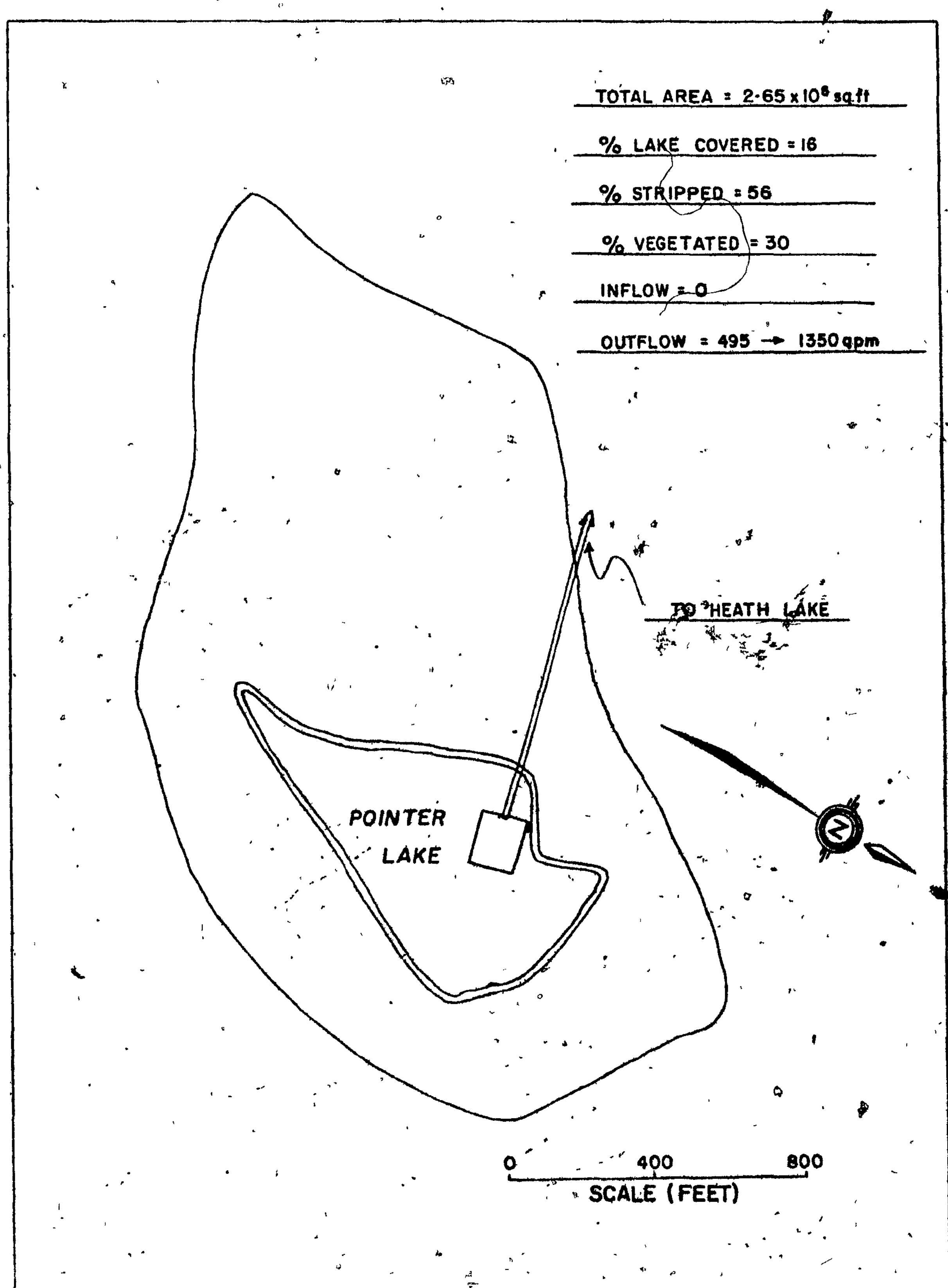


FIGURE 3E

HEATH SUB-BASIN

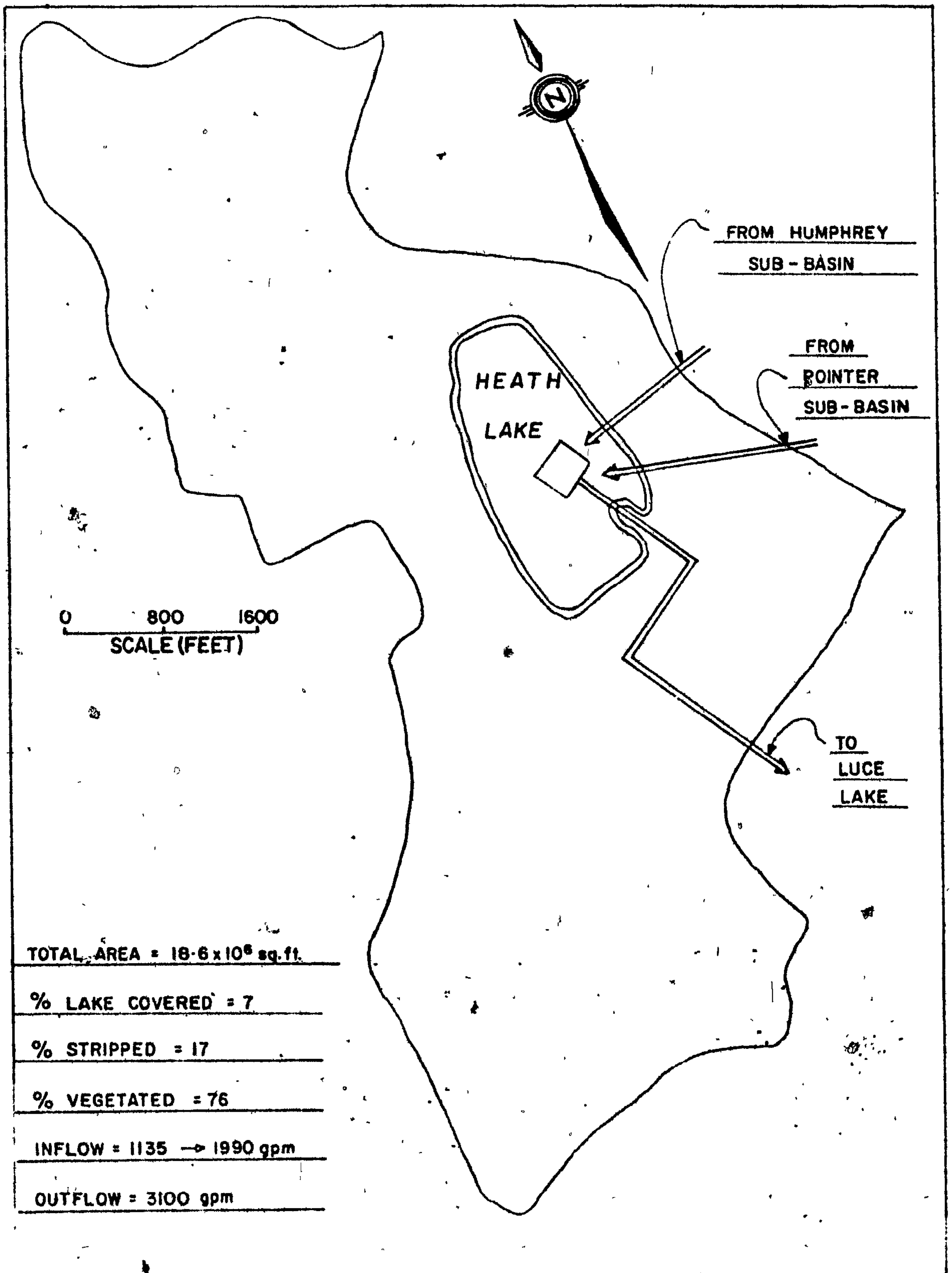


FIGURE 3F

SMALLWOOD SUB-BASIN

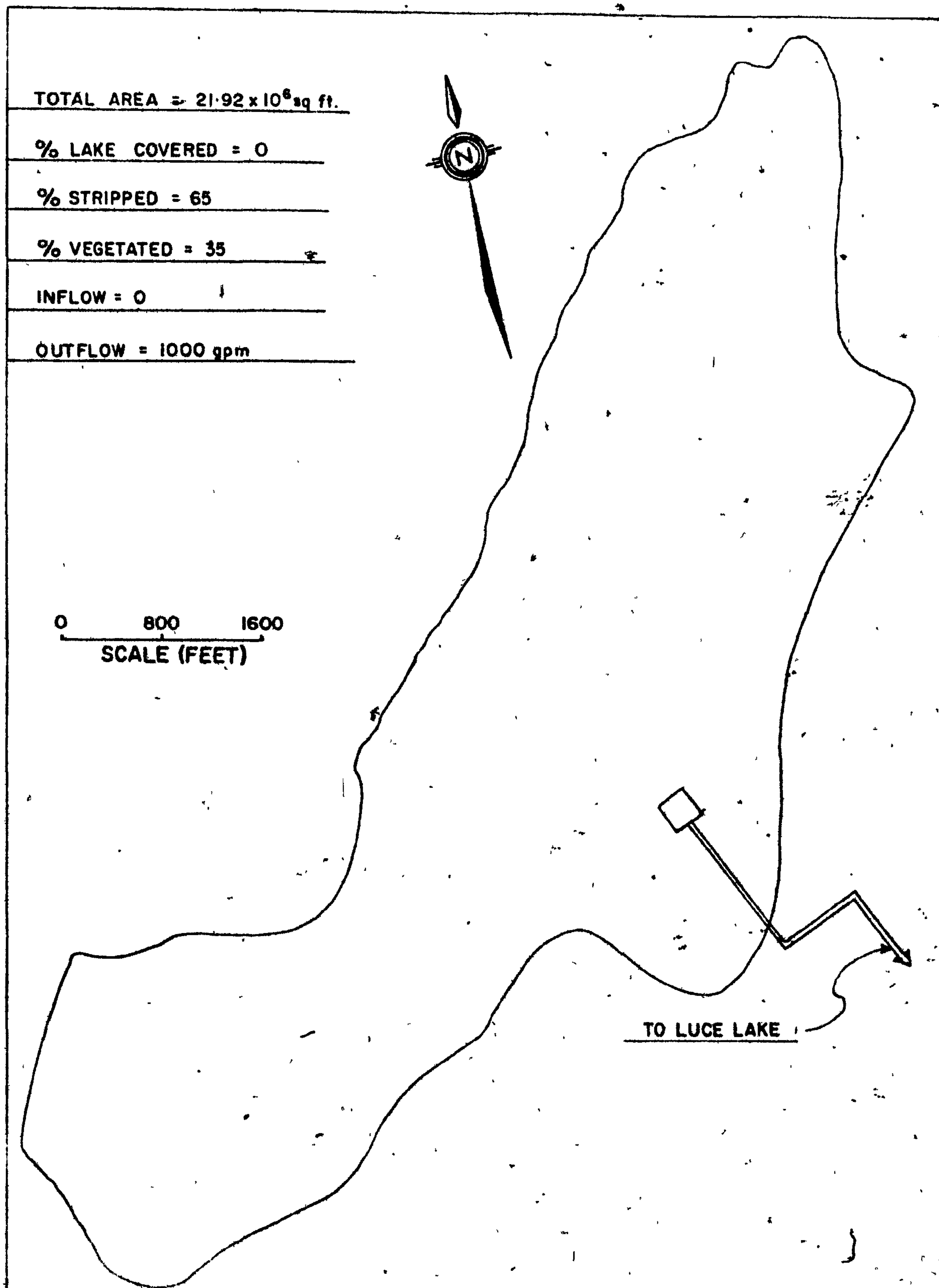
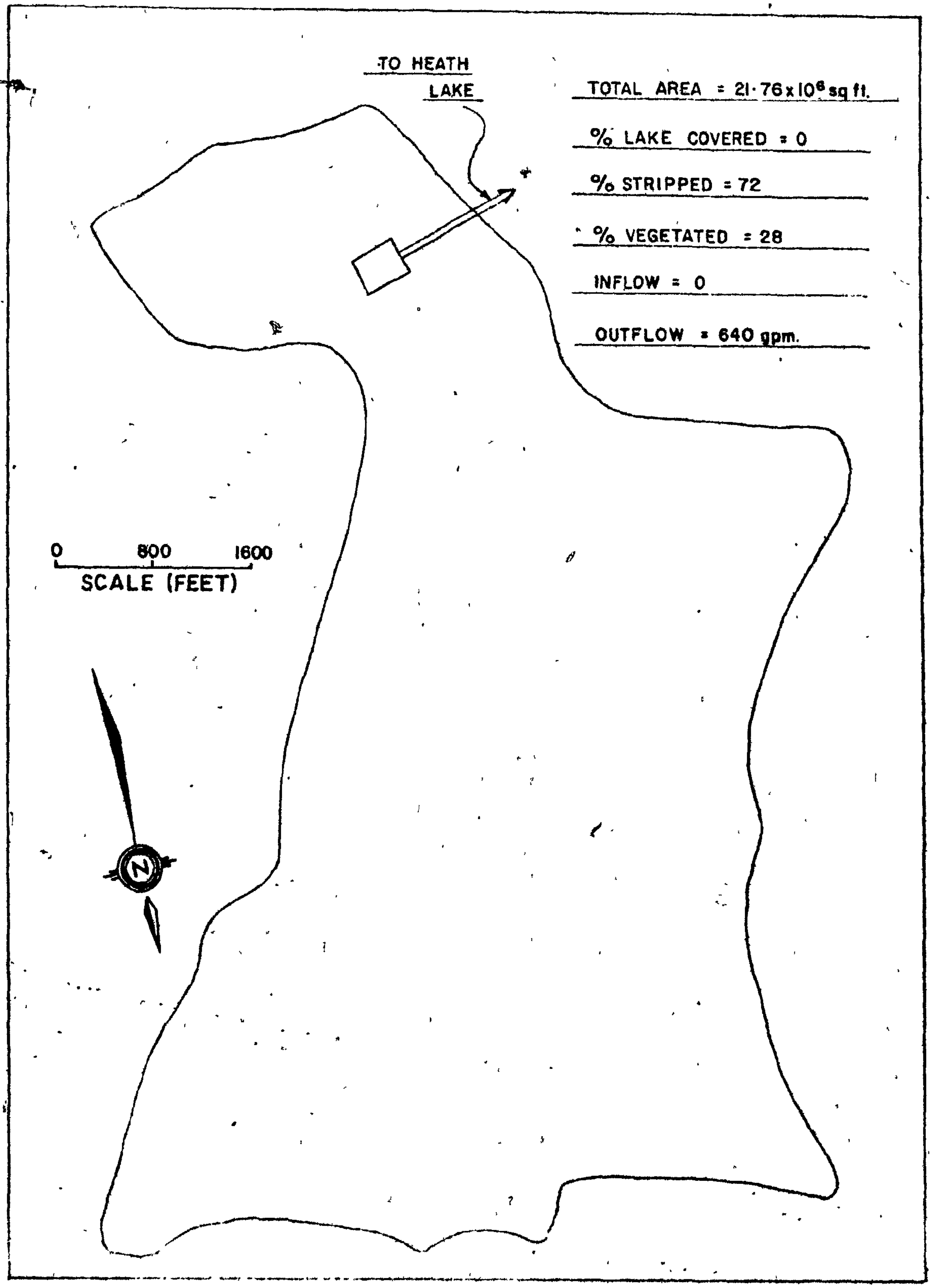


FIGURE 3G

HUMPHREY SUB-BASIN



The central core of the study area, which is comprised of the six sub-basins, is bounded by three natural drainage basins. To the west, water flows into Carol Lake; to the north and northeast, water passes through a system of small lakes enroute to Wabush Lake; to the south and southeast, the water drains to Luce Lake, and also, eventually to Wabush Lake. The three watershed lines, radiating from the margin of the central part of the study area, mark the limits of these three basins.

From a dewatering viewpoint, it suffices to budget the natural precipitation into three components. The first of these includes all the water which is returned directly to the atmosphere, by evaporation, transpiration, or sublimation. This component represents a percentage of the total water input which may be omitted from the dewatering potential calculations.

The second component comprises all forms of surface run-off water. Within the drainage sub-basin of a pit, this represents water which finds its way to the lower levels, where it may or may not pool, depending upon the infiltration characteristics. In areas surrounding the drainage sub-basins, this component represents water carried out of the mining area, and therefore a second part of the total input to be omitted from the dewatering calculations.

The remaining component of the budget includes all the water which infiltrates the ground and enters the subsurface flow system. This component is extremely difficult to measure, but can be calculated if the total precipitation, and the evapo-transpiration and the surface run-off components of the water budget, are known.

The greater part of the field season was spent in activities designed to obtain actual values of the surface run-off and evaporation components of the cycle. Unfortunately, because the field season was only one summer's duration, the measurements of these parameters were not completed, and so it was not possible to arrive at a figure for the infiltration factor. It was observed, however, that during the course of the summer, the surface run-off over the whole area decreased. A corresponding fall in ground water levels was also observed over the same time period with the result that the upper ground layers were drier in the latter half of the summer than in the early part when the ground was almost completely saturated. It would appear therefore that the infiltration factor increases through the summer months.

In order to perform quantitative analyses upon the hydrologic cycle, so that the estimates of dewatering potential can be obtained in Chapter 5, it is necessary to assume a figure for the infiltration factor during the summer months. It seems reasonable to suppose that this figure lies between 25% and 75% of the precipitation remaining after the quantity lost through evapo-transpiration has been subtracted. Since no accurate information is available, the calculations are performed using three different values: 25%, 50%, and 75%. The effect of having such a wide range of uncertainty in this factor of the analyses can be seen in the calculations, and is discussed in the conclusions presented in Chapter 6.

The atmospheric return, and surface flow components of the hydrologic cycle will now be considered. The techniques employed in the field in attempting to quantify these components will be described, and the theoretical assumptions discussed. Before this can be done however, it is necessdry to consider the nature of the precipitation, and the seasonal climatic effects in the study area.

3.2 Climatic Effects

It is very difficult indeed to estimate precisely the events of the hydrologic cycle of the study area during the winter months. Certainly for at least four months, and perhaps for more than five, the ground surface is solidly frozen, preventing infiltration. The lakes are also frozen, for about six months of the year, limiting evaporation from their surfaces, but not water transfer across the lake/sediment interfaces. It is also usual for the recharge areas of the land surface to become frozen before the discharge areas (i.e. pit walls and floors) during the autumn cooling period.

The data presented in Table A1 of Appendix 1 shows an average annual precipitation of 35 inches, with a probable maximum value of less than 45 inches. Table A6 of Appendix 1 shows the breakdown of the precipitation figures obtained from the Wabush Airport meteorological station, into rainfall and snowfall components. The data show that in an average year 48.5% of the total precipitation falls as snow. They also show that this figure is quite constant, and is reliable to within ± 5%. Interestingly, there is no apparent correlation between the total yearly precipitation and the snowfall component percentage.

Some of the early snowfall may melt and run off or infiltrate, however, the bulk of the snowfall accumulates until the spring thaw occurs. Drifting by wind action, the degree of "wetness" of the snow will strongly affect its distribution. Throughout the winter, water will be recycled into the atmosphere by sublimation of the snow.

Records of the snow depth are kept throughout the winter at the Wabush Airport Meteorological Station. Comparing these to the precipitation record shows that, on average, between 60% and 70% of the winter snow is lost before the spring thaw. The station is situated in a low, flat area however, and wind action probably accounts for a part of the reported loss. Wind effects within the study area will certainly redistribute the snow, but are not likely to effect such a significant reduction of the total quantity.

With the spring thaw, a large part of the accumulated snow cover will melt and find the lower levels as surface flow. Then, as the ground thaws, infiltration will occur. Evidence from water observation holes within the central part of the study area (see Chapter 4), seems to indicate that the ground becomes completely saturated during the spring thaw period. However, the rate of thaw and the quantity of precipitation during the thaw, may be important controls of the spring melt sequence.

A 40% reduction figure is assumed to allow for sublimation and other losses from the winter precipitation of the study area. The remainder of the winter precipitation is released into the hydrologic cycle during the one to two month spring melt period. This increment of water may be treated in the same way as normal summer precipitation for the purposes of the dewatering potential calculations. However, since the spring melt period reflects the period of heaviest water addition to the system, it should be considered separately in terms of evaluating the maximum capacity of the dewatering system.

Quite clearly, the collection of data on the quantitative aspects of the hydrologic cycle during the winter months, would in itself, be a major research project. Since such an undertaking is wholly impractical for the purpose of the present study, these aspects of the water cycle must necessarily be treated in a somewhat intuitive fashion, at risk of introducing significant errors. It is possible to compensate any such errors in the final analysis of the dewatering system, for they primarily affect only the spring melt period of the year.

3.3 Surface Water Flow

There are three measureable forms of surface water flow within the study area:

(1) steady stream flow, interconnecting the lakes or supplied by ground water recharge.

(2) intermittent stream flow draining land areas as pure surface run-off.

(3) pipeline flow delivered by pumps draining lakes and pit floor sumps.

In addition to these, is non-channel surface run-off into lakes or pits following heavy rainfall. The land drainage network comprising division (2) is quite well developed, carrying significant quantities of water during the spring flood and up until the end of June. After this time, however, it dries up and remains inoperative except in times of heavy rainfall.

Water flow measurements were made by a variety of means, all of which are described in standard hydrology texts (see for example, Chow, 1964). Pipe flows were calculated from gravity drop measurements at the discharge exits. Weir flows were calculated according to standard equations relating to both rectangular and V-notch crest shapes. The flow through culverts was calibrated in a rather elaborate fashion, by measuring the flow rate with a Gurley Flowmeter, and applying the value to the cross-sectional area of the channel. Each of these techniques is described more fully in Appendix 2, particularly where modifications were made to standard textbook procedures. Relevant figures, graphs, and tables of results are included in that section.

Much of the field season was spent in measuring the quantitative elements of the surface water flow network, and in constructing and calibrating the necessary equipment. Because of the time-consuming nature of siting, building and installing weirs, records were not available from some until late in the field season. Indeed two of the weirs (for Luce Lake input streams 1 and 5, respectively, see Figure A7), were never installed, but made in preparation for the following field season. Some of the weir flow records are not comprehensive therefore, but they are certainly representative.

The flow network between the drainage sub-basins is as follows:

(1) Sherwood Basin - no drainage outlet

(2) Noname Basin - no drainage outlet

(3) Humphrey Basin - pumping to Heath Basin

(4) Pointer Basin - pumping to Heath Basin

(5) Heath Basin - pumping to Luce Lake

(6) Smallwood Basin - pumping to Luce Lake

This flow network is shown schematically in Figure 3A and is quantified according to the results of the water flow measurements calculated in Appendix 2. For the Humphrey and Smallwood Basins, which contain operating open pits, the ground water is maintained by sump pump at a level a few feet below the pit floor. The quantity of water that is removed from these sub-basins is sufficient to support this balance, and approximately equals the excess input from rainfall and ground water sources. For the Heath and Pointer sub-basins, the discharge water is sufficient to equal the input, and to effect a partial dewatering of the respective lakes. For the remaining two basins, evaporation and infiltration and subsequent net loss of water to the ground water flow network, appears to balance the input from precipitation and other sources.

Unfortunately, with regard to making an accurate assessment of the water balance within the sub-basins, the fact that some of the water is pumped introduces many problems. Continual maintenance work on the installation is carried out (replacement of pipelines, pumps, electrical supply units, etc.). Occasional breakdown occurs and irregular shutdowns because of blasting or other mining operations, are quite frequent. Thus the pumps rarely run without interruption for any long period of time, and it is practically impossible to keep detailed records of when each part of the pumping system is or is not functioning.

Again, therefore, as with the topographic problem, the human interference factor introduces further problems and complications. As a result, in areas of mining activity, a greater dependence on estimation and intuition is required than would be necessary in a similar study in an area under purely natural controls. For whereas it is not possible to measure many of the effects of human interference, they may well be taken into account when making average estimates of the flow quantities.

The combined total surface outflow of the study area sub-basins, as described above, is directed into Luce Lake. In addition to this source of supply, the lake is fed by a "steady" stream from Hakim Lake, which is situated off the base map area, approximately 5000 feet in a southwesterly direction. Luce Lake is also fed by several intermittent streams which flow during the spring melt period. Luce Lake drains out through two culverts at its southern end and the resulting stream flows south to southeast. Along its course it is joined by other minor streams until it passes over a wooden weir approximately one mile downstream to discharge into Wabush Lake. Both the culverts (Appendix 2B) and the weir (Appendix 2C) were used to calculate the outflow from the lake.

The total surface flow input to Luce Lake in the August/-September period of the field season can be calculated from the information presented in Appendix 2, Table All. Figure A7 shows the locations of the streams and the Smallwood Mine pipeline.

The water in streams 1, 2 and 3 is mainly supplied by the Heath Basin pipeline, which terminates on the ridge above this part of the lakeshore. The cumulative flow over weirs 2 and 3 is about 1300 gal./min. The flow in stream 1 is nearly equal to that in stream 3 (personal estimate) giving a total for the three of approximately 2400 gal./min. This figure matches well with the calculated flow of 3100 gal./min. in the supply pipeline, allowing for some loss by infiltration. Streams 4 and 6 are minor streams with fairly steady base flow components of ground water origin. Their combined flow is about 300 gal./min. Stream 5 carries the flow from Hakim Lake and flows at about 2000 gal./min. (personal estimate). Finally the sump pump in Smallwood Mine delivers an average flow to the lake in the region of 1000 gal./min.

Thus, the total inflow from all measureable sources in late summer equals 5700 gal./min. ± 10%. A very significant comparison can be made with Figure A8 of Appendix 2, which shows a nearly similar outflow value for Luce Lake during the same period of the summer. It is quite clear therefore, that very little exchange takes place between the ground water and the lake water in the system.

The cross-over (see Figure A8) between the calculated flow rates from the weir and the culverts, which occurs on July 29 may not be significant. However if it is remembered that the culverts are upstream from the weir, then a simple interpretation can be put forward. Thus in the early summer, the ground between the measuring stations may be saturated and contributing water to the stream, whereas later in the summer, as the ground becomes drier, the stream assumes an influent condition. This interpretation is in full agreement with the discussion of the ground water conditions given in Chapter 4.

3.4 Atmospheric Return

In any water budget study, the evapo-transpiration is an extremely difficult component of the water cycle to quantify. Lysimeter experiments are time-consuming, and require specialized equipment. Moreover, relating the experimental results to the actual field conditions is not straight forward, since the evaporation rate depends upon many variables. While the present work does not have scope for including an extensive evapo-transpiration study, it is an important factor, since water returned to the atmosphere need not be handled by the dewatering system.

In view of these considerations, a rather empirical approach to the problem is adopted. A percentage of the total precipitation, representative of the atmospheric return for each of the three land surface types - vegetated, non-vegetated, and water covered - is estimated. Since any part of the study area can be considered in terms of these three land types, an appropriate composite reduction percentage can be calculated and used in the budget analysis. This represents the simplest, and probably the only, practicable way of treating the evapo-ration and transpiration factors with regard to the specific problems of the present study.

In section 3.2, an atmospheric return figure of about 40% was suggested as reasonable for the winter season. Assuming the winter to be of six months duration - mid-October to mid-April - it includes approximately 44% of the total annual precipitation. Thus 18% of the yearly input can be completely eliminated from the dewatering potential calculations. Of the remainder, 26% represents the spring melt component of the cycle. The final 56% must be treated as the normal summer component of the precipitation.

Nebiker (1957) carried out evaporation and transpiration studies in the town of Schefferville, which is located 90 miles north of the study area. The differences in climate between Schefferville and the study area are slight, especially in the summer months. In particular, the precipitation cycle is very similar, while the mean daily temperature is only marginally lower in the more northerly locality. It seems reasonable therefore, to use the results of Nebiker's work as most nearly representative of the study area conditions, in the absence of any in-situ research.

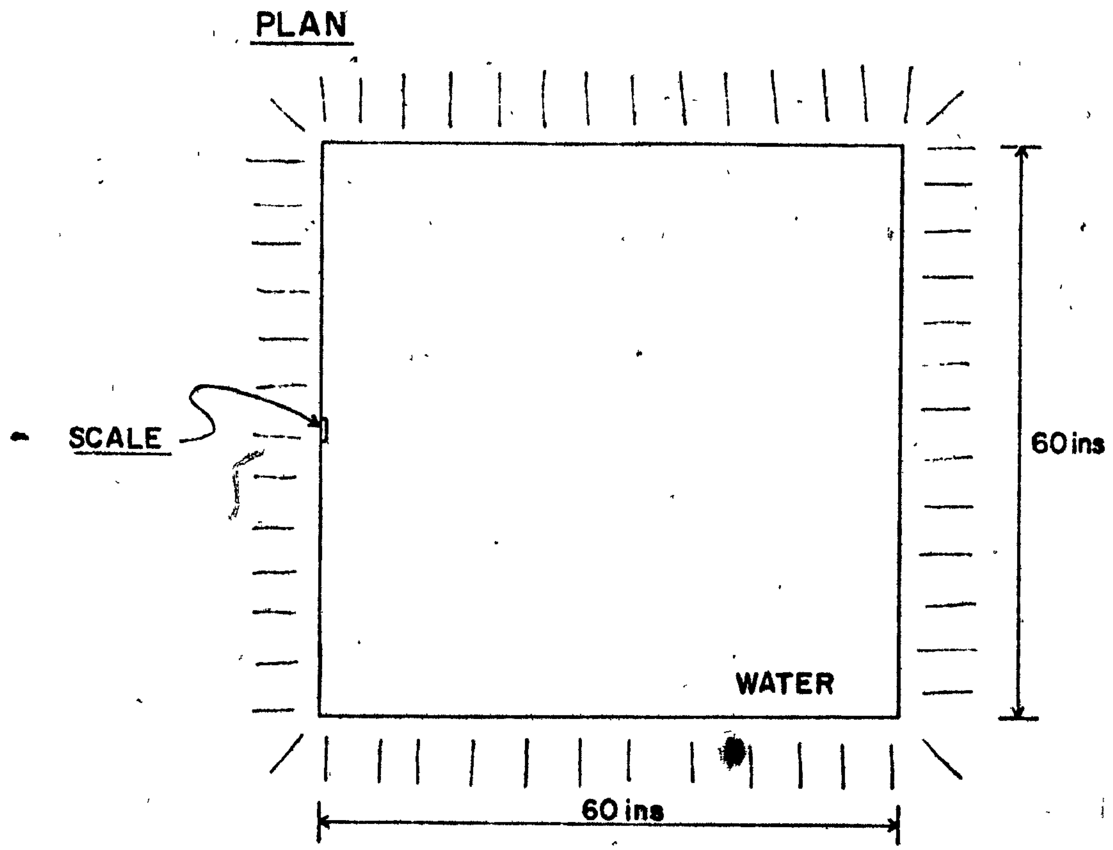
Nebiker set up several lichen-covered lysimeter tests and recorded an average 0.034 in./day water loss over the summer period. This result is very different from the Thornthwaite calculated transpiration value, quoted from Hare in Chapter 2. There are two clear reasons for this discrepancy. The 0.12 in./day value from the Thornthwaite calculation refers to a boreal forest vegetation (more like that in the study area) and not to a vascular-tissueless lichen cover. Indeed the latter appears to even reduce water losses compared to a standard bare soil test. Secondly, Nebiker reports lower than average sunshine-hours throughout the whole of his field season.

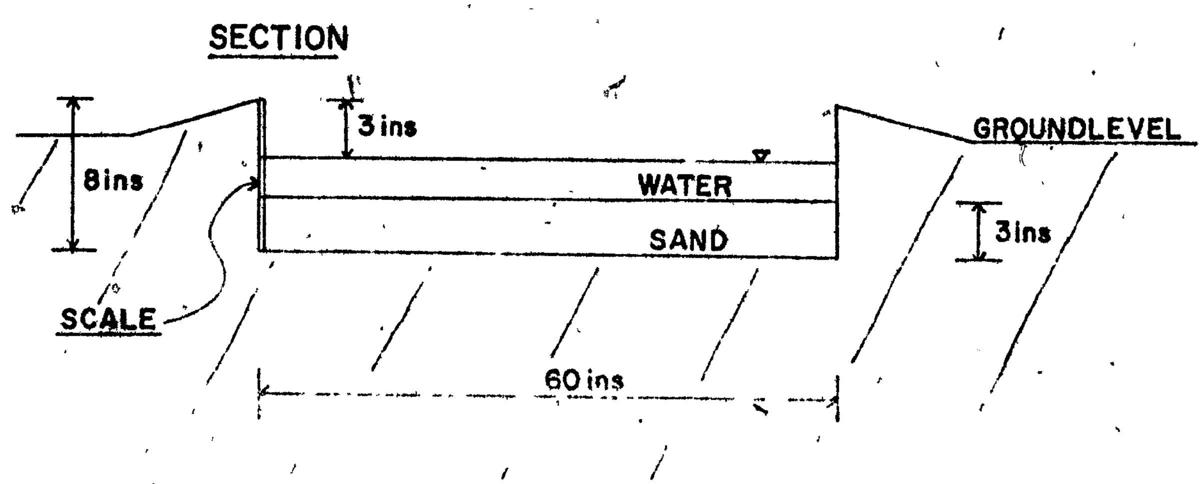
In addition to the lysimeter tests, Nebiker also made latent evaporation measurements using a Bellani black plate atmometer. His results from this apparatus, representing the maximum possible evaporation from a wet, horizontal plane, black surface, averaged about 0.08 in./day.

Within the study area, a 60-inch square, metal evaporation tank was constructed and installed near the rain gauge station by the side of Heath Lake. The tank, (see Figure 3H) was buried in sand to minimize heating of the walls, and had a 3-inch sand cover on its bottom.

FIGURE 3H

EVAPORATION TANK DESIGN





The tank was initially filled with water to within three inches of its top edge. The water level was then observed at regular intervals. The results of several tests are shown in Table A7 of Appendix 1.

Despite its rather simple nature, the evaporation tank gave very sensible results, which agree well with those from Nebiker's atometer test. A better control was maintained over external conditions during the course of the shorter tests than over the cumulative test. It is clear from the test results that a complete daily record of weather conditions would be needed in order to accurately predict the evaporation rate. However, since the cumulative test includes a wide variety of conditions, it is reasonable to assume that this represents a nearly average value. A 0.06 in./day evaporation rate over the 30-day period corresponds to an atmospheric return rate of 52% of the total precipitation. Combining the results of the tests therefore, with the fact that the rainfall during the cumulative period was somewhat higher than the normal monthly average, indicates that a conservative free-water surface evaporation rate would return approximately 50% of the precipitation to the atmosphere.

The evaporation rate from the land surface surrounding the lakes of the area must now be considered. Where plants with vascular tissue predominate, as is the case in the study area, the transpiration rate will be higher than the free-water surface, evaporation rate. Clearly, Nebiker's 0.034 in./day rate for lichen cover is not applicable under these conditions. However, the Thornthwaite calculated rate must represent a near-maximum possible value; for this rate requires a 100% recycling of the precipitation, which, since at least intermittent run-off is observed, would imply a removal of water from ground water storage.

Ground water table fluctuations, where measured (see Chapter 4) do show an overall decline over the summer period. Moreover, land surface drainage channels, without lake or ground water sources, are dry for much of the summer following the cessation of the spring flood. It would seem therefore, that while the predicted 0.12 in./day value is, from the total budget allowance, approximately at a maximum, it does seem to be reasonable. However in order to be consistent with previous conservative estimates, a transpiration value of 90% of the total precipitation will be assumed.

An estimate of the evaporation losses from the stripped parts of the study area is very difficult to make, owing to both the variety of the surface texture, and the absence of relevant information. Within the pits, the land surface consists of highly fractured, open-jointed rock. Around the margins is more massive, less permeable rock, with, in parts, remnant soil cover.

If the land were perpetually saturated, it would be logical to expect an evaporation value lying between those obtained for free-water and vegetated land surface. However this is not the case, for, at least during the latter half of the summer, the unvegetated land surface is often dry. As a crude estimate, the 50% value of the free-surface water condition will at worst be very conservative in relation to possible pumping requirements.

CHAPTER 4 - SUB-SURFACE HYDROLOGY

4.1 Hydrological Interpretation of the Rock Types

The rock types of the study area are well indurated, Pre-cambrian metasediments, and consequently have very low primary porosities. As a result, their hydrological characteristics depend entirely upon the development of secondary porosity. Thus, the permeabilities are controlled by the abundance of open joints and fractures throughout the area, and by the amount of leaching in the carbonate members of the Lower Wabush Formation. Fracture density is not the same everywhere, but is dependent upon several factors, especially the host rock type, and depth below surface.

It was possible to study the rocks of the area in surface exposures, and also in sub-surface sections along the many thousand feet of ore-train tunnels that interconnect the loading pockets for the mines. In addition, large quantities of drill core and core-log information were available for reference. The ore-train tunnels, which descend to several hundred feet below the surface, clearly show the impervious nature of the rocks at these depths. For, only where rare, narrow fracture zones (probably representing minor faults, and usually less than ten feet wide) are encountered, is any seepage observed.

Three of the rock types, Carol quartzite, Katsao schist, and Hornblende schist, show very few open fractures at all. Thus, from a practical viewpoint, they can be considered impermeable; an assumption which is supported by direct field evidence. For example, during the reconnaissance mapping of the area, when old drill holes were checked for water-table information, several holes were found in the Carol quartzite unit. However, all these holes were dry, even in one case to a depth of 500 feet below the land surface. Furthermore, Figure 4B shows how the Hornblende schist acts as a water flow barrier between Pointer Lake and Smallwood Mine.

In addition to the three impermeable units, the area is mainly underlain by rocks of the Upper and Lower Wabush Formation. Though the porosity of the latter may be augmented by leaching effects, water flow generally takes place through fissures. That these may not always be fully interconnected, was demonstrated by a pumping well installed in the Wabush Formation. The well site, located on the east side of Smallwood Mine, was drilled to 90 feet below surface by two ten-inch diameter holes situated 30 feet apart. The water level in each rose to within ten to 12 feet of the surface, and a 300 gal./min. pump was installed in one of the holes, at a depth of 50 feet. After several hours of pumping, the water level in the hole was lowered to the level of the pump; at which point the discharge became unsteady and was reduced by a factor of at least one half. However the water in the second hole remained at its original level, even after that in the pumping well had been kept lowered for many hours.

The distribution of fractures within the study area is significantly affected by the mining activities. Within the pits, blasting, and stress relief subsequent to the removal of material, tend to open the fracture planes and increase the permeability. It is also standard practice to drill the explosives holes to about ten feet below the planned floor level. This is done so that the bench floor can be established on a rock fragment base, to facilitate levelling and grading. Thus beneath each part of a pit floor is a sub-grade layer of repacked, fragmentary material, between ten and 15 feet thick. This is a very high permeability zone through which water flows freely. It ensures a steady supply for the pit floor sump, and encourages efficient drainage.

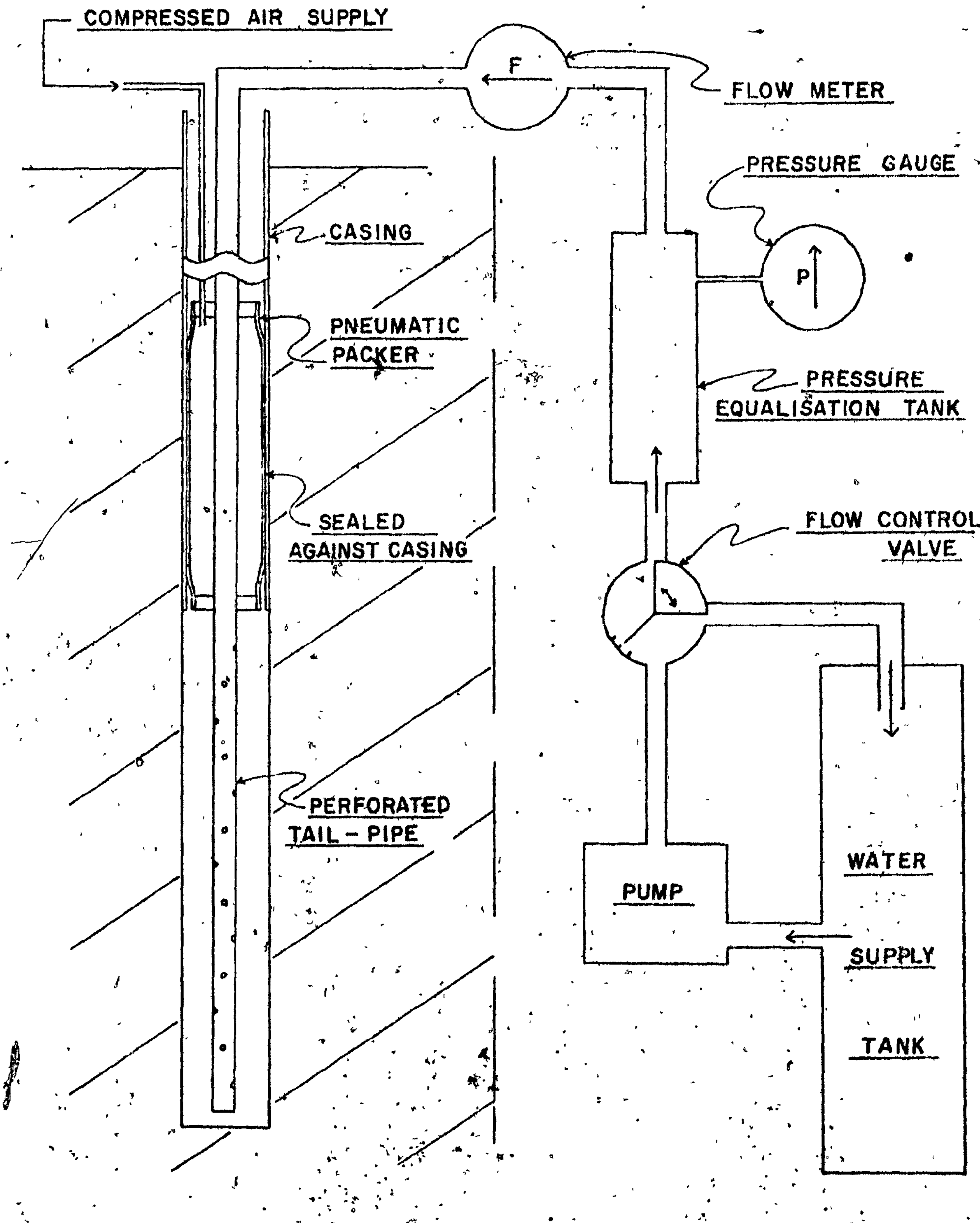
The heavily leached, carbonate material described in Chapter 2 must be considered in terms of an inter-granular flow network rather than a fissure flow system. While the area of outcrop is not very large, it is important, as was stated earlier, because it lies between Luce Lake and Smallwood Mine, and could possibly act as a flow channel between the two. The permeability of the unit was measured therefore, in order to determine how much water seepage should be expected in the future, when the pit floor is lowered to its ultimate projected depth.

It was possible to perform Packer tests on the leached material, because it is fairly isotropic and has an inter-granular flow network. The tests were made with a pneumatic, single packer system at varying depths down diamond drill holes. The basic set-up is shown in Figure 4A and the tests were carried out sequentially down each hole. This is by drilling, testing, drilling deeper, testing at the new level, drilling deeper, et cetera.

During the course of each test, water is pumped into the hole at various pressures, and the flow rate is measured at each pressure. The graph of the flow rate versus the pressure is a curve, which, adjusted for the dimensions of the packer, and the water table elevation, can be

FIGURE 4A

PACKER TEST SYSTEM



directly related to the permeability. In the case of the tests in the study area, very consistent values were obtained for the leached carbonate permeability, ranging between 0.22 and 0.58 gal./day/ft^2 (personal communication F. Khan). This is within the normal range of silt/fine sand permeability, and thus closely approximates the value which would be expected from the physical properties of the material.

Even with Luce Lake as the major recharge source, a permeability of this order of magnitude should not create any major dewatering problem. The eventual situation at Smallwood Mine can be equated to a 2000 feet long pit face adjacent to the leached carbonate material, extending to a depth of approximately 200 feet. Even assuming a potential gradient of unity, the resulting flow would only be of the order of 140,000 gal./day, or 100 gal./min. In order to obtain a true picture of the conditions, and to obtain a more accurate estimate of the flow, detailed plans of the ultimate pit shape are required, so that a complete flow-net analysis can be performed. Unfortunately, these plans are not available to the author at this time.

4.2 Spatial Distribution of the Rock Types

From the discussion in the previous section, it is seen that the rocks of the area can be assembled into three groups of approximately similar hydrological properties. Namely, the leached Lower Wabush with a relatively well-developed intergranular flow network, the Carol quartzite, Hornblende schist and Katsao schist group - practically impermeable, and the upper and Lower Wabush units which form a group with flow characteristics that are essentially dependent upon fracture development and frequency.

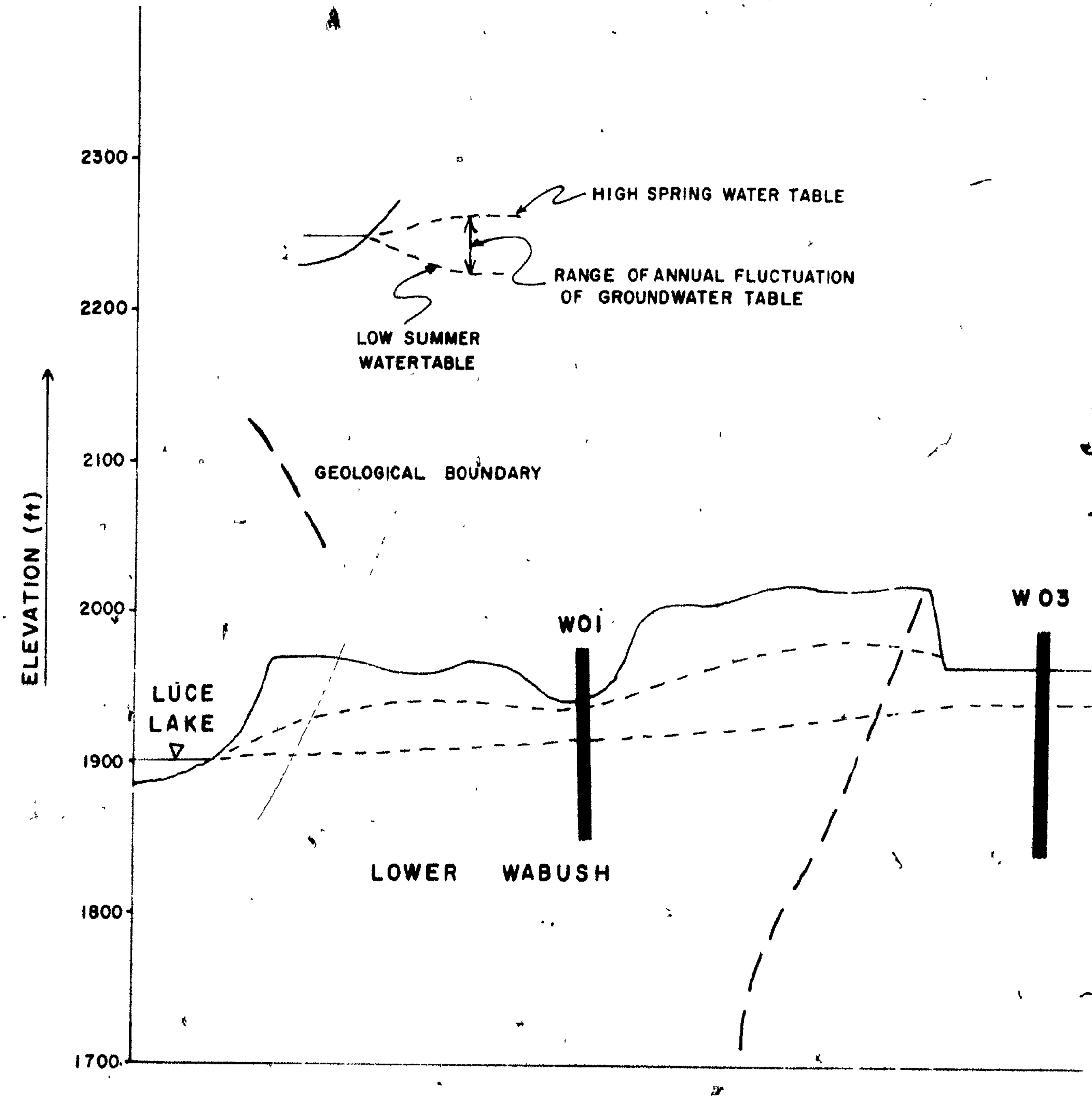
If this hydrological interpretation is considered with regard to the structural pattern of the area, an approach to handling the sub-surface water conditions (for dewatering purposes) becomes evident. The surface outcrop margins of the impermeable rock units define the edges to what may be termed <u>ground water sub-basins</u>. These sub-basins may be considered somewhat analagous to the surface drainage sub-basins, and, in places, their boundaries are co-linear (reflecting the geological control of the topography.

From a dewatering viewpoint, with regard to water entering a particular pit, the ground water sub-basins may also be bounded, in lateral extent, by elevation control.

Thus, if the ground water flow network is visualized in a part of the study area, it is clear that water can only flow down gradient into a pit. For any one ground water sub-basin therefore, parts of its lateral boundary will be geological contacts, and parts will be ground water divides. As the pit is deepened, the geological contacts will not be affected, but the elevation-controlled boundaries must be adjusted to the newly-defined flow network.

The extent of the ground water sub-basins, in the third dimension, may be controlled by two factors (except for the area of heavily leached Lower Wabush Formation, which must be considered a special case), firstly by the natural closing of the fractures (main flow network) with depth, and ultimately, by the sub-crop contact with the impermeable units.

A section, running between Heath Lake and Luce Lake is presented (Figure 4B) to show the real existence of the ground water sub-basin concept. The ground water table is interpolated from water observation holes, pit floor sumps, and lake levels. Information about the sub-surface geology is taken from numerous drill hole logs, and mine


HIGH SPRING WATER TABLE
RANGE OF ANNUAL FLUCTUATION OF GROUNDWATER TABLE
LOW SUMMER WATERTABLE
GEOLOGICAL BOUNDARY
ELEVATION (ft)
2300
2200
2100
2000
1900
1800
1700
LUCE LAKE
W01
W03
LOWER WABUSH

1oF

LUCE LAKE TO HEATH LAKE SECTION

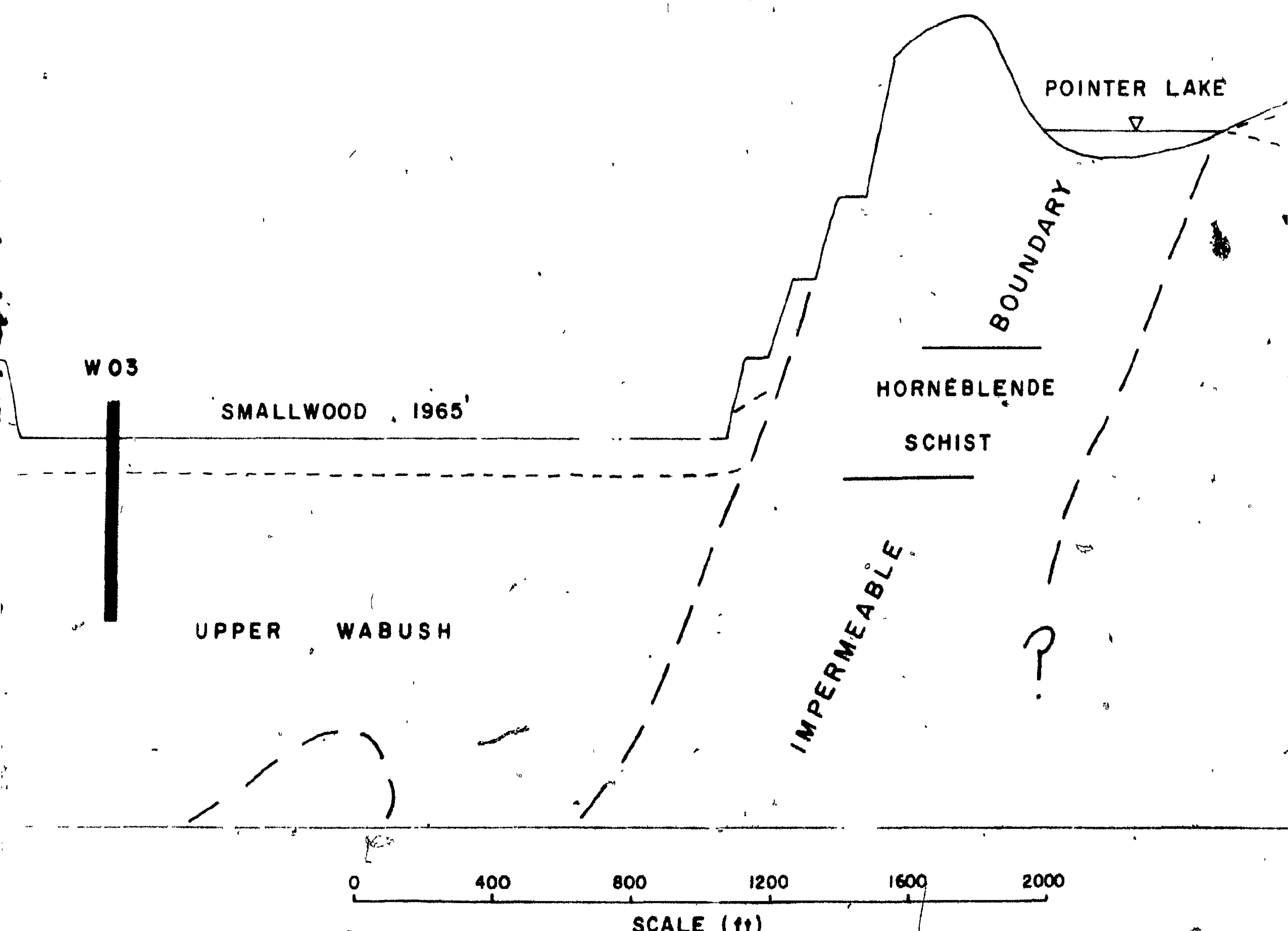
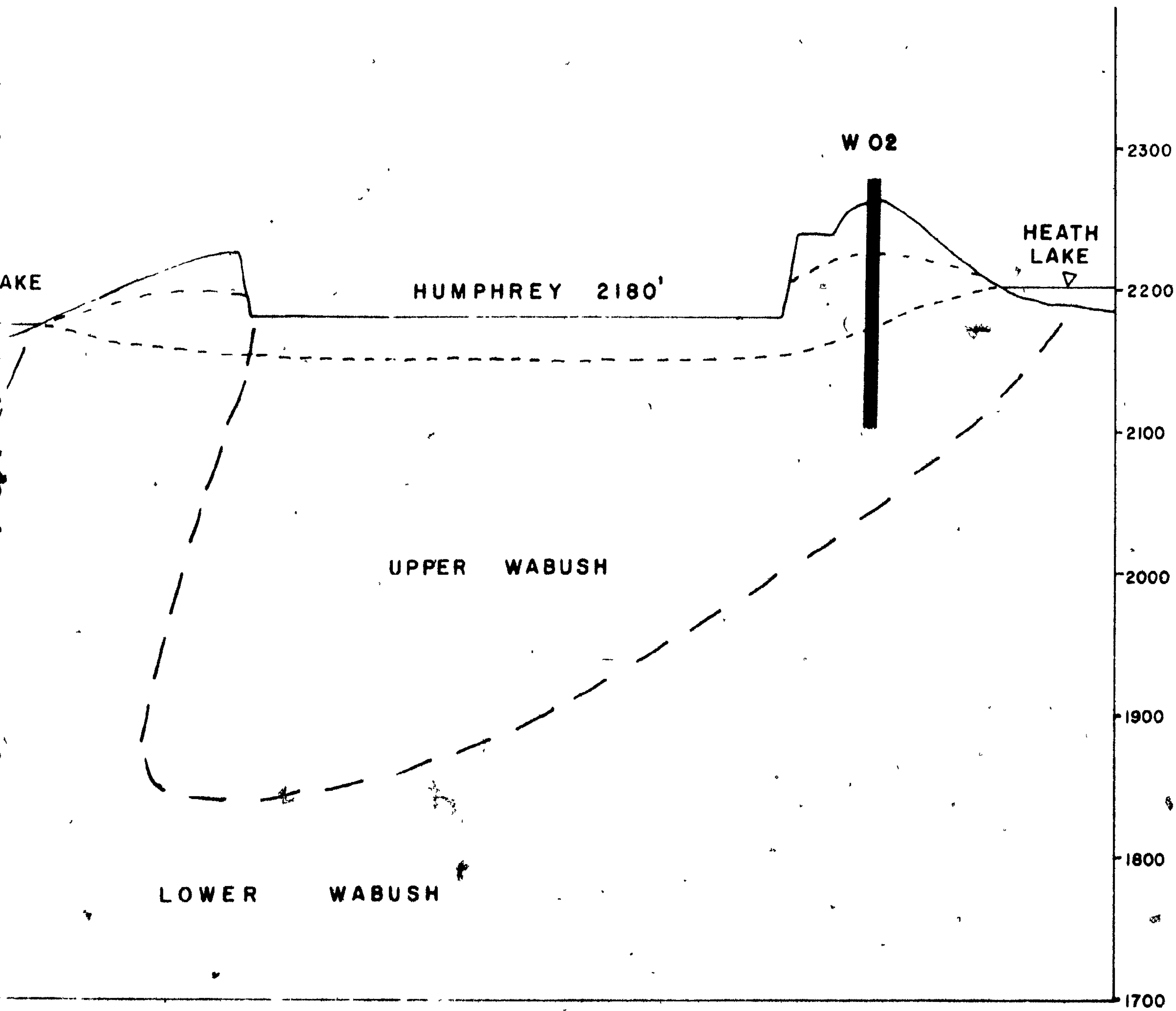


FIGURE 4B.



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engineers' sections. The section crosses an impermeable boundary in the form of the Hornblende schist unit, between two adjacent sub-basins and it shows quite clearly the discrete nature of the ground water systems on either side of the boundary.

The reality of the ground water sub-basin concept is also supported by many field observations. For example, the places where most seepage occurs along the pit wall faces of Smallwood Pit are found where the ground water sub-basin is of significant extent beyond the pit limit. Conversely very little seepage occurs along the face of the Hornblende schist unit, which corresponds to a sub-basin margin.

The limits of the ground water sub-basins, within the study area, are shown on Sheet 2. The sub-basins are, unlike the drainage sub-basins, not necessarily completely isolated. For example, the sub-basin surrounding Humphrey Mine may be connected to the Smallwood sub-basin in the area to the northwest of Pointer Lake. However this interconnection is only of a limited nature, and it is unlikely that any significant quantity of ground water flows between the two basins. The approach to calculating the dewatering potential of selected mine areas, is presented in the following chapter, but first a more complete picture of the sub-surface water regime is presented.

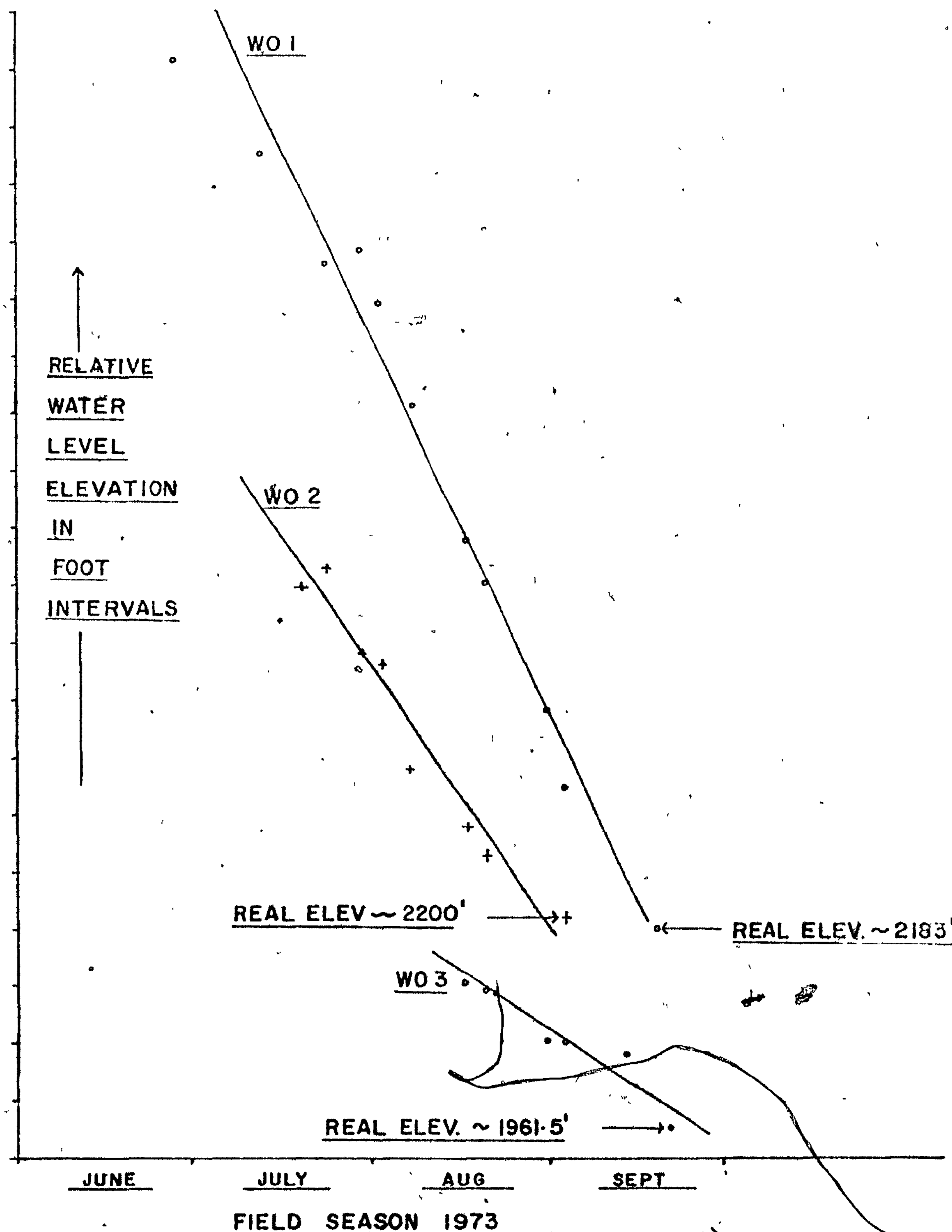
4.3 Temporal Effects

Several permanent water observation holes were set up in the central part of the study area during the course of the field season. The holes were cased with plastic piping (one inch or two-inch diameter), and provided with caps at the surface. In each hole, the bottom ten feet of the casing was perforated with quarter-inch diameter holes to permit easy transfer of water. Most of the holes were set up late in the summer, when drilling equipment became available at the close of the exploration program. However, water levels were monitored over much of the field season in the three earliest holes to be established. The sites of these holes are shown on Sheet 2, and the water level data is presented in Figure 4C. Information from three of the holes was included in Figure 4B.

The water level in each hole shows a quite distinct and fairly steady, decline over the summer months. The scatter about the trend lines on the graph is a reflection of day to day rainfall variation. The marked difference in gradient between the trend of W03 and that of W01 and W02 is caused by the difference in absolute elevation of the holes. The water level in hole W03 is approaching the surface level of Luce Lake, which is undoubtedly the ground water

FIGURE 4C

GROUNDWATER FLUCTUATION WITH TIME



base level within the sub-basin containing the observation hole. The rate of decline of the water table must naturally be reduced as it approaches this base level.

The steady decline of ground water levels observed during the summer months does not seem to continue throughout the whole year. If this were so, it would entail a continuous dewatering of the area, whereas in reality there has been no noticeable change in the ground water condition since the mining began. Moreover it was observed that the permeable ground was very near saturation in the early part of the summer. Clearly therefore, the water level decline over the summer period must be related to a seasonal cyclicity of the ground water condition.

In view of there being no markedly wet, or dry, season in the area, and since, in winter the ground water system is effectively sealed up, it follows that spring melt-water must provide the recharge necessary to balance the seasonal cycle. In absolute terms, the limits of the fluctuations in the ground water levels are easily defined.

In spring, the ground may become fully saturated up to the ground surface. At the other extreme, the lake levels within the area probably determine the lowest stand of the ground water, since, as possible recharge reservoirs, the lakes will act as buffers in the system. Of course, where the mines are excavated below the lake levels they will artificially lower the ground water table, and be susceptible to this recharging effect. In actual fact, the climatic conditions will determine how nearly the ground water fluctuations approach the absolute limits. The major factor is likely to be the mechanism of the spring thaw, since this closely controls the recharge of the system. A very rapid thaw favours heavy run-off and reduced infiltration, whereas the reverse is true if the thaw comes slowly. Of course, many other factors are involved, particularly the quantity of precipitation in the year, the amount of evapo-transpiration, and the depth and degree of the winter ground frost.

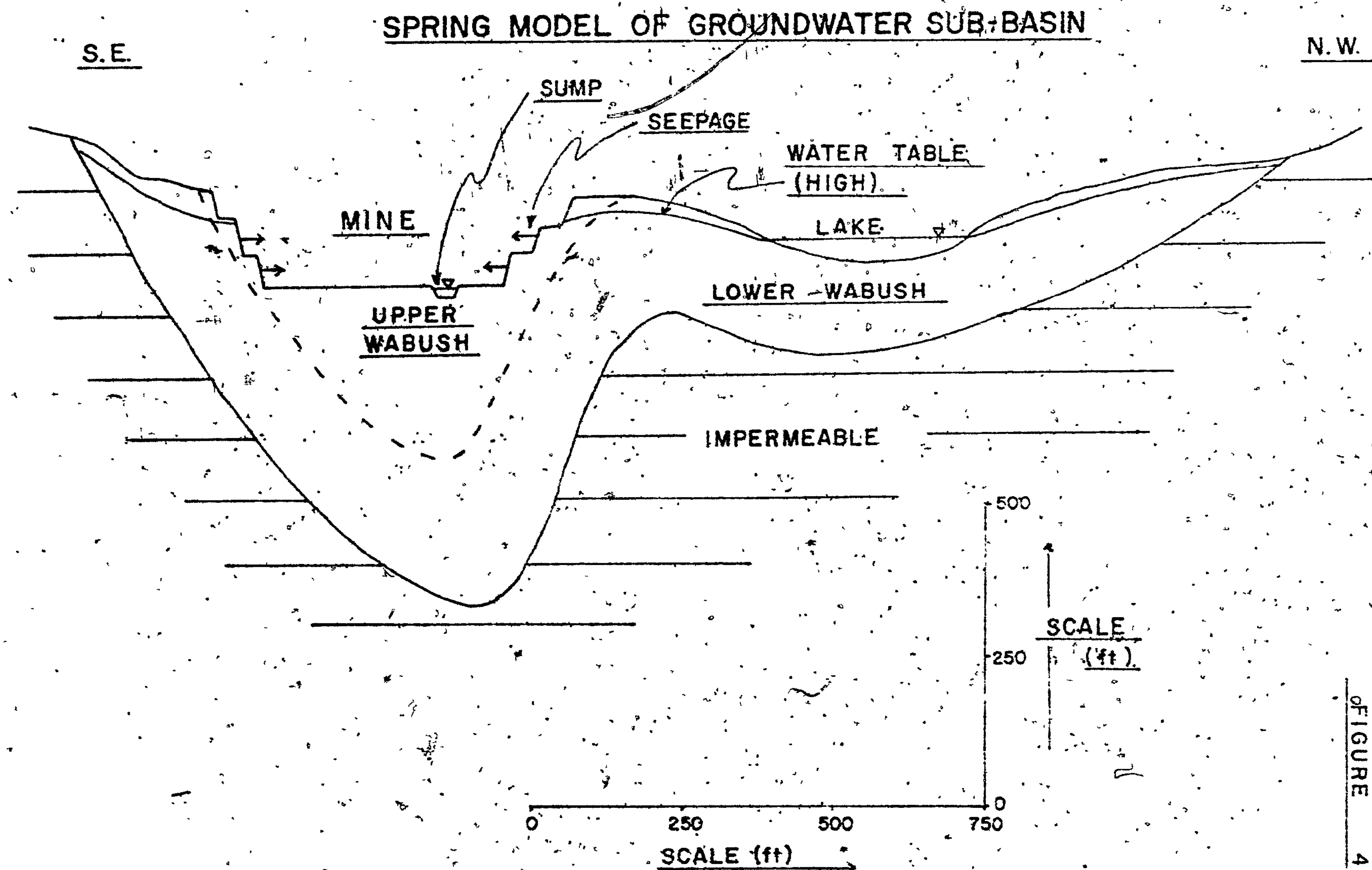
A complete description of the ground level fluctuations could only be obtained by continuously monitoring a large number of water observation holes, spread over the whole study area. The dewatering potential calculation can be made without this information however, because the approximate nature of the seasonal cycle is known, and the maximum possible recharge, in any one year, can be estimated.

4.4 Summary

The ground water system in the study area consists of a number of spatially restricted sub-basins. The water levels in these sub-basins rise and fall in response to a seasonal, climatic cycle. As far as can be ascertained from the reports of mining personnel, long-term recharge or discharge trends are absent, and the yearly water budget balances.

Figure 4D and 4E are intended to represent the system in a schematic way; for an idealised sub-basin, containing a lake and an open pit. The position of the water table is shown, at the spring high, and summer low, levels. The dimensions of the section, and the geological conditions, are based on the conditions found in the study area. The ground water/pit floor relationship is closely modeled on observations made in Smallwood Mine, and is strongly controlled by the action of the sump pump. The permeability of the rocks within the sub-basin should be envisaged in terms of the open fracture density; and thus be expected to decrease with depth.

In order to calculate the dewatering potential of a pit, it is necessary to know how much water it receives from



SPRING MODEL OF GROUNDWATER SUB-BASIN
S.E.
N.W.
SUMP
SEEPAGE
WATER TABLE
(HIGH)
MINE
LAKE
UPPER
WABUSH
LOWER WABUSH
IMPERMEABLE
500
250
0
SCALE
(ft)
0
250
500
750
SCALE (ft)

FIGURE 41

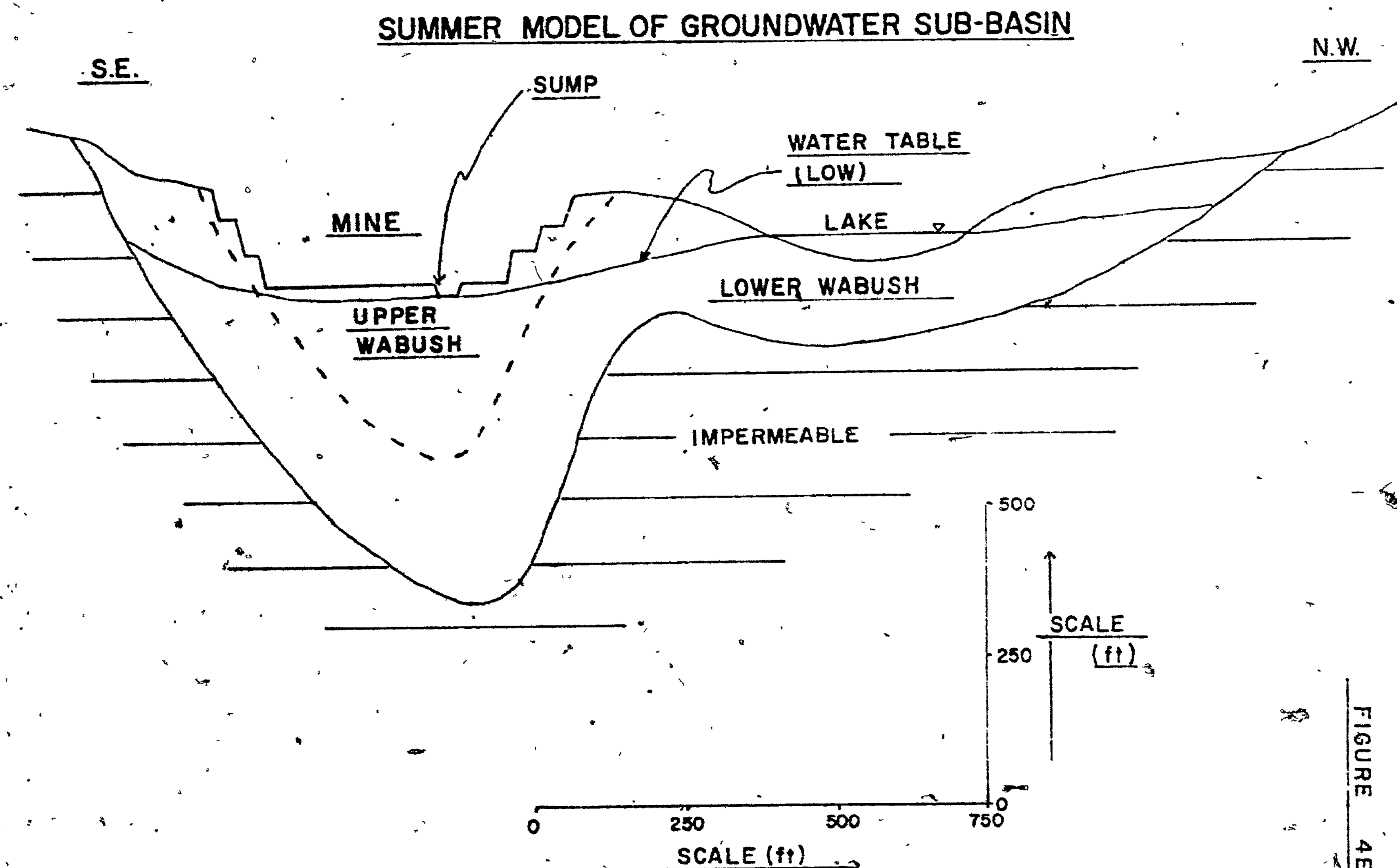

SUMMER MODEL OF GROUNDWATER SUB-BASIN
S.E.
N.W.
SUMP
WATER TABLE
(LOW)
MINE
LAKE
LOWER WABUSH
UPPER
WABUSH
IMPERMEABLE
500
250
0
SCALE
(ft)
0
250
500
750
SCALE (ft)

FIGURE 4E

ground water sources. This will be the quantity of water that drains into the pit from those parts of the surrounding sub-basin with higher piezometric head. In any one year, the amount of water removed from storage is very small, because of the relatively slow rate of pit-deepening. Therefore, the ground water entering the pit must be approximately equal to the annual flow-through.

The flow-through, each year can be equated with the normal annual recharge, since the ground water system is in near-equilibrium. It is reasonable, because of the seasonal climatic cycle to quantify the ground water recharge in terms of two distinct components: -

(1) The lesser of these is composed of that percentage of the summer precipitation which infiltrates the ground. This can be estimated, over the up-gradient area of the ground water sub-basin, using the figures derived in Chapter 3.

(2) The bulk of the ground water recharge is obtained during the spring thaw. The spring melt-water is dissipated in two ways, by infiltration, and by surface run-off. Unfortunately, it is almost impossible to say how the melt-water is propor-

tioned between these two routes. It may be noted however, that a significant percentage must take each of the routes, in order to account for both the observed run-off and the ground water level rise. Possible divisions are discussed in section 5.2 below.

CHAPTER 5 - QUALITATIVE AND QUANTITATIVE MINE DEWATERING ANALYSES

5.1 Introduction

The preceding chapters contain a summary of the available information relating to the hydrology and hydrogeology of the study area. An attempt has been made to explain the observed phenomena and to systematise the complex hydrological cycle by the introduction of such concepts as drainage and ground water, sub-basins. Where documented information was lacking concerning certain items in the hydrological cycle, with respect to the infiltration versus run-off factor, reasoned estimates were proposed. It now remains to show how the foregoing may be used to define the dewatering aspects of the mining operation, and how quantitative assessments of the dewatering potential can be derived.

Section 5.2 describes what qualitative deductions can be made based upon the information gathered, and how these could be applied to modify and improve dewatering practices. Several of the points are illustrated by reference to the dewatering operation at the Smallwood Mine. Section 5.3 outlines, in general terms, the approach and methodology for calculating the quantitative aspects of the dewatering operation. The approach is based upon a straight forward water budget application in the context of surface drainage and ground water, sub-basins. This line of development is taken to its natural conclusion in section 5.4 which presents a worked example of the dewatering potential calculations using the raw data from Smallwood Mine. It is shown, by repeating the calculations, how the final figures are affected by varying the factors which were required to be estimated in the development of the analysis procedure.

5.2 Qualitative Analysis of Mine Dewatering Potential

The qualitative aspects of the hydrological system in the mining area can be pictured more easily once the drainage and ground water sub-basins have been defined. Thus, once the surface water and ground water recharge catchment areas have been identified, they can be protected, as far as possible against ecological damage in the hope that the maximum possible return of water to the atmosphere will be effected by the natural fauna. Alternatively, restorative work or modifications to the natural system, such as drainage re-alignments, can be properly assessed.

Once the ground water sub-basin has been described, and the recharge areas surrounding a pit have been located, predictions can be made as to where likely sources of pit wall seepage will occur. For example, at the western extremity of the Smallwood Pit it can be seen (see Sheet 2) that a large area of the ground water sub-basin extends beyond the pit limit, and, in fact, seepage along the western pit face is quite noticeable in the field. It seems possible that, by combining this type of information with a modified dewatering potential calculation of the form presented in the following section, not only could suitable locations for peripheral dewatering wells be identified, but their probable capacities could also be predicted.

Considering the climatic data collected in the thesis, and particularly the importance of the seasonal cycle with respect to water availability, it would appear that an ideal dewatering plan could be designed. The aim in this would not solely be to match the potential water input, but also to take into account some of the operating problems set forward at the beginning of the thesis, such as seepage water icing in early winter, or maintenance difficulties associated with damage caused by fly-rock following blasting. The basic outline of such a plan would be as follows:

(1) high capacity sump pumps needed for approximately two months of the year to control spring melt-water run-off.

(2) small to medium capacity pumps set in shallow wells for protection, and located at the lower levels of the pit to carry away normal summer flows.

(3) small to medium capacity pumps set in medium

depth wells at the pit margin to intercept the recharge component from outlying regions of the ground water sub-basin.

The quantitative aspects (pumpage, total capacity, et cetera), of such a system can be estimated from analyses of the type presented in the following section. Moreover, the possibility exists, that, by modelling changes in the parameters defining the drainage and ground water sub-basins according to the future mine expansion plans, system designs could be obtained in advance for each stage of a pit's development from inception to completion. This would greatly facilitate budgeting and planning for equipment purchases, and would provide for a systematic growth of the dewatering system to keep pace with the development of the pit.

5.3 Quantitative Analyses of Mine Dewatering Potential

In order to assess the quantity of water to be removed from a pit in the mining area, it is necessary to combine the data and concepts described in the previous chapters into a water budget format. It should be recalled that some major assumptions were made with respect to certain aspects of the hydrological cycle, such as the winter precipitation reduction figure of 40% and the stripped land surface evaporation figure of 50% and that these estimates were intended to be conservative with respect to calculating the dewatering potential. The problem of partitioning the normal summer precipitation between infiltration and surface run-off was discussed in Chapter 3 and it was proposed that, in the absence of any guiding information, three different values, namely 25%, 50% and 75%, would be used in order to assess the effect of this parameter.

A further assumption is required in order to make a similar partitioning of the spring melt-water between surface run-of and infiltration to ground water recharge. It has already been noted that, when the winter snow accumulation thaws, it provides recharge enough to saturate much of the permeable ground in the area, and also to provide significant quantities of surface run-off. As the field work is continued, and records are obtained from the weir installations made during the field season, values for the surface run-off component of the spring melt will be available in order to define the partitioning more accurately. However, as it was noted in Chapter 3, the climatic conditions at the time of the thaw are likely to have a major influence upon the behavior of the melt-water. It should be allowed therefore, that a considerable degree of inaccuracy will always be involved with this portion of the hydrological cycle. In order to assess the effect of this factor, it will also be permitted to vary between 25% and 75% in the actual calculations presented in the following section.

Within the framework of these conditions, the quantitative analyses of the dewatering potential for a particular pit may be made according to the following plan. Two separate calculations are made, one to determine the normal summer dewatering requirements, and one for the peak spring dewatering capacity. The analysis is presented in a step-wise fashion with a commentary of explanations:

(A) <u>The average Summer dewatering potential</u>

Step (1) Identify the surface drainage sub-basin containing the pit and determine the ground surface conditions within the area in terms of the percentages of vegetated, stripped and lake-covered land, from the data presented in Figures 3B to 3G. Proportion the normal summer precipitation (56% of the yearly total) among the three areas and apply the approximate atmospheric return figure to each area, according to the discussion presented in section 3.4. Thus 90% of the precipitation is returned in vegetated areas, 50% in lake-covered areas and so on. The sum of these figures represents the total available atmospheric input to the surface drainage sub-basin over the summer months.

Step (2) Following the discussion concerning the distribution of this input between surface flow and ground infiltration, apply the appropriate percentage reductions in order to obtain the surface flow component. This figure represents the normal overland flow input to the pit over the summer months.

Step (3) Repeat the operations carried out in Step (1) for the area comprising the ground water sub-basin surrounding the pit, in order to obtain the total available atmospheric input to this area over the summer months.

Step (4) Determine what proportion of this quantity is proposed to be considered as actual recharge by applying the inverse of the actual reduction fraction employed in Step (2). The resulting quantity represents the quantity of ground water recharge which is obtained in the sub-basin over the summer months and which may be expected to move into the pit.

Step (5) Take the quantity of winter precipitation supposed to be remaining at the start of the spring thaw (60% of the actual winter precipitation) and apply this figure over the area of the ground water sub-basin. This represents the total available melt-water input to the area.

Step (6) Reduce this quantity by the appropriate surface run-off versus infiltration partition factor, according to the discussion presented at the beginning of this section, to obtain the proposed ground water recharge to the sub-basin area for the spring thaw period. This represents a further component of ground water storage which will be released into the pit over the summer period.

Step (7) Sum the figures obtained in each of sections 2, 4 and 6 to obtain a value for the total quantity of water to be removed from the pit over the summer months.

Step (8) Average this value over an eight-month period to obtain the dewatering requirements between June, when the spring thaw is complete, and October, which is the onset of the winter. This value can be represented in terms of gallons per minute by the use of appropriate scaling factors. The value can then be directly related to pump capacity requirements to match the dewatering system design.

(B) <u>The peak Spring dewatering potential</u>

Step (9) Take the reduced winter precipitation quantity, as in Step (5), and apply it over the area of the surface drainage sub-basin. Apply the inverse fraction of the run-off versus infiltration partition factor to obtain the quantity of overland flow derived from the spring thaw over the surface drainage sub-basin.

Step (10) Average this value over a two-month period to obtain the spring melt-water input to the pit during the months of April and May. This quantity should also be expressed in gallons per minute.

Step (11) The peak spring dewatering potential value is obtained by combining the normal summer month flow (from Step (8)) with the additional spring overland flow component; this figure represents the maximum required capacity of the dewatering system.

5.4 Quantitative Analysis of Mine Dewatering for Smallwood Pit

The analysis procedure outlined in the previous section was performed using the available data for the Smallwood Pit. In order to assess the effects of changing the surface run-off versus infiltration factor and the spring thaw run-off versus infiltration partition factor, six different applications of the analysis were made. Firstly the spring partition factor was held constant at a 50% value and the calculations were made using summer run-off versus infiltration factors of 25%/75%, 50%/50%, and 75%/25%. The roles were then reversed, and the calculations were repeated for the same range of values for the spring partition factor while holding summer run-off versus infiltration factor constant at 50%.

A summary of the pertinent raw data, and the actual calculations are presented in Appendix 3 of the thesis. The results of the calculations are presented on the following table for comparison. It is quite clear from the results obtained that: -

(1) changing the value of the summer run-off versus infiltration factor has a very limited effect

TABLE 5A

RESULTS OF DEWATERING ANALYSIS

CALCULATIONS FOR SMALLWOOD PIT

	Spring Run-Off/Infiltration Partition Factor			
Summer Run-Off Versus Infiltration Factor	$\frac{25}{75}$	$\frac{50}{50}$	$\frac{75}{25}$	$\frac{\text{Inf.}}{\text{Rnf.}}$
$\frac{25}{75}$		$\frac{654}{1366}$		$\frac{\text{Ave. Summer Flow*}}{\text{Peak Spring Flow}}$
$\frac{50}{50}$	$\frac{524}{1589}$	$\frac{689}{1399}$	$\frac{855}{1210}$	$\frac{\text{Ave. Summer Flow}}{\text{Peak Spring Flow}}$
$\frac{75}{25}$		$\frac{738}{1448}$		$\frac{\text{Ave. Summer Flow}}{\text{Peak Spring Flow}}$
$\frac{\text{Inf.}}{\text{Rnf.}}$				

* All flows expressed in U.S. gallons per minute.

upon the calculations. The total range of the flow rates, for both the normal summer dewatering potential and the peak spring potential, is within ± 10% of the mean value despite the fact that the run-off/infiltration factor was varied by ± 50% of its mean value. This result reflects the fact that the actual available precipitation input during the summer months is itself of secondary importance in the overall water budget picture.

(2) changing the value of the spring run-off versus infiltration partition factor has a marked effect upon both the average summer dewatering potential and the peak spring dewatering potential figures. The effect does not seriously change the total water quantity to be removed in the year, but it severely changes the timing of the removal. Thus when a large part of the water runs off, high spring peak values are recorded, with corresponding lower average summer values. The reverse is true when the larger proportion of the water infiltrates the ground.

In order to be able to apply these figures in a real assessment of the dewatering system for the pit, it should be recalled that a sizable variation in the spring partition factor is likely as a result of differing climatic effects from year to year, namely with respect to the conditions experienced during the spring thaw. Thus in order to be realistic, the maximum values for both the summer dewatering potential (855 U.S. gal./-min.) and the spring dewatering potential (1589 U.S. gal./min.) should be used. Both these figures might be further increased (up to 10%) by the effect of changing the summer run-off versus infiltration factor. Furthermore, both the figures are averaged pumping values and do not take into account sudden water input to the system which may occur as a result of greatly increased overland flow following, for example, a torrential rainfall. It would appear therefore, that the dewatering potential figures for the Smallwood Pit should be:

(1) for the average summer dewatering potential,
855 + 20% = 1026 U.S. gal./min.

(2) for the peak spring dewatering potential,
1589 + 20% = 1907 U.S. gal./min.

For comparison of these figures to the actual dewatering conditions recorded in the 1973 field season, the following observations may be recalled:

(1) the primary dewatering installation in the pit was a single high capacity (1800 U.S. gal./min.) sump pump, which functioned in a periodic fashion during the summer with a resulting average estimated output of approximately 1000 U.S. gal./min.

(2) in the spring period, this pump was operated more or less continuously and was augmented during several two-to-three day periods by a smaller pump rated at 350 U.S. gal./min. Thus the peak pumping rate, in a one-month period, was probably of the order of 2150 U.S. gal./min., and approximately 1800 U.S. gal./min. in the second month.

CHAPTER 6 - CONCLUSIONS

Several aspects of the hydrogeological cycle in the study area were investigated during the summer field season. Stream flows were measured or estimated where time did not allow for measuring facilities to be installed. The existing dewatering system was also monitored and measurements were taken where possible in order to determine the quantities of water moving through the system. The evaporation rate from a standing water body, and the precipitation in the study area were also measured during the field season. Certain problems were encountered during the field work, which were specifically related to the mining activities and these complicated the study beyond what would be expected in an environment unaffected by man's activities. These problems, and their affects upon the study, are described ~~in the thesis~~.

The data collected in the field season were combined with those available in the literature from nearby locations, and a picture of the seasonal hydrological cycle was derived. The effects of the seasonal cycle upon the mining activities were thus able to be defined. This information was then used in the latter part of the thesis in order to describe a modified dewatering system for the mines in the area which would be better adapted to the climatic environment.

The surface drainage network of the study area was entirely re-mapped during the field season, thereby taking into account the effects of ten years of mining activity, which had considerably modified the area's physiography. During the course of the work, six drainage sub-basins were identified, being areas without surface water outlets which were isolated from the natural stream network by the mining activities. The distribution of vegetation in these areas was also mapped in order that they could be incorporated with information obtained on the hydrogeological cycle into a system of calculations aimed at determining the dewatering potential of the area.

The geological units of the study area were observed and separated into hydrogeological types so that a model of the ground water system of the area could be defined. Water level measurements, pump tests, and packer tests were made in parts of the area in order that quantitative data could be obtained, and that a true picture of the temporal and spatial fluctuations in the ground water body could be derived. These data were combined with those obtained for the climatic and surface water flow conditions in order that a complete definition of the hydrogeological cycle in the study area could be made.

It was possible, because of the inter-relations between the hydrogeological units and the structure of alternating synclines and anticlines in the area, to define a number of hydrogeological sub-basins within each of which exists a relatively independent body of ground water. This concept was utilized at the end of the thesis along with that of surface drainage sub-basins in order to carry out a water budget analysis of the dewatering potential at one of the pits in the mining area.

Several conclusions of interest were obtained in different areas during the course of the study; the most significant of these are collected below:

(1) The evaporation rate during the summer months from a standing surface water body was found to be approximately equal to 50% of the average precipitation in the same time period. It was also observed that the calculated Thornthwaite evapo-transpiration rate for the area, which gives a value of almost 100% recycling of the precipitation, appears to be approximately correct.

(2) It was found, as expected, that the hydrogeological cycle in the area is very strongly dependent upon the seasonal climatic changes. The cycle is made up of three basic components, namely:

(a) the spring thaw - when large quantities of water are released into the surface flow network and into the ground water reservoirs.

(b) the summer period - during which the area experiences a gradual drying and surface stream and ground water flows decrease.

(c) the winter period - during which little water movement takes place, but large accumulations of snow and ice occur.

(3) The ground water bodies in the area, which are mainly found in fractured or leached carbonate rocks, undergo a steady, natural dewatering during the summer period. In the winter period the ground is sealed by the frost layer throughout much of the area and little ground water

recharge or discharge takes place. In the spring thaw however, the ground is heavily recharged by the melt-water and it appears that the ground becomes almost fully saturated during this time.

(4) Since, as a result of the hydrogeological interpretation and mapping, it was possible to define the extent of the ground water sub-basins in the area, it was possible to relate these to the open pits. In this way it was possible to predict areas from which significant quantities of ground water seepage could be expected. This information may be used to determine the locations for peripheral dewatering well installations and also to select areas to be protected against ecological damage.

(5) A water budget analysis of the dewatering requirements of the Smallwood Pit was made using the concepts of the surface drainage and ground water basins, the climatic data obtained for the area, and some basic assumptions about the hydrogeological cycle in the area. The analysis showed that during the spring thaw, for a period of approximately two months, an average water flow of the order of

1900 gal./min. could be expected. In the summer period, of approximately five months, a much lower quantity of water would need to be pumped from the pit and this should be of the order of 1000 gal./min. It was found that these figures are in close agreement with the real values estimated for the existing dewatering system in the pit.

(6) It was deduced, based upon the nature of the seasonal cycle and the quantitative requirements of the dewatering, that an ideal dewatering system for a pit in the area should consist of:

(a) a large capacity sump installation to handle the spring melt-water which would be operational for approximately two months of the year.

(b) shallow pit floor wells which would provide protection for the pumps during blasting and which would comprise the normal summer dewatering system.

(c) medium depth peripheral wells intercepting ground water from source areas outside the pit margins. The locations of these could be identified from the ground water sub-basin mapping, and they would serve to reduce the icing problems associated with pit wall seepage during the early winter months.

The quantitative aspects of the system could be defined from the water budget analysis of the dewatering potential. Moreover, the system could be planned in advance of the mining operation by constructing a dewatering potential model based upon the mine development schedule.

(7) Assumptions were made concerning the infiltration versus surface run-off partitioning of water input to the area in order to make the dewatering potential analysis. The effects of these assumptions were checked by repeating the analyses using different factors, and two main observations were made:

(a) the calculated dewatering requirements of a pit in the area are affected very little whether the available summer water input is considered to flow as surface run-off or in a ground water flow system.

(b) a major change in the analysis is observed if the spring melt-water is considered to flow as mainly surface water or as sub-surface water. It may also be noted that this effect is largely unpredictable, since the particular rate and mechanism of the thaw might lead to much greater surface run-off in one year and much greater ground water infiltration in another.

The studies carried out in the area were of a limited nature and are incomplete in several aspects. Additional work is required in order that a better understanding of the hydrogeological environment may be obtained, and so that the dewatering potential analysis may be further refined. In particular, it is felt that additional information would be most useful in the following areas:

(1) Field observations during the winter months are required to determine more accurately the snowfall accumulation pattern over the study area and to

provide information about ground water flow at this time of the year.

(2) Additional stream flow measurements are required particularly through the spring period in order to permit a more accurate quantitative assessment of the overland flow component of the melt-water input to the area.

(3) Test wells should be constructed at the peripheral dewatering sites in order to verify and more accurately quantify the predictions made from the ground water sub-basin analysis.

Despite the shortcomings identified in the work done to date and the clear necessity for additional study in some areas, it is felt that considerable progress has been made towards obtaining an understanding of the hydrological cycle in the study area, and in applying the knowledge so that the dewatering requirements can be identified and assessed. To date this has been achieved for a relatively slight cost which may be almost wholly expressed in terms of approximately two man-years labour. While it is difficult to assess the economic value of the studies, it would appear that the complete study would be justified if only two or three days of pit production per year were saved as a result of applying the findings of the study.

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APPENDIX 1

The following tables summarize climatological data relevant to the thesis. The tables referred to Wabush Airport, contain data abstracted from the publications of the Atmospheric Environment Commission. Those referring to Heath Lake contain data collected by the author within the study area.

TABLE A1

TOTAL MONTHLY PRECIPITATION 1961-1972*
(inches of water)

WABUSH AIRPORT

	61	62	63	65	66	67	68	69	71	72	AVERAGE
Jan	1.42	3.80	3.56	3.27	2.02	3.25	1.44	3.12	1.67	2.74	2.63
Feb	0.63	0.47	2.96	2.50	1.08	1.84	3.24	2.39	1.73	2.26	1.91
Mar	1.35	1.38	1.61	0.89	1.94	0.59	2.74	2.59	1.95	3.73	1.88
Apr	0.34	0.55	1.40	1.54	1.16	1.84	2.56	1.30	3.11	1.67	1.55
May	2.44	1.74	1.11	0.91	3.03	2.85	1.41	1.98	3.34	1.19	2.00
Jun	3.74	3.09	2.68	3.85	2.40	2.38	1.73	4.67	3.37	2.16	3.01
Jul	2.58	3.23	5.29	5.09	6.22	3.87	4.00	3.87	3.58	3.52	4.13
Aug	3.00	3.11	2.53	5.67	3.65	2.52	4.96	4.62	4.96	3.13	3.82
Sept	3.13	3.15	3.70	3.31	3.20	6.02	3.81	6.38	5.38	6.12	4.22
Oct	3.31	1.83	3.13	2.86	5.30	3.45	4.59	3.50	3.43	3.23	3.46
Nov	3.55	1.78	2.21	3.44	3.98	4.32	1.86	3.42	5.70	2.01	3.23
Dec	3.75	2.61	2.30	1.87	3.85	2.40	4.53	5.44	2.81	1.91	3.15
Total Yearly	29.24	26.74	32.48	35.20	37.83	33.33	36.87	43.30	41.03	33.67	35.0

*Excluding 1964 plus 1970 - data incomplete

TABLE A2

MEAN DAILY TEMPERATURE 1961-1972*

(degrees Fahrenheit)

WABUSH AIRPORT

	61	62	63	64	65	66	67	68	69	71	72	Av.
Jan	-13.2	-14.0	-7.5	-7.6	-11.4	4.8	-11.2	-11.4	4.3	-5.8	-11.6	-7.7
Feb.	- 7.0	-15.6	-11.3	-1.0	- 5.7	2.9	-11.5	- 0.3	3.3	-5.6	-12.7	-5.9
Mar	7.2	16.3	1.2	-0.2	8.4	17.4	0.1	4.4	11.9	10.9	- 1.3	6.9
Apr	30.0	16.8	25.3	22.8	21.1	26.4	17.4	26.8	11.4	27.1	21.0	22.4
May	36.1	34.8	34.6	36.5	35.1	33.9	36.0	37.7	34.4	38.9	31.4	35.4
Jun	46.5	48.0	47.7	47.2	47.5	48.6	51.6	49.1	47.7	47.6	48.4	48.2
Aug.	54.0	53.4	51.3	51.2	49.2	52.7	55.3	47.2	53.8	51.5	52.0	52.0
Sep	47.2	43.9	40.0	43.0	41.8	43.4	45.0	51.5	39.2	44.7	41.7	43.8
Oct	32.8	33.4	33.9	27.3	26.3	31.2	33.4	37.4	26.7	34.4	25.1	31.1
Nov	23.2	16.5	22.8	15.8	11.5	22.1	20.2	15.8	25.3	13.7	11.5	18.0
Dec.	11.1	0.6	-6.6	-3.1	-3.1	1.1	4.6	5.7	5.9	-10.8	-15.2	-0.9

*Excluding 1970 - data incomplete

TABLE A3

TOTAL MONTHLY PRECIPITATION 1973 AND MEAN MONTHLY TEMPERATURE DURING FIELD SEASON

WABUSH AIRPORT

	PRECIPITATION (inches of water)	TEMPERATURE (degrees Fahrenheit)
January	2.57	-
February	1.62	
March	2.45	
April	3.95	
May	2.09	40.9
June	3.91	53.2
July	4.20	60.2
August	1.62	57.5
September	2.01	43.4
October	4.30	
November	2.33	
December	4.92	
	35.97	

TABLE A4

DAILY PRECIPITATION FIELD SEASON 1973

(inches of water)

WABUSH AIRPORT

	May	June	July	August	September
1	-	.28	.10	-	-
2	.20	.19	.15	-	.45
3	.43	-	-	-	-
4	-	-	.04	-	-
5	-	-	.13	-	.01
6	-	.02	-	-	.14
7	-	.66	-	-	.20
8	-	-	-	.03	.03
9	-	.54	.17	-	.04
10	-	.02	-	-	.09
11	.05	-	.96	.11	.19
12	.29	.14	.26	.13	.11
13	.01	-	.74	-	-
14	.01	-	.38	-	.06
15	-	-	.01	.04	.05
16	-	-	.07	.04	.04
17	-	-	-	-	-
18	-	-	-	-	.02
19	.08	-	.09	-	-
20	.03	-	.01	-	.05
21	.22	.02	.29	.19	.02
22	.46	-	.03	.23	.03
23	.02	.01	.06	.05	-
24	-	-	.10	.03	-
25	-	.09	-	.14	-
26	.01	.29	.04	-	-
27	.09	1.09	.19	.23	.41
28	.15	.56	.38	.23	.06
29	-	-	-	.06	-
30	-	-	-	.11	.01
31	.04				
	2.09	3.91	4.20	1.62	2.01

TABLE A5

DAILY PRECIPITATION - FIELD SEASON 1973

(inches of water)

HEATH LAKE

	July	August	September
1	-	-	-
2	-	-	.31
3	-	-	-
4	-	-	-
5	-	-	-
6	-	-	-
7	-	.02	-
8	-	.06	-
9	-	-	-
10	-	-	-
11	-	.07	.26
12	-	.55	-
13	-	-	-
14	-	-	-
15	-	-	1.31
16	-	.04	.40
17	-	-	-
18	-	-	-
19	-	-	.06
20	-	-	-
21	-	-	-
22	-	.17	-
23	-	.15	.16
24	-	.21	End
25	-	-	-
26	Start*	.23	-
27	Start*	.24	-
28	Start*	.21	-
29	1.03	-	-
30	-	.06	-
31	-	.03	-
		2.04	

TABLE A6

SNOWFALL/RAINFALL COMPONENTS OF PRECIPITATION

(inches of water and inch equivalents)

1961-1972*

WABUSH AIRPORT

	Total Prec.	Total Rainfall	Total Snowfall	Snow % of total
61	29.24	15.52	13.72	47
62	26.74	13.65	13.09	49
63	32.48	15.50	16.98	52
65	35.20	19.11	16.09	46
66	37.83	20.24	17.59	47
67	33.33	17.44	15.89	48
68	36.87	17.43	19.44	53
69	43.30	23.90	19.40	45
71	41.03	21.68	19.35	47
72	33.67	16.93	16.74	50

Average 48.5%

* Excluding 1964 plus 1970 - data incomplete

TABLE A7

EVAPORATION TANK TEST RESULTS

(inches of water)

Test Period	Average Weather	Initial Level	Final Level	Total Prec.	Total Evap.	Evap. per day
Aug. 9 to Aug. 17	Dull	3.00	3.04	0.66	0.62	0.08
Aug. 17 to Aug. 20	Sunny and Breezy	3.04	2.59	0.00	0.45	0.15
Aug. 20 to Aug. 22	Dull	2.59	2.63	0.18	0.14	0.07
Aug. 22 to Aug. 29	Mixed	2.63	2.88	1.04	0.79	0.11
Cumulative Test						
Aug. 17 to Sept. 17	Mixed	3.04	4.75	3.56	1.85	0.06

APPENDIX 2

This section contains all the water flow data from tests made in the study area. Brief outlines of the test procedures are also included. Flow rates refer to U.S. gallons per minute throughout.

2.A Pipe Flow Measurements

Pipe flow rates were calculated by first deriving the velocity of water flow, from the shape of the gravity fall curve, at the pipe exit. The method used is reliable wherever the pipe is within a few degrees of horizontal, at its discharge end. In each case measured, the calculated value was found to match well with the theoretical capacity of the supply pump.

The equation of the flow velocity of the water in the pipe, and that governing its downward acceleration as it leaves the pipe, may be combined, and simplified to the expression: -

$$V = \frac{4x}{Y}$$

where,

V = velocity of flow

y = l - f

x, l, f = see Figure A1

The quantity of flow through the pipe is then calculated as the product of the flow velocity and the cross-sectional area of the flow. The latter value is taken directly from

FIGURE A1

PIPE DISCHARGE MEASUREMENTS
FOR GRAVITY FALL FLOW CALCULATIONS

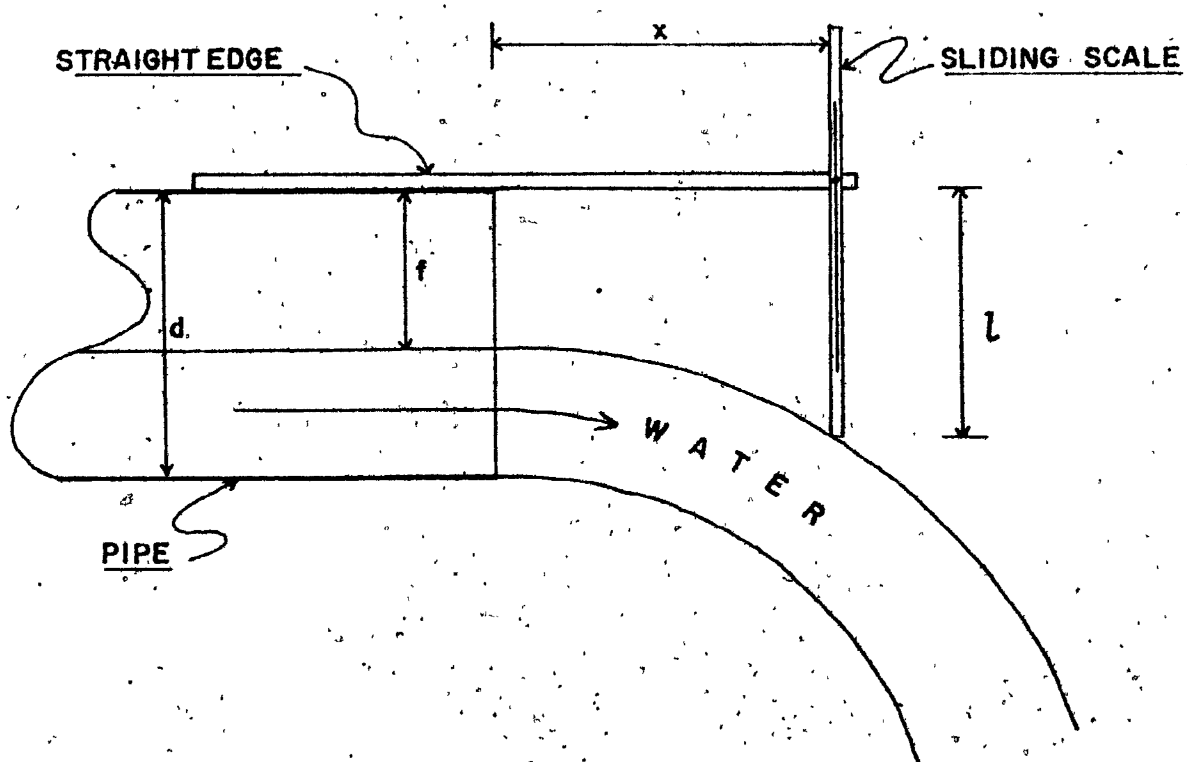


FIGURE A2

RELATIONSHIP BETWEEN AREA OF FLOW (A) AND WATER DEPTH IN PIPES

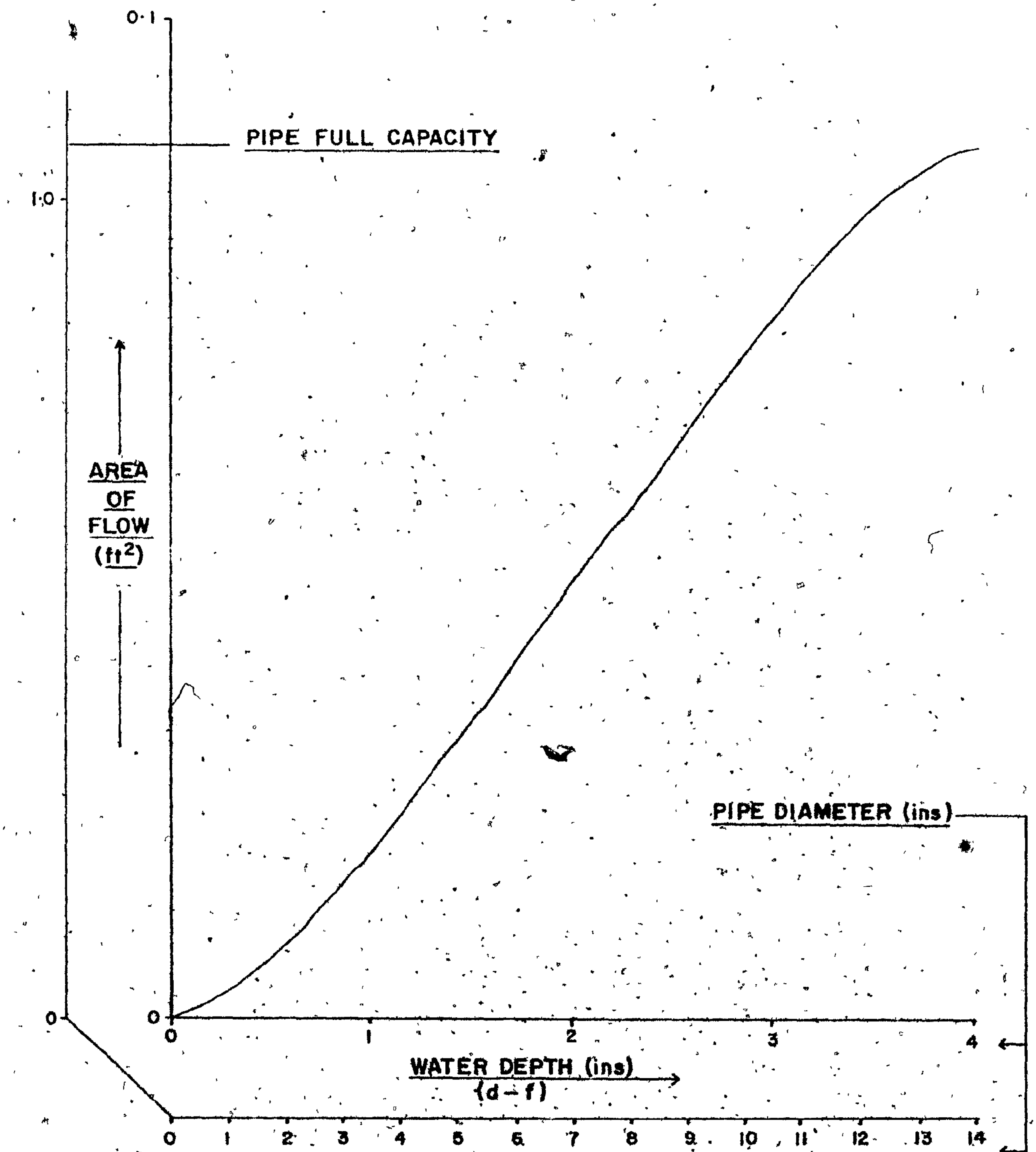


Figure A2 once d and f are known.

Flow measurements were taken on all the pumping set-ups in the study area, with the exception of that from the sump of Smallwood Mine. Direct measurement of the flow in this system was not possible because the discharge end of the pipeline was inaccessible. However, considering the capacity of the pump, and the periodic manner in which it functioned, it could be expected to deliver an average 1000 gal./min. to Luce Lake. Table A8 shows the calculated flow values for the remaining pumping systems in the study area.

TABLE A 8

PIPELINE FLOW MEASUREMENTS

PIPELINE EXTENT	PIPELINE DIAMETER	DATES	FLOW RATE
From Pointer Lake to Heath Lake	14"	Before July 5	495 gpm
		July 5 - July 28	840 gpm
		After July 28	1350 gpm
From Humphrey Sump to Heath Lake	14"	Throughout Field Season	640 gpm
From Heath Lake to Luce Lake	14"	Throughout Field Season	3100 gpm

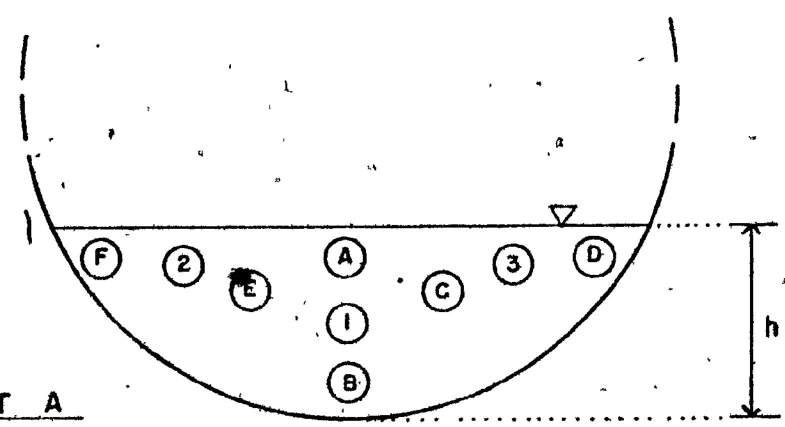
2.B Culvert Flow Measurements

The water leaving Luce Lake does so by a stream that passes through two 60-inch diameter culverts which carry the water beneath a lakeshore road. The velocity of flow through each culvert was measured on two separate occasions by using a Gurley flowmeter. The first set of measurements were made in a period of low flow; the second set were taken at a higher flow rate. For each set of readings, the flowmeter was placed in different parts of the culverts in order to obtain velocity profiles. Figure A3 shows the approximate positions of the flowmeter within each of the culverts (numbered positions refer to the low flow rate set, lettered ones to the higher). The accompanying Table A9 shows the average of four velocity readings taken at each of the positions in Figure A3.

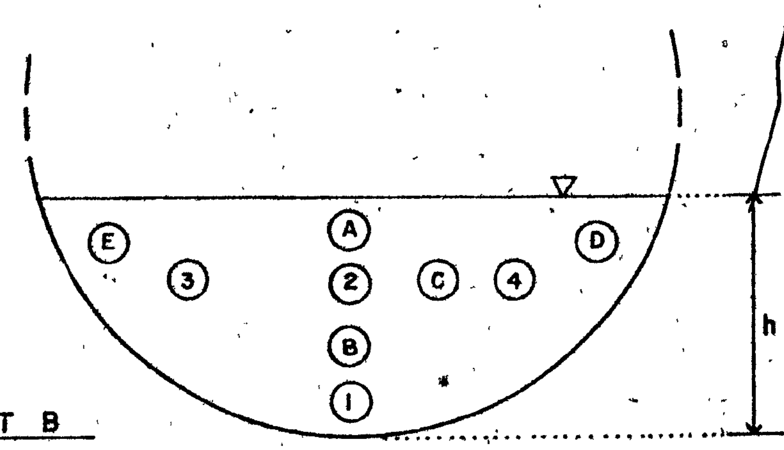
The mean velocities thus derived were then plotted as a function of the water depth in the culvert (h); see Figure A4. A linear relationship was assumed to be representative within the narrow range of variation recorded. Figure A5 shows the cross-sectional area of the flow through a 60-inch diameter culvert, also as a function of the water depth (h). The flow quantity (Q) is the product of the flow velocity and the cross-sectional area. By having both

FIGURE A3

POSITIONS OF FLOWMETER TO MEASURE VELOCITY OF FLOW(V) IN CULVERTS



CULVERT A



CULVERT B

FIGURE A4

RELATIONSHIP BETWEEN FLOW VELOCITY (V) AND WATER DEPTH (h) IN CULVERTS

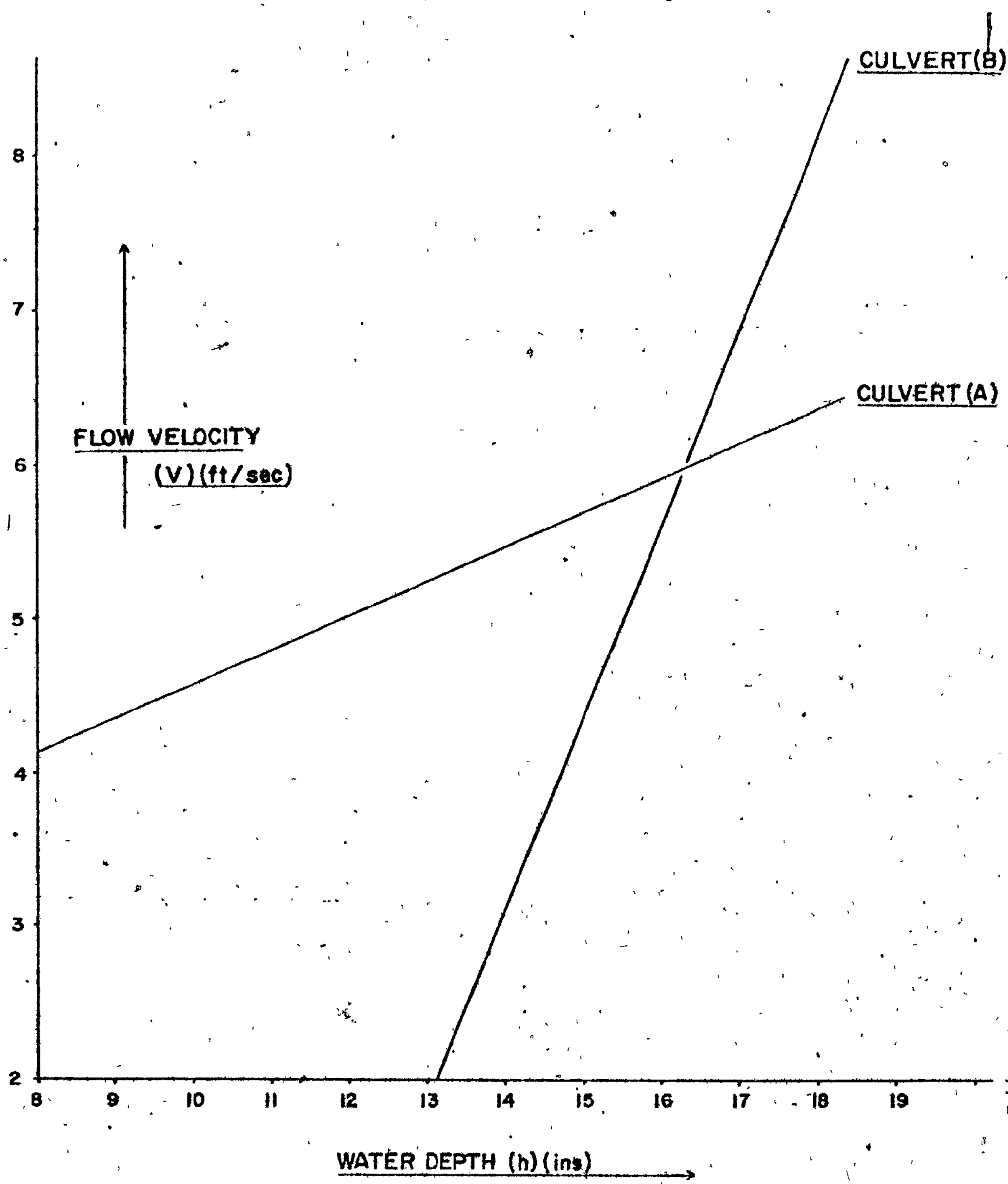
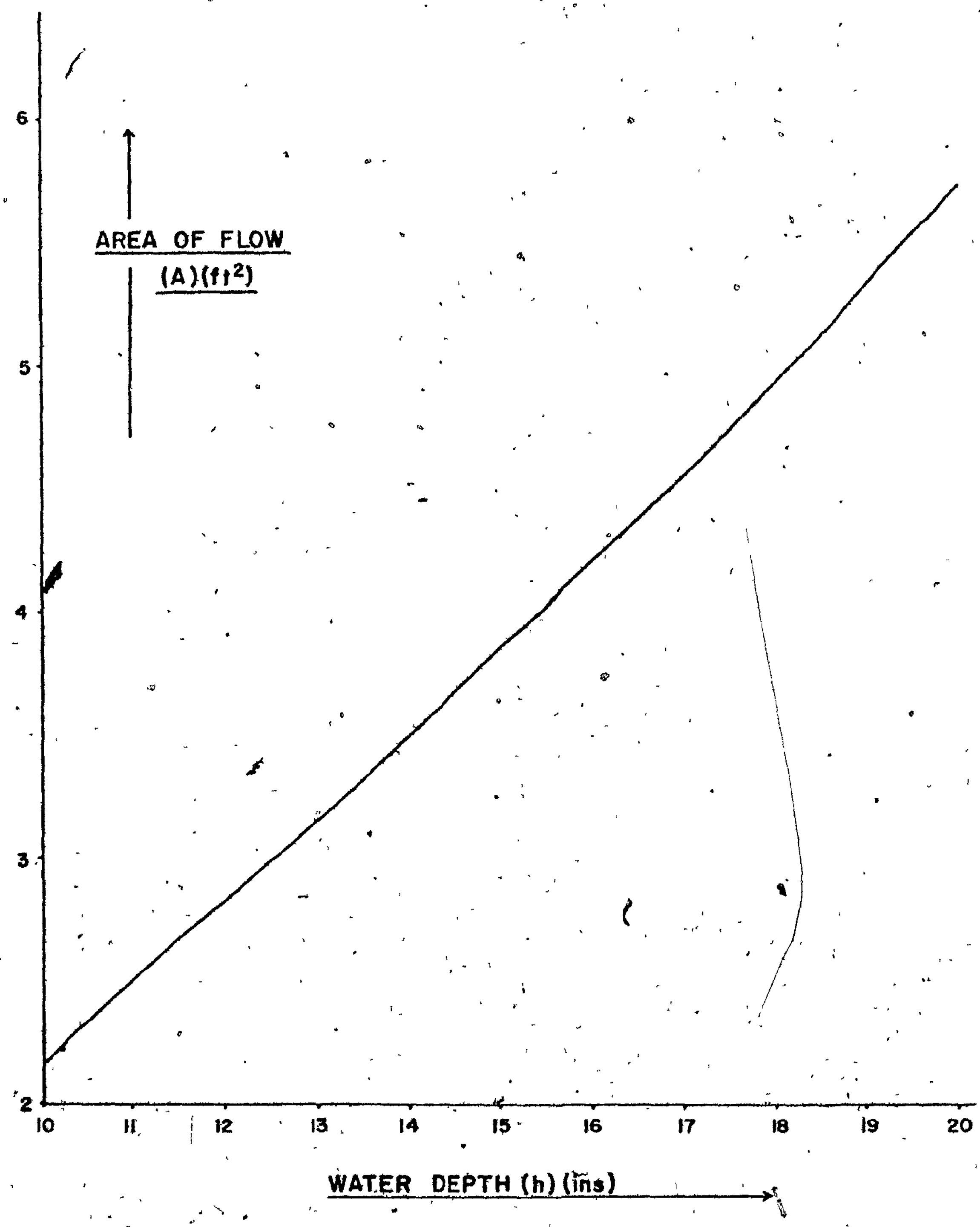


FIGURE A5

RELATIONSHIP BETWEEN AREA OF FLOW (A) AND WATER DEPTH (h) IN CULVERTS



these variables calibrated in terms of (h), a record of the water flow was easily obtained from regular measurements of the water depth in each culvert.

The total surface outflow from Luce Lake is the sum of the flows in each culvert. Table A18 gives the values of the flow rate during the field season. Figure A8 shows these values plotted along side those obtained for the flow over the weir located downstream of the culverts.

TABLE A9

FLOWMETER VELOCITY MEASUREMENTS IN CULVERTS

Culvert A		Culvert B	
Position	Avg Vel (ft/sec)	Position	Avg Vel (ft/sec)
1	4.96	1	4.74
2	4.96	2	5.33
3	4.55	3	3.36
		4	3.76
MEAN	4.82	MEAN	4.67
A	6.41	A	7.09
B	6.53	B	7.13
C	6.15	C	6.86
D	4.78	D	5.19
E	6.11	E	6.76
F	5.15		
MEAN	5.85	MEAN	6.61

TABLE A10

CULVERT FLOW MEASUREMENTS OF LUCE LAKE DISCHARGE

DATE	WATER DEPTH IN A (ins.)	WATER DEPTH IN B (ins.)	COMBINED FLOW RATE (USgpm)
JUN. 26	12.50	15.00	15,296
30	11.50	14.00	12,536
JUL. 3	13.00	15.00	15,990
7	12.48	14.16	14,291
11	11.40	13.68	[illegible]
13	13.68	16.20	[illegible]
15	15.80	17.30	[illegible]
18	14.28	16.68	21,006
20	13.20	15.36	16,832
23	12.72	15.24	16,095
25	12.24	13.92	13,191
26	12.24	14.16	13,784
30	12.60	15.00	15,486
AUG. 2	11.04	13.68	11,456
4	9.60	11.76	7,392
6	9.12	11.74	7,047
8	10.56	12.84	9,659
20	10.68	13.32	10,637
SEPT. 23	10.20	12.65	

2.C Weir Flow Measurements

For accurate water flow measurements, it is necessary that weirs be sharp-crested and not susceptible to leakage or under-seepage. The installation problems associated with the latter conditions are many and often difficult to eradicate. The sharp crest, which requires that the water "breaks" cleanly from the downstream face, is necessary for the calibration equations to hold good (see Figure A6). Two types of weir were used in the study: rectangular, for larger flows, and 90° V-notch for smaller streams.

The quantity of flow (Q) over a sharp-crested rectangular weir may be calculated from the formula:

$$Q = CLH^{3/2}$$

where, C = discharge coefficient constant: 3.33

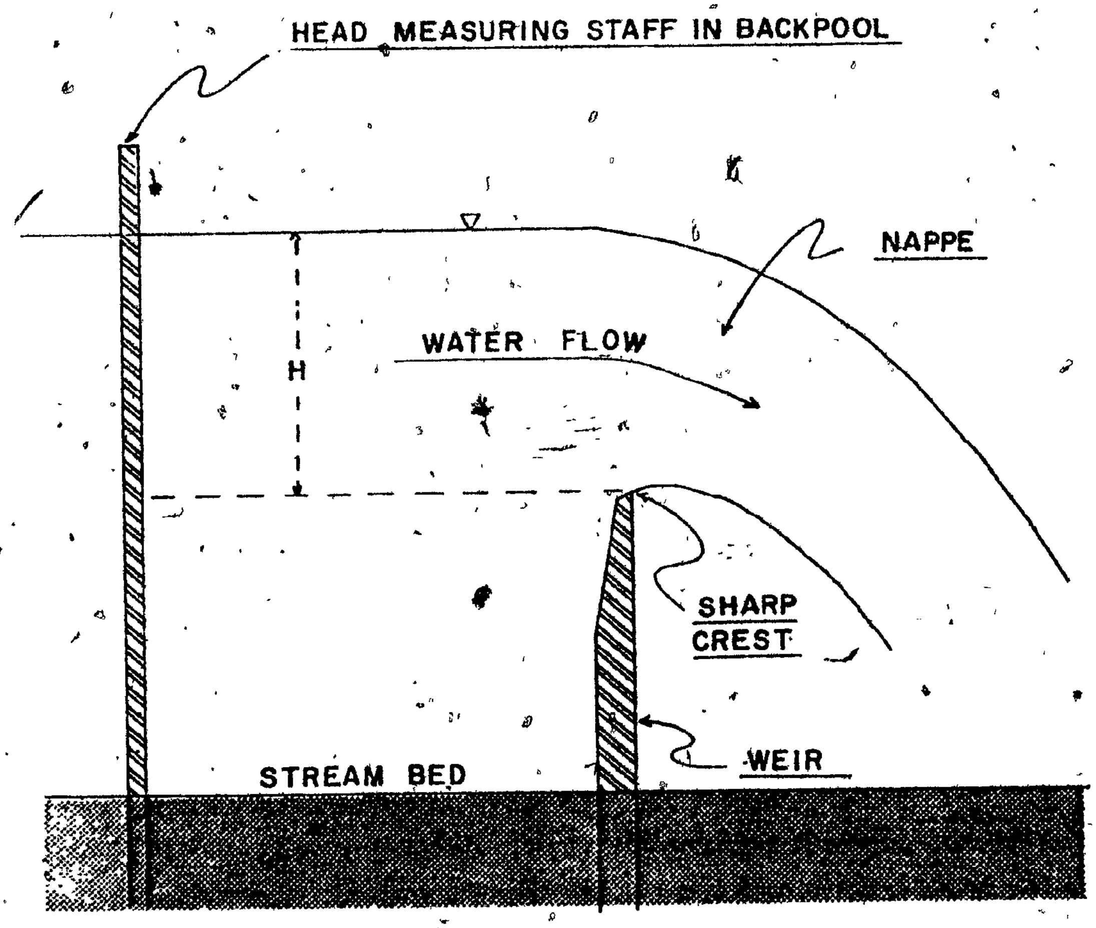
L = length of crest

H = head

When the crest length (L) is less than the width of the stream, an end-correction must be made to allow for the contraction of the flow. Thus:

FIGURE A6

WATER FLOW OVER SHARP-CRESTED WEIR



$L = L' - 0.2H$

where, L' = measured crest length

With a 90° V-notch weir, the flow is given by the equation:

$Q = CH^{5/2}$

where, C = discharge coefficient constant = 2.5

H = head

The largest weir in the area is that on the outflow stream from Luce Lake. This is an old timber construction with a large backpool and observable leakage of the order of several hundred gal./min. (personal estimate). During the course of the field season, renovations were carried out to improve the break of the nappe on this weir by installing a new higher crest. The leakage through the weir represents an error factor of about 5% of the measured flow rate.

The remainder of the weirs were constructed and installed during the field season. They were arranged around the perimeter of Luce Lake to measure the stream inflow. This part of the project was not completed however, and will be continued in a future field season. The location of those weirs which were installed are shown in Figure A7, and the

FIGURE A7

LOCATION OF WEIRS ON STREAMS FLOWING INTO LUCE LAKE

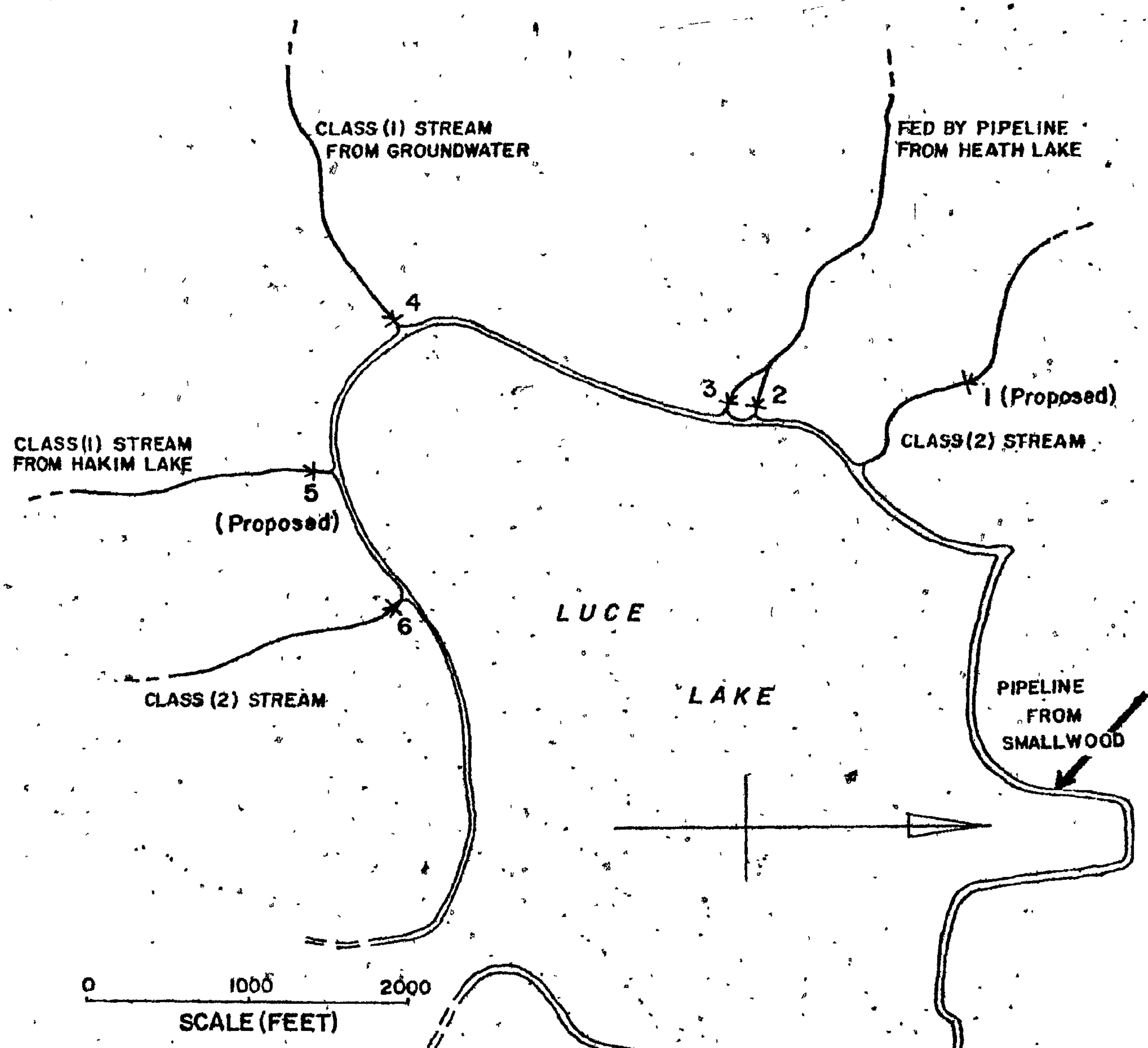


TABLE A11

WEIR FLOW MEASUREMENTS OF STREAMS ENTERING LUCE LAKE

Date	Weir No.	Head (ft)	Flow Rate (USgpm)
Aug.9	4	.313	61.3
Aug.17	4	.313	61.3
Aug.20	2	.573	278.8
Aug.22	3	.989	1091.4
Aug.22	2	.583	291.2
Aug.22	4	.307	58.6
Aug.22	6	.500	198.3
Aug.30	2	.560	263.3
Aug.31	3	.985	1080.4
Sep.16	2	.603	316.8
Sep.16	3	.979	1064.0
Sep.16	4	.438	142.4
Sep.23	2	.573	278.8
Sep.23	4	.375	96.6
Sep.23	6	.500	198.3
Sep.28	2	.525	224.1
Sep.28	3	.938	956.1
Sep.28	4	.417	126.0
Sep.28	6	.640	367.7

readings from the weirs are given in Table A11. Table A12 contains the values of the flow over the large weir on the Luce Lake outflow stream.

Figure A8 is a graph of the flow rate over the large exit weir versus time during the field season. The flow values from the culverts on the same stream are also plotted along with the daily precipitation values from the Heath Lake rain gauge station. Within the limits of measurement accuracy (between 5% and 10%), the two stream flow curves match very closely. There is also a significant relationship between rainfall and streamflow. The two major precipitation periods, June 25 - 28, and July 11 - 14, are followed by peaks in the stream flow, showing a time lag of between three and four days.

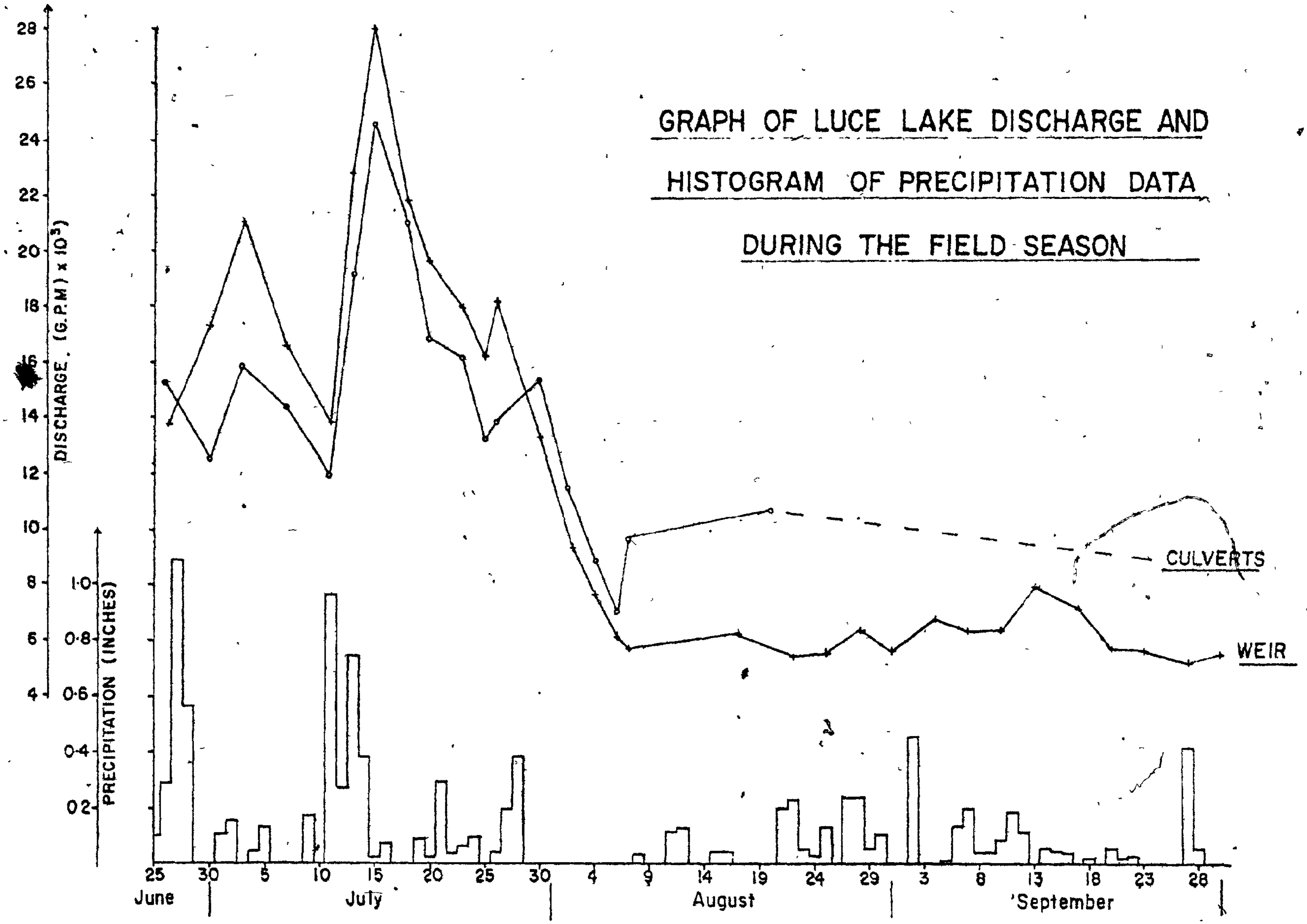

GRAPH OF LUCE LAKE DISCHARGE AND
HISTOGRAM OF PRECIPITATION DATA
DURING THE FIELD SEASON
DISCHARGE, (G.P.M) x 10³
PRECIPITATION (INCHES)
CULVERTS
WEIR
June
July
August
September

FIGURE A8

TABLE A12

WEIR FLOW MEASUREMENTS OF LUCE LAKE DISCHARGE

Date	Head (ft)	Flow Rate (USgpm)
June 26	1.34	13,753
June 30	1.57	17,306
July 3	1.80	21,079
July 7	1.52	16,525
July 11	1.34	13,753
July 13	1.90	22,781
July 15	2.19	27,910
July 18	1.81	21,750
July 20	1.71	19,580
July 23	1.61	17,890
July 25	1.50	16,199
July 26	1.62	18,118
July 30	1.25	13,264
Aug 2	0.98	9,290
Aug 4	0.86	7,635
Aug 6	0.76	6,131
Aug 7	0.70	5,733
Aug 17	0.78	6,229
Aug 22	0.71	5,416
Aug 25	0.72	5,529
Aug 28	0.79	6,340
Sept 1	0.73	5,643
Sept 4	0.82	6,698
Sept 7	0.79	6,340
Sept 10	0.79	6,340
Sept 13	0.92	7,934
Sept 17	0.86	7,185
Sept 20	0.74	5,758
Sept 23	0.73	5,643
Sept 27	0.69	5,183
Sept 30	0.71	5,416

APPENDIX 3

This section contains all the calculations carried out in order to obtain the Figures for the Mine Dewatering Potential Analyses presented in Chapter 5.

Summary of information abstracted from text of thesis for use in these calculations: -

annual precipitation		35.7 ins.
normal summer precipitation		20 ins.
remnant winter precipitation		9.1 ins.
atmospheric reduction figure	- vegetated	90%
	- stripped	50%

Smallwood surface drainage sub-basin

area	21.92×10^6 sq. ft.
stripped	65%
vegetated	35%
lake-covered	0%

Smallwood ground water sub-basin

area	40.85×10^6 sq. ft.
stripped	56%
vegetated	44%
lake-covered	0%

(1) With spring recharge partition constant at 50%, varying summer infiltration factor 25%, 50%, 75%

(A) Average Summer Dewatering

Step 1

$$\left(\frac{65}{100} \times 21.92 \times \frac{10}{12}\right) + \left(\frac{35}{100} \times 21.95 \times \frac{2}{12}\right)$$

$= 1.305 \times 10^7$ cu. ft.

Step 2

$$\left(\frac{100-25}{100}\right) \times 1.305 = 9.79 \times 10^6 \text{ cu. ft.}$$

Step 3

$$\left(\frac{56}{100} \times 40.85 \times \frac{10}{12}\right) + \left(\frac{44}{100} \times 40.85 \times \frac{2}{12}\right)$$

$= 2.106 \times 10^7$ cu. ft.

Step 4

$$\frac{25}{100} \times 2.106 = 5.27 \times 10^6 \text{ cu. ft.}$$

Step 5

$$40.85 \times \frac{9.1}{12} = 3.098 \times 10^7 \text{ cu. ft.}$$

Step 6

$$\frac{50}{100} \times 3.098 = 15.49 \times 10^6 \text{ cu. ft.}$$

Step 7

$$9.79 + 5.27 + 15.49 = 30.55 \times 10^6 \text{ cu. ft.}$$

Step 8

$$\frac{30.55 \times 3}{365 \times 2} = 1.26 \times 10^5 \text{ cu. ft./day}$$

$$\frac{1.26 \times 7.48}{1440} = 654 \text{ U.S. gpm}$$

(B) Spring Peak Dewatering

Step 9

$$21.92 \times \frac{9.1}{12} \times \frac{100-50}{100} = 8.31 \times 10^6 \text{ cu. ft.}$$

Step 10

$$\frac{8.31 \times 6}{365} = 1.37 \times 10^5 \text{ cu. ft./day}$$

$$\frac{1.37 \times 7.48}{1440} = 712 \text{ U.S. gpm}$$

Step 11

654 + 712 = 1366 U.S. gpm

Repeat Using 50%

Step 2

$$\left(\frac{100-50}{100}\right) \times 1.305 = 6.26 \times 10^6 \text{ cu. ft.}$$

Step 4

$$\frac{50}{100} \times 2.106 = 10.53 \times 10^6 \text{ cu. ft.}$$

Step 7

$$6.26 + 10.53 + 15.49 = 32.38 \times 10^6 \text{ cu. ft.}$$

Step 8

gives 689 U.S. gpm

Step 11

gives 1399 U.S. gpm

Repeat Using 75%

Step 2

$$\left(\frac{100-75}{100}\right) \times 1.305 = 3.26 \times 10^6 \text{ cu. ft.}$$

Step 4

$$\frac{75}{100} \times 2.106 = 15.80 \times 10^6 \text{ cu. ft.}$$

Step 7

$3.26 + 15.80 + 15.49 = 34.55 \times 10^6$ cu. ft.

Step 8

gives 738 U.S. gpm

Step 11

gives 1448 U.S. gpm

(2) With summer infiltration factor constant at 50%, varying spring recharge partition 25%, 50%, 75%:

(A) Average Summer Dewatering

Step 2

gives 6.26×10^6 cu. ft.

Step 4

gives 10.53×10^6 cu. ft.

Step 6

$\frac{25}{100} \times 3.098 = 7.75 \times 10^6$ cu. ft.

Step 7

$6.26 + 10.53 + 7.75 = 24.54 \times 10^6$ cu. ft.

Step 8

gives 524 U.S. gpm

(B) Spring Peak Dewatering

Step 9

$$21.92 \times \frac{9.1}{12} \times \frac{100-25}{100} = 12.47 \times 10^6 \text{ cu. ft.}$$

Step 10

gives 1065 U.S. gpm

Step 11

gives 1589 U.S. gpm

Repeat Using 50%

Step 8

gives 689 U.S. gpm

Step 11

gives 1399 U.S. gpm

Repeat Using 75%

<u>Step 6</u>

$$\frac{75}{100} \times 3.098 = 23.24 \times 10^6 \text{ cu. ft.}$$

<u>Step 7</u>

$$6.26 + 10.53 + 23.24 = 40.03 \times 10^6 \text{ cu. ft.}$$

<u>Step 8</u>

gives 855 U.S. gpm

<u>Step 9</u>

$$21.92 \times \frac{9.1}{12} \times \frac{100-75}{100} = 4.16 \times 10^6 \text{ cu. ft.}$$

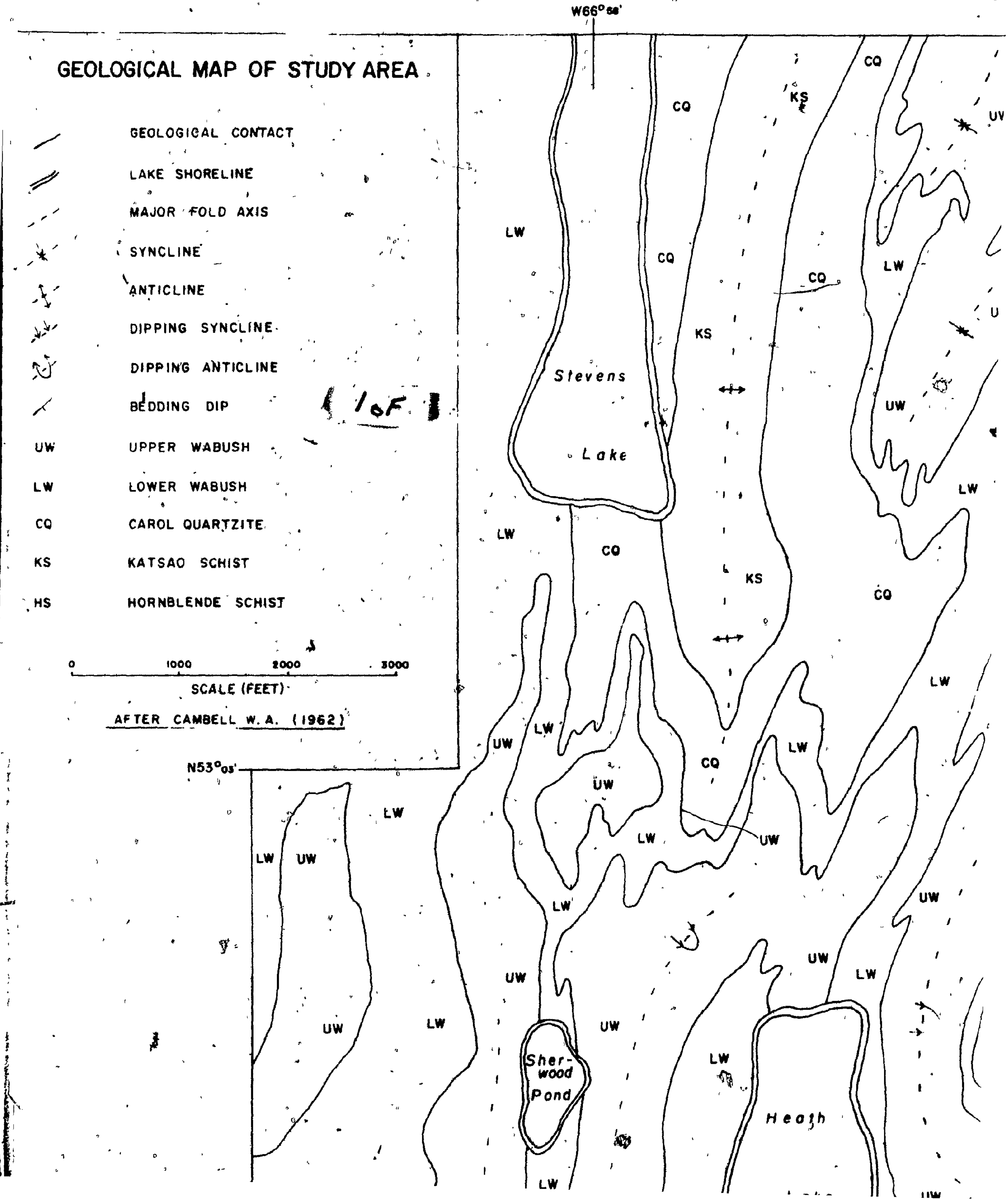
<u>Step 10</u>

gives 355 U.S. gpm

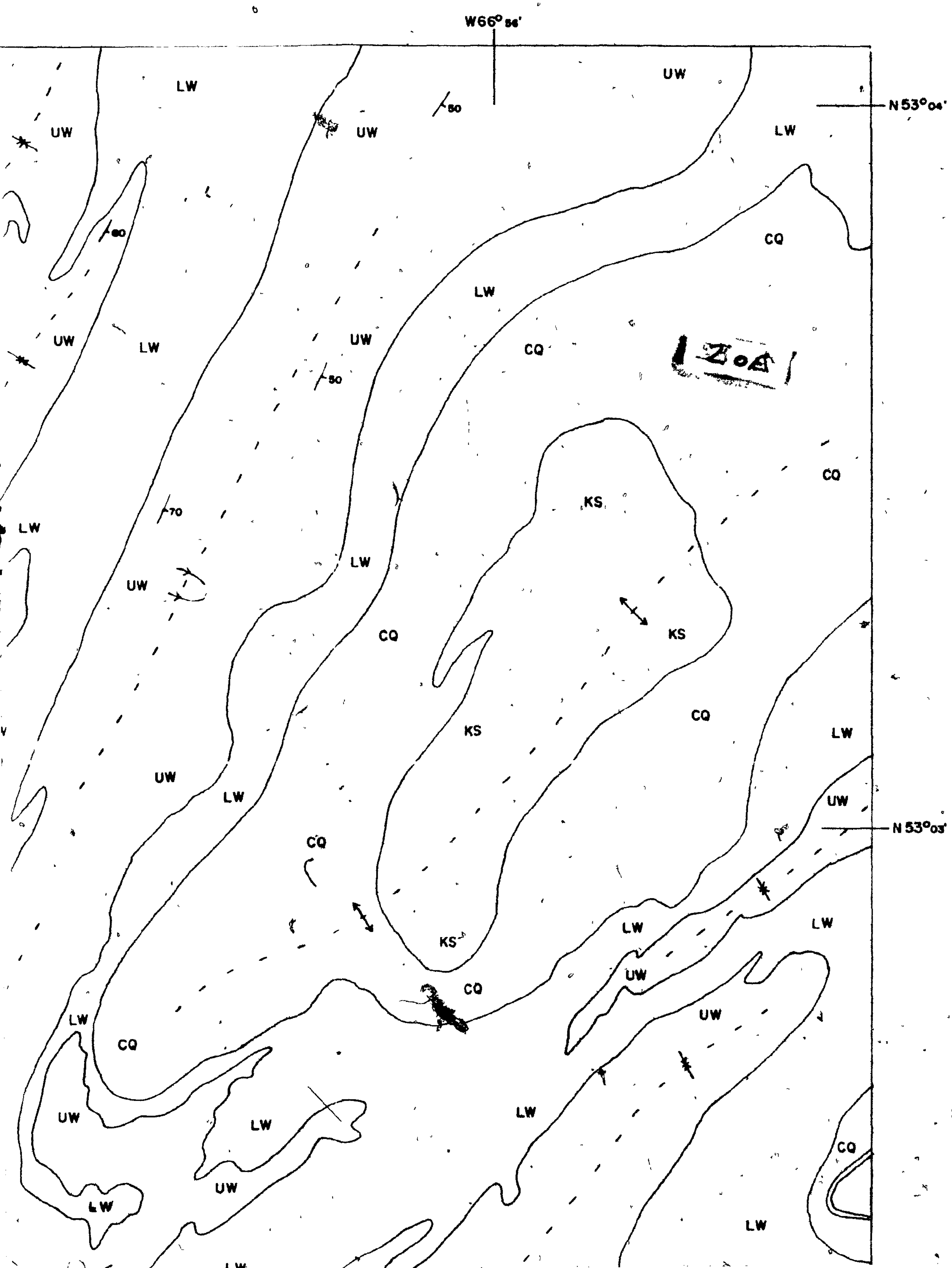
<u>Step 11</u>

gives 1210 U.S. gpm

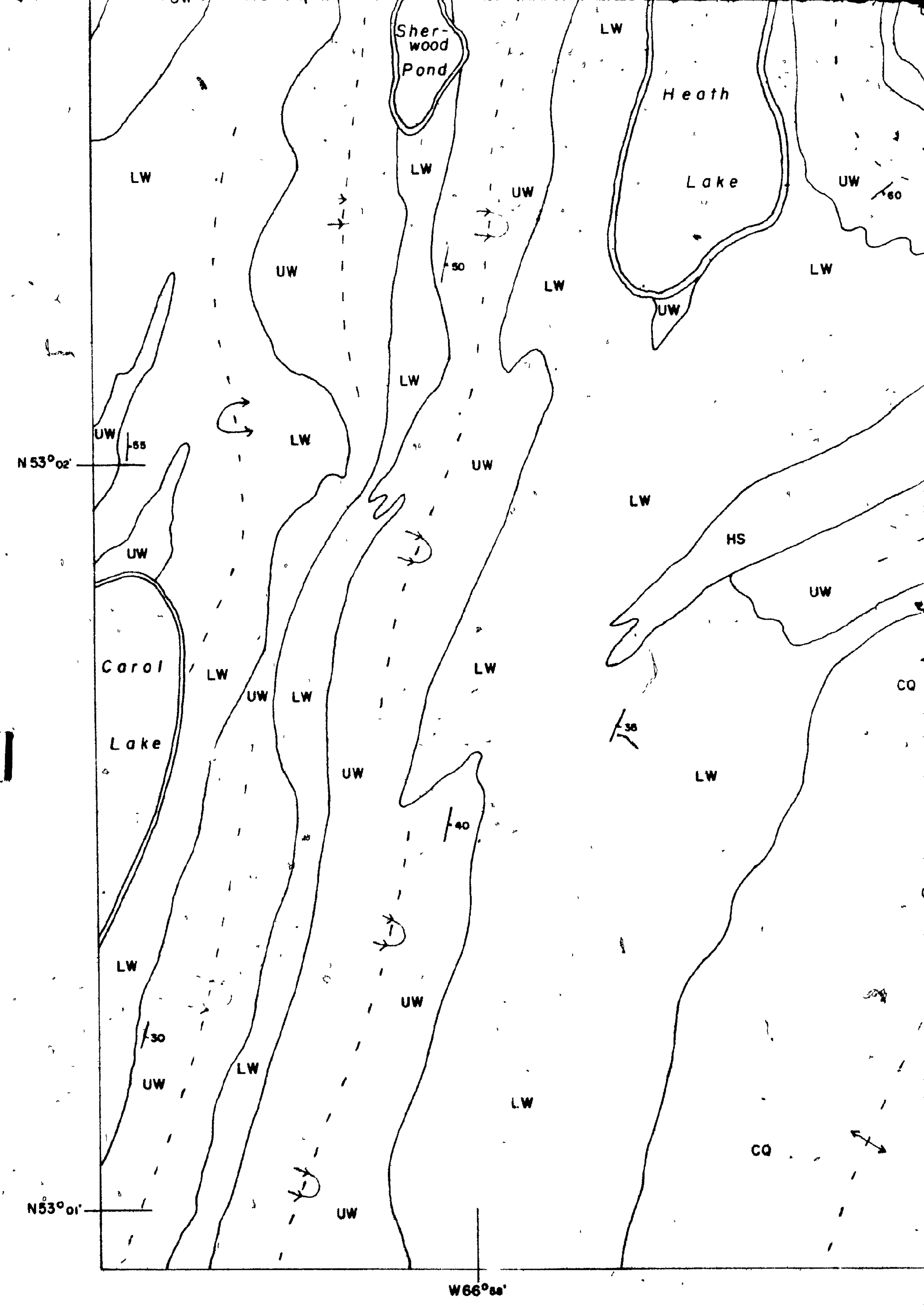
SHEET 1


GEOLOGICAL MAP OF STUDY AREA
GEOLOGICAL CONTACT
LAKE SHORELINE
MAJOR FOLD AXIS
SYNCLINE
ANTICLINE
DIPPING SYNCLINE
DIPPING ANTICLINE
BEDDING DIP
UW UPPER WABUSH
LW LOWER WABUSH
CQ CAROL QUARTZITE
KS KATSAO SCHIST
HS HORNBLENDE SCHIST
0 1000 2000 3000
SCALE (FEET)
AFTER CAMBELL W. A. (1962)
1 of 1
W66°
N53°05'
Stevens Lake
Sherwood Pond
Heath
UW
LW
CQ
KS

1



3a



Sher-
wood
Pond
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Heath
Lake
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60
LW
UW
50
LW
UW
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UW
LW
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55
N 53° 02'
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UW
LW
HS
UW
Carol
Lake
LW
UW
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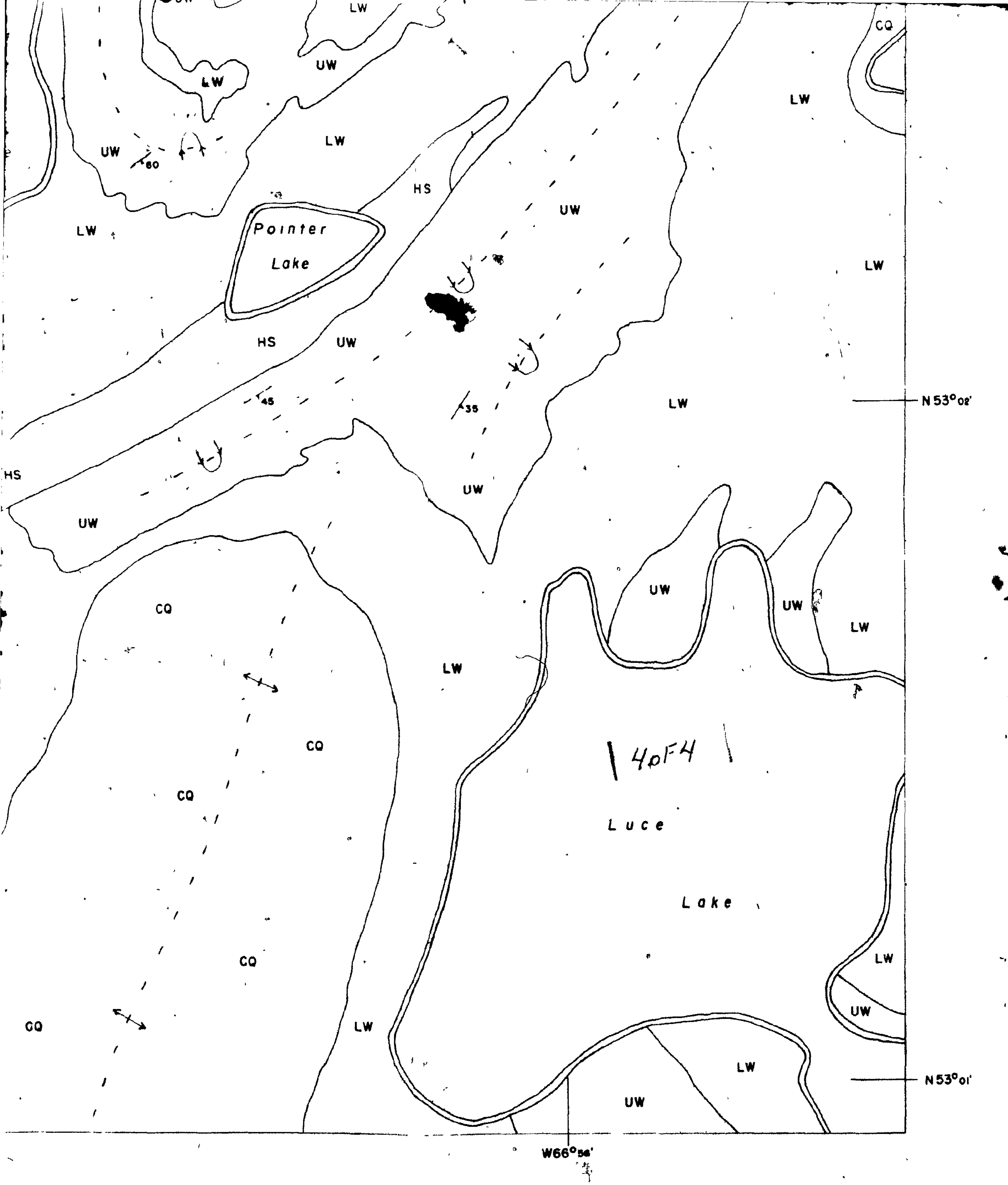
LW
CQ
UW
N 53° 01'
W 66° 58'



LW
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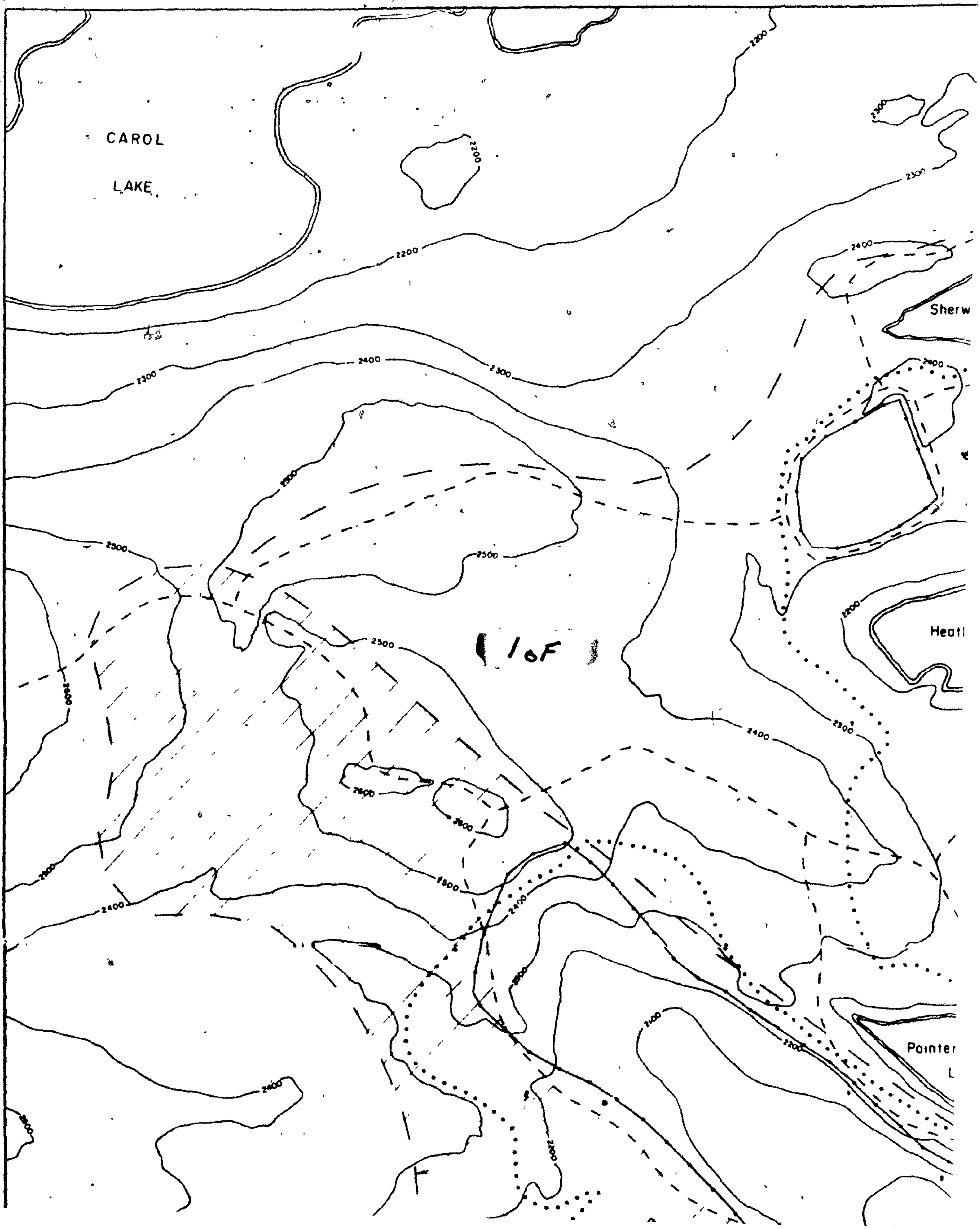
N53°01'
W66°58'


CAROL
LAKE
2200
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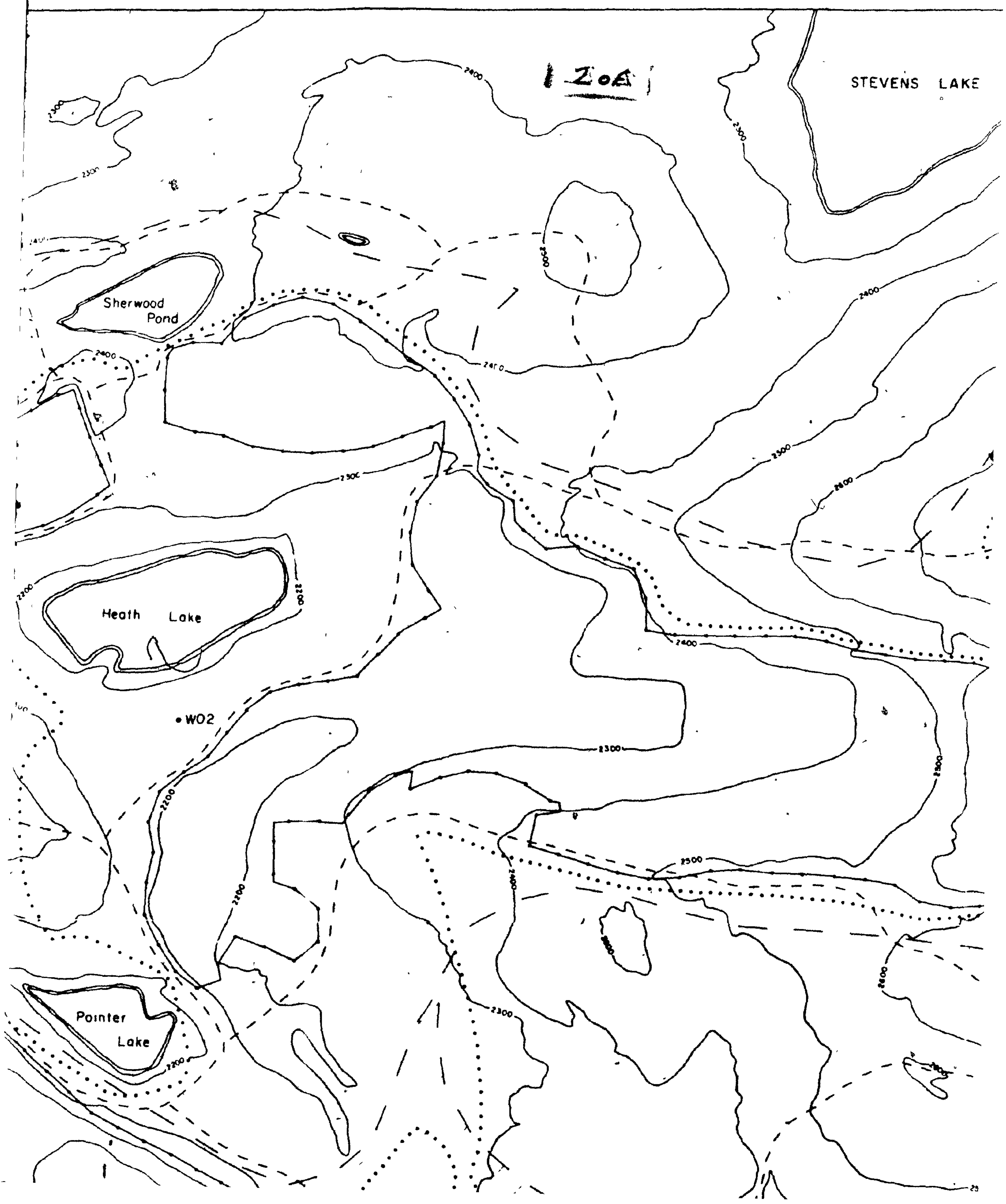
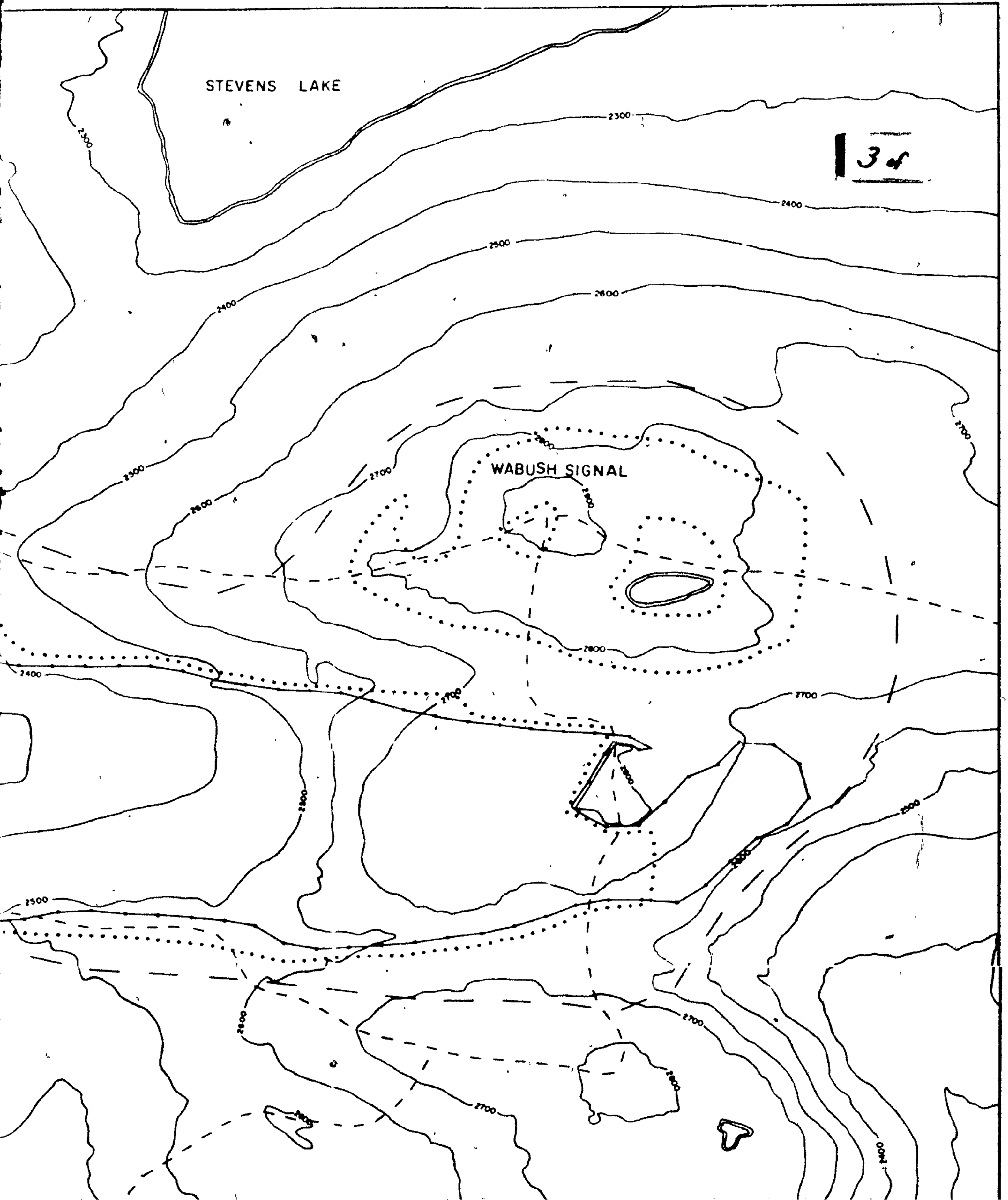
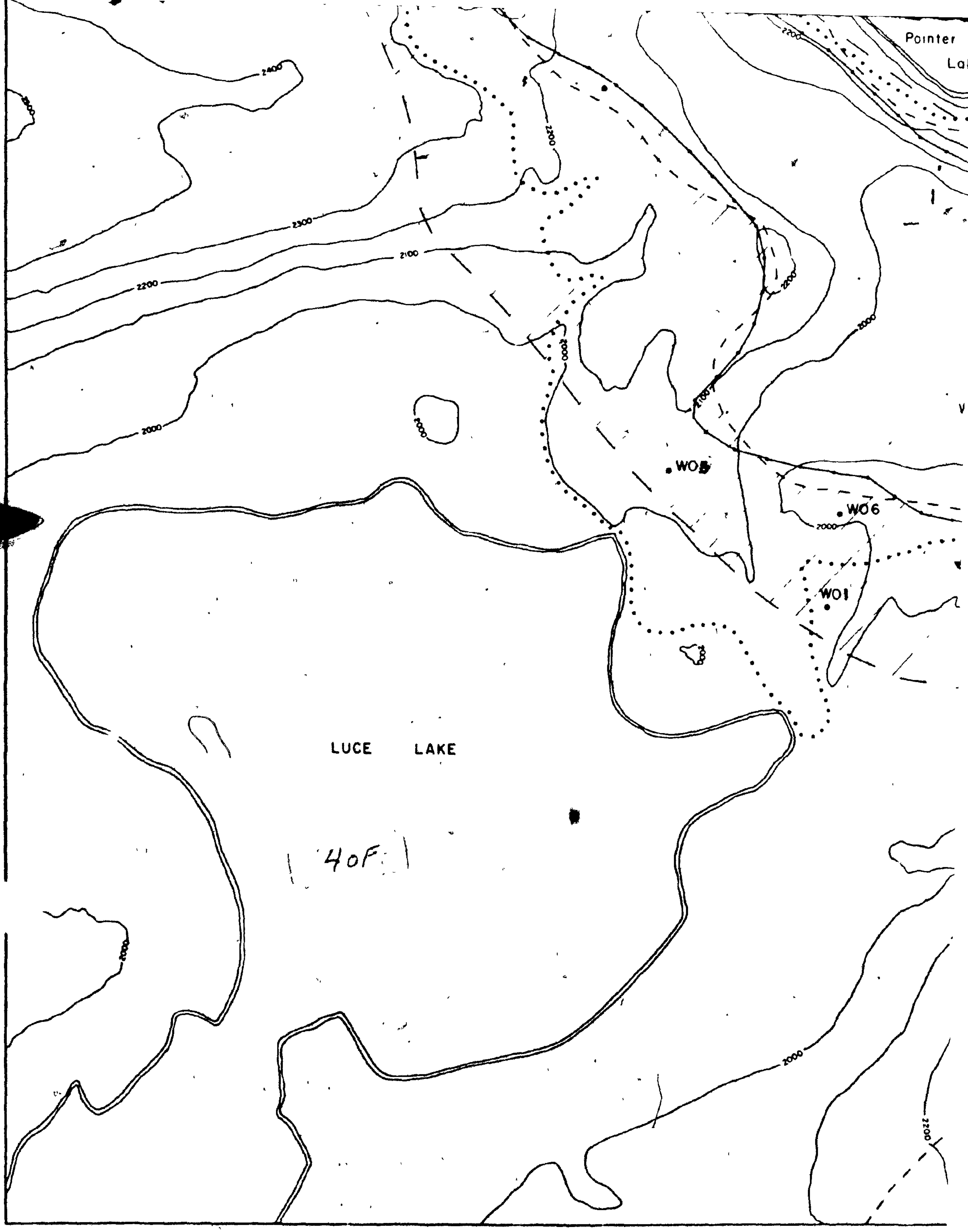
2400
2500
2600
2100
Sherw
Heatl
Pointer
L
1oF

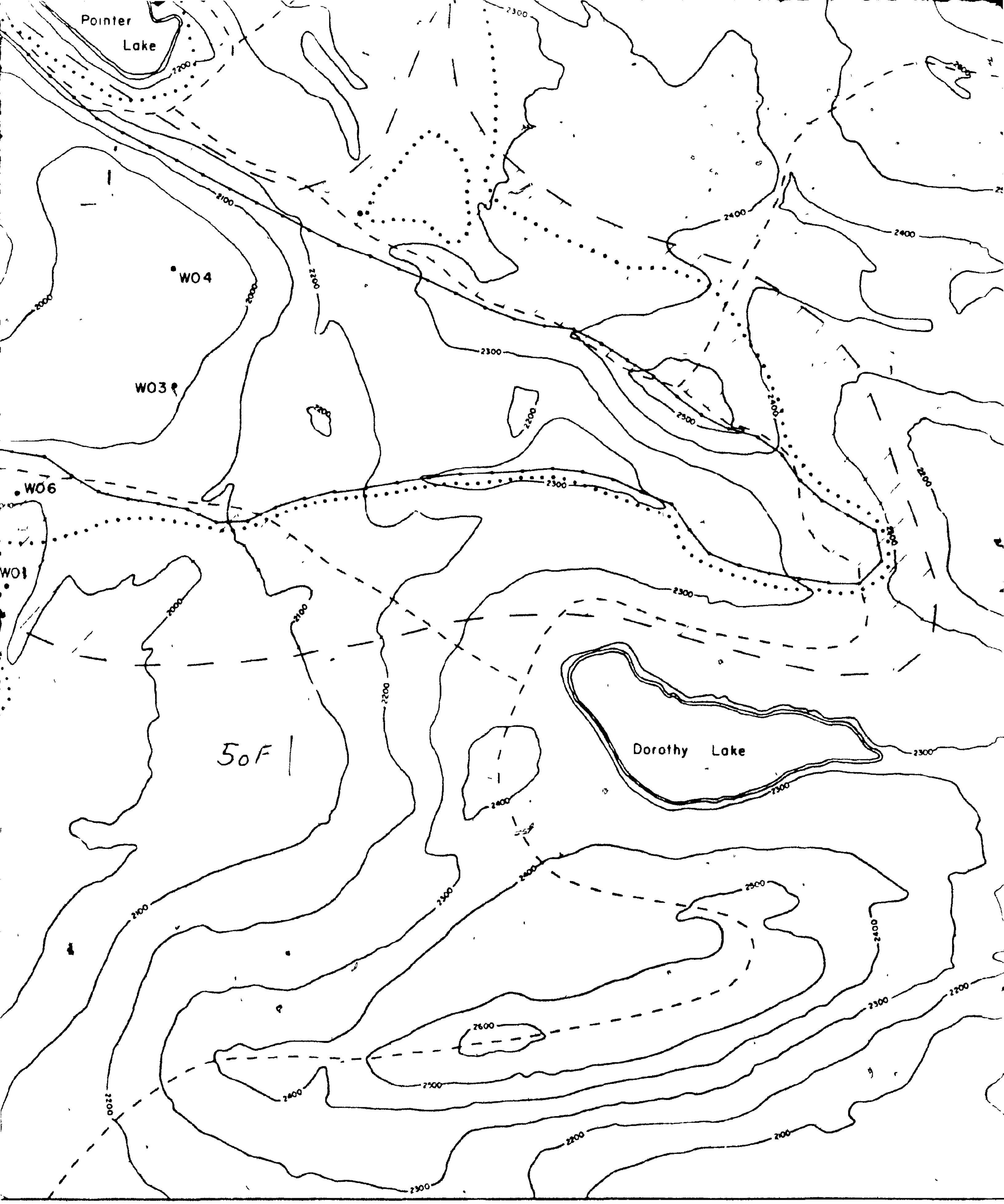


120A
STEVENS LAKE
Sherwood Pond
Heath Lake
Pointer Lake
W02
2300
2400
2200
2500

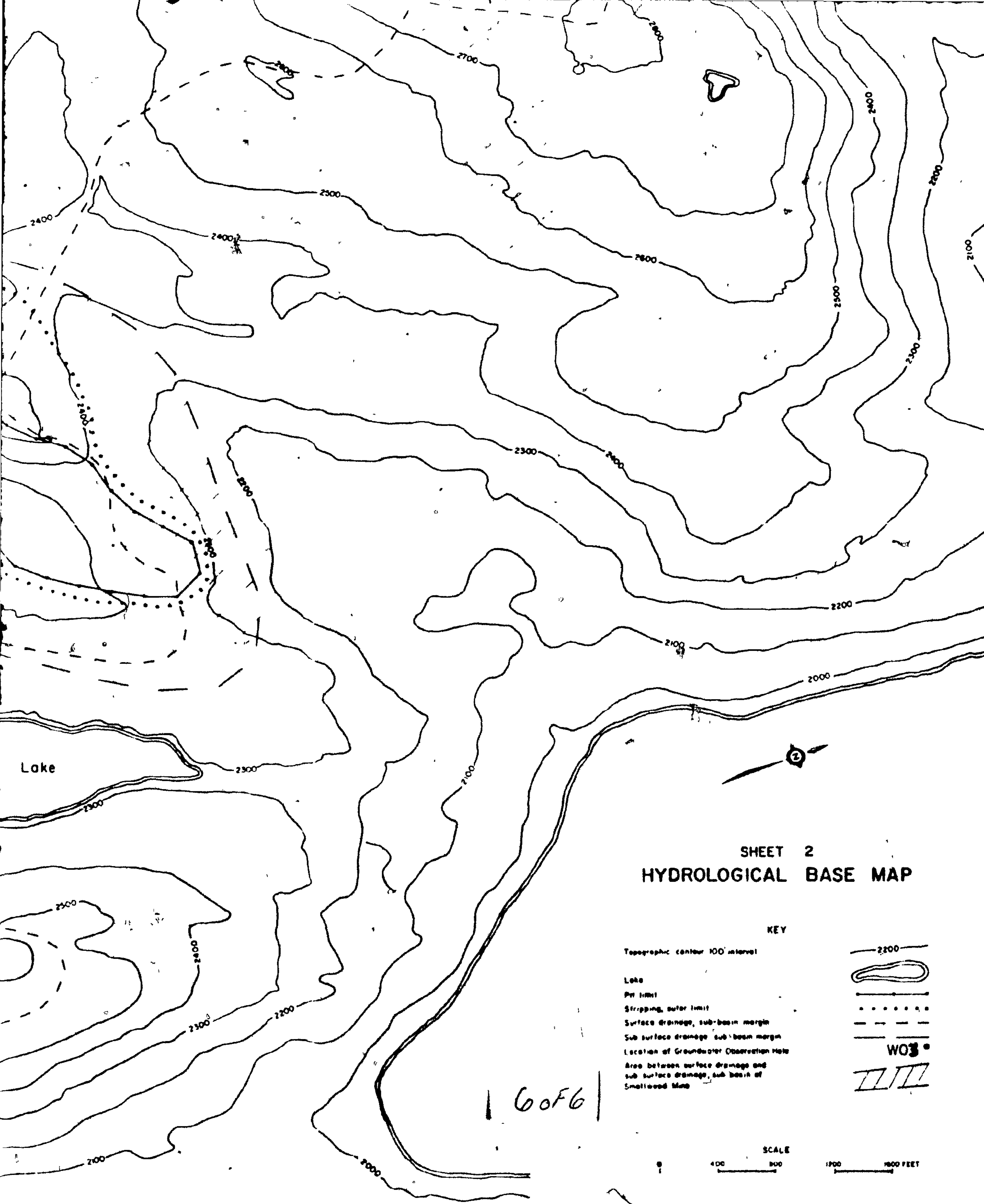

STEVENS LAKE
WABUSH SIGNAL
3 of
2300
2400
2500
2600
2700
2800



Pointer
2400
2300
2200
2100
2000
WO5
WO6
WO1
LUCE LAKE
4oF



Pointer Lake
WO4
WO3
WO6
WO1
5oF
Dorothy Lake
2000
2100
2200
2300
2400
2500
2600



SHEET 2
HYDROLOGICAL BASE MAP
KEY
Topographic contour 100' interval
2200
Lake
Pit limit
Stripping, outer limit
Surface drainage, sub-basin margin
Sub surface drainage sub-basin margin
Location of Groundwater Observation Hole
WO3
Area between surface drainage and sub surface drainage, sub basin of Smallwood Mine
SCALE
0
400
800
1200
1600 FEET
Lake
2700
2800
2600
2500
2400
2300
2200
2100
2000
6 of 6