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DEPARTMENT OF LANDS, FORESTS, AND WATER RESOURCES

CANADA-BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT

TECHNICAL SUPPLEMENT II TO FINAL REPORT

A HYDROLOGICAL STUDY OF THE OKANAGAN RIVER BASIN

WATER INVESTIGATIONS BRANCH
BRITISH COLUMBIA WATER RESOURCES SERVICE
DEPARTMENT OF LANDS, FORESTS AND WATER RESOURCES
PARLIAMENT BUILDINGS
VICTORIA, BRITISH COLUMBIA

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CANADA-BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT

A HYDROGEOLOGICAL STUDY OF THE OKANAGAN RIVER BASIN

TASKS 38, 39, 40 & 41

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CANADA-BRITISH COLUMBIA OKANAGAN BASIN AGREEMENT

TECHNICAL SUPPLEMENT II TO FINAL REPORT

A HYDROGEOLOGICAL STUDY OF THE OKANAGAN RIVER BASIN

by

E. Gordon Le Breton
Water Investigations Branch

with

Hydrogeological reconnaissance reports on
Vaseux Creek and Vernon Creek Sub-basins

by

E. C. Halstead
Inland Waters Branch
Department of the Environment

Penticton Creek and Pearson Creek Sub-basins

by

P. L. Hall
Water Investigations Branch

Lambly Creek and Greata Creek Sub-basins

by

E. Gordon Le Breton
Water Investigations Branch

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ILLUSTRATIONS

TABLES

The O'Keefe Valley aquifer, in the important tributary valley in the area, extends throughout the entire length of this (the O'Keefe) valley. The maximum known thickness of the deposits in this valley is 575 feet, of which the saturated thickness is close to 350 feet. At the south end of the valley the aquifer consists primarily of clean sand and gravel, but at the north end thedeposits are known only from surface field mapping.

A moderately important aquifer trending from southwest to northeast occurs in a bedrock channel about 4½ miles north of Armstrong. The aquifers in this valley and the O'Keefe Valley are unconfined (or water table) aquifers.

Well yields, in the depth range 700 to 1200 feet, vary considerably in the main valley area. Yields range up to 10 igpm for wells suited to domestic supplies to 500 igpm or possibly more for wells suited to industrial or irrigation requirements. In the Enderby area yields of 500 igpm or over are anticipated from wells 800 to 875 feet deep. Yields from similarly deep wells elsewhere in the main valley are anticipated to be low, from 30 to 250 igpm.

Wells in the depth range of 300 to 600 feet in the Armstrong area may produce from 200 to 850 igpm. In the O'Keefe valley yields of up to 500 igpm are anticipated from wells completed to depths of about 550 feet. The narrow unconfined aquifer 4½ miles north of Armstrong is expected to have well yields of about 50 igpm. Estimated well yields will need further verification from properly constructed and tested production wells and observation wells.

From underflow calculations a total rate for groundwater movement towards Okanagan Lake of about 3 1/3 cfs (2370 acft/yr) has been determined. This figure seems reasonable compared to a recharge rate of 6 cfs (4350 acft/yr) from 1 inch of precipitation reaching the water table over a recharge area estimated as 80 square miles.

The total quantity of recoverable water available by water mining has been calculated as 66,500 acre feet, most of which would be obtained from the O'Keefe valley. However, as the recharge from precipitation in the O'Keefe valley is equivalent to only about 3/4 cfs (540 acft/yr) the length of time required to replenish the supply would be about 100 years.

The potential available for groundwater withdrawal without depleting supplies is estimated at from 3 1/3 to 6 cfs. It is believed that present utilization of groundwater is not close to the lower figures. This potential does not include that of the Enderby area which falls in the hydrologic regime of the Shuswap River Valley.

The chemical quality of the groundwaters is very good. The total dissolved solids content of groundwaters in the study area is commonly from about 200 to 500 ppm. It is primarily calcium and magnesium bicarbonate type water. The water is quite suitable for human consumption and for irrigation use and should require only very little treatment for industrial purposes.

The economics of groundwater development indicate that for one locality limited preliminary groundwater investigations including some seismic, test drilling and pump testing may cost about $45,000. High yield production wells producing about 800 igpm including pump and pump house are estimated to cost from $25,000 to $50,000 the actual costs varying with such factors as difficulty of drilling conditions and well diameter.

Task 38 comprised a study of 6 sub-basins. The objective of the reconnaissance studies was to determine whether or not the groundwater component of sub-basins was in sufficient volume to warrant expenditure of more time and funds to provide as complete as possible an assessment of its contribution to the hydrologic regime.

Sub-basin studies generally prove low baseflows and that the groundwater component of total runoff is small. There is likely very little groundwater discharge from the sub-basins that is not measured as streamflow.

It may be stated that the groundwater program carried out under the joint Canada-British Columbia Okanagan Basin Study agreement considerably increases knowledge and understanding of the hydrogeology of the north end of the Okanagan River Basin and of some selected sub-basins.

ACKNOWLEDGEMENTS

The author especially wishes to acknowledge the active field participation in this study by Mr. E. C. Halstead, Hydrogeologist, Inland Waters Branch, Department of Environment, Government of Canada and Mr. P. Hall, Hydrogeologist, Groundwater Division, Water Investigations Branch, British Columbia Water Resources Service, whose written contributions are contained within this report. The author is also indebted to the comments of both men and Dr. J. C. Foweraker during the planning stages of the work. The overall groundwater program of studies was drawn up primarily by Dr. J. C. Foweraker, not only for 1970 but also for subsequent years, prior to the writer's employment with the Groundwater Division. Field trips have also been made with the foregoing personnel. Editing of the final report was carried out by members of the Groundwater Review Board, Mr. D. H. Lennox, Head, Groundwater Subdivision, Inland Waters Branch, Mr. E. C. Halstead, Research Scientist, Hydrologic Sciences Division, Inland Waters Branch, and by Dr. J. C. Foweraker, Chief, Groundwater Division, Water Investigations Branch.

Most of the 1970 field season was spent in the company of technical staff members, Mr. J. Gulliver and Mr. D. Johanson. Mr. Gulliver did considerable work on contract preparations for seismic, test drilling and pump test programs being in constant communication with the Chief of the Division during this time. Mr. D. Johanson proved a worthy technical assistant on sub-basin fieldwork. Mr. J. Jaundrew joined the former men on test drilling Contracts 42 and 43 conducted under Task 40. Mr. A. Allport was field assistant on Task 41 in 1971.

Thanks must be expressed to Mr. W. Bailey, Provincial Sanitary Engineer, Dr. M. R. Smart, Director, North Okanagan Health Unit, Vernon and to Dr. D. A. Clarke, Director, South Okanagan Health Unit, Kelowna, for help in obtaining copies of chemical analyses of groundwaters. Mr. A. Lynch and Mrs. I. Kalnins, Provincial Water Resources Laboratory and Mr. S. Reeder, Federal Government Laboratory, Calgary ran chemical analyses on groundwater samples submitted as part of the program of studies.

Acknowledgement is made to Mr. D. Currie regarding notes on the planning stages of sub-basin groundwater studies and to Mr. Orest Tokarsky for several helpful suggestions in hydrogeological mapping. Both men are hydrogeologists with the Groundwater Division, Research Council of Alberta.

The author wishes to acknowledge the work of the men of both drilling companies involved in the test drilling programs, Wardean Drilling Company Limited and Big Indian Drilling Company Limited. Invaluable help was provided in commencing the mud programs, under Contract 42, by Mr. D. Larsen and under Contract 43, by Mr. C. Laing, both of Baroid Mud Company. The test pumping contract was carried out by Mr. J. Moore, Osoyoos Tile Works and Water Wells. Local residents were very cooperative in offering land sites for test drilling and permitting seismic operations on their property. Draughting has been done by Mr. P. Dixon and Mr. W. McInnes.

A HYDROGEOLOGICAL STUDY OF THE NORTH END OF THE OKANAGAN RIVER BASIN

1. INTRODUCTION

The purpose of this study was twofold, one to try to determine the groundwater flow into and from Okanagan Lake and the groundwater potential of the main valley-fill deposits, particularly in the area from the north end of Okanagan Lake to the town of Enderby on the Shuswap River, and two, to determine the groundwater component of six selected sub-basins to more fully understand the hydrologic budget of the Okanagan River Basin.

1.1 Methods of Investigation

For information on the geology of the Okanagan River Basin, reference was made to geological maps and reports of the Geological Survey of Canada and the Department of Mines and Petroleum Resources, Province of British Columbia and to lithologic logs and electric logs. Air photos were used to supplement field studies. Forest cover and topographic maps of the Department of Lands, Forests and Water Resources, Province of British Columbia and reports of the Department of Mines and Petroleum Resources, were used for information on vegetation and landforms of the region.

Existing water-well records on file in the Groundwater Division supplied by water-well drillers or obtained from water-well inventories, were plotted and interpreted; these records form an important part of this report. Also used were data obtained from other Government agencies and local unpublished areal groundwater investigations. The elevations of most wells, test holes and field features were estimated from 1 inch to 12,000 inch and 1 inch to 50,000 inch topographic maps.

In addition to studying existing information, preliminary hydrogeological investigations of a qualitative nature were undertaken to understand more about the groundwater regime of selected sub-basins (Task 38). Seismic investigations (Task 39) were conducted as important preliminary work on which to base the far more expensive groundwater-test drilling programs (Task 40). A well development and test pumping program (Task 41) was conducted for the purpose of estimating well yields in the test holes completed under Task 40. Tasks 38 to 40 were completed in the 1970 field season and Task 41 in the 1971 field season.

1.2 Previous Investigations

Local areal investigations were previously carried out by Mr. E. Livingston, P. Eng., Consulting Groundwater Geologist, formerly Chief, Groundwater Division, by Dr. J. C. Foweraker, P. Eng., present Chief of the Groundwater Division and by other staff members. Publications directly concerned with groundwater studies in the Okanagan River Basin, include "Groundwater Investigation - Mount Kobau, British Columbia", E. C. Halstead, Inland Waters Branch, Department of the Environment, Government of Canada (1969).

2. GEOGRAPHY

2.1 Location and Extent of the Area

The Okanagan River Basin lies between parallels of latitude 49°00' and 50°40' north and between meridians of longitude 118°45' and 120°18' west. The total area of the drainage basin in Canada is 3018 square miles. However, in this hydrogeological study, emphasis is placed on the flatter-lying areas in the north end of the main valley and the O'Keefe tributary valley which comprise the settled areas, and on some selected sub-basins. The total area of the main valley (to about 1,500 feet above sea level) is about 215 square miles of which 131 square miles is occupied by Okanagan Lake, and only about 70 square miles is land area. The total area of the sub-basins is about 350 square miles.

The Okanagan River Basin falls partly within the Thompson Plateau which has a gently rolling upland of low relief, within the Shuswap Highland consisting of gentle or moderate sloping plateau areas, and the Okanagan Highland which includes rounded mountains and ridges and gentle open slopes. Within the Okanagan River Basin these areas are dissected by numerous short creeks. (Holland, 1964).

2.2 Topography and Drainage

Okanagan Lake is the principal body of water occupying the main valley. Okanagan River flows from the south end and through the smaller lakes of Skaha and Vaseux before entering Osoyoos Lake at the south end of the valley. The important tributary valleys in terms of groundwater movement are the O'Keefe Valley trending north to south entering the main valley near the north end of Okanagan Lake, Mission Creek Valley entering Okanagan Lake approximately near the centre of the east side of the lake, and Coldstream Valley running from the east and entering the main lake south of the town of Vernon.

The elevation range of the basin lies mainly between 1,000 and 6,000 feet above sea level. The distance from the drainage basin divides to the main valley is as much as 30 miles, but is commonly less than 15 miles. Gradients range from nearly vertical to nearly horizontal, with an initially rapid rise to 4,000 or 5,000 feet from the main valley floor at 1,000 to 1,600 feet per mile for 3 to 4 miles. Above 4,000 feet, the average slope is much less, up to 300 feet per mile.

2.3 Climate

The climate of the area, according to Köppen's classification, is

Middle Latitude Steppe (BSk) in which B = Dry climates, S = Semiarid, and k = Cold; mean annual temperature less than 64.4°F but mean temperature of warmest month over 64.4°F. (Canada, Department of Mines and Technical Surveys, 1957.) The average temperature ranges between 47.9°F at Oliver in the south end of the valley, and 44.6°F at Armstrong in the north end. The respective averages for precipitation are 10.79 and 17.18 inches per year.

3. GEOLOGY

3.1 Bedrock Geology

A description of the bedrock geology, for the purposes of this report, is limited to the north end of the Okanagan Valley from Enderby on the Shuswap River to Okanagan Lake. The bedrock geology can be divided into 3 main subdivisions. One, rocks of the Monashee Group occur on the east side of the valley. These rocks comprise mainly gneiss, but schist, quartizite, calcareous gneiss and marble are common. The rocks exhibit metamorphism of uniformly high grade and are of sedimentary origin (Jones, 1959). The other two subdivisions occur on the west side of the valley separated from the former by the Vernon-Sicamous fault system. Rocks of the Mount Ida Group are of both sedimentary and volcanic origin and have been subjected to low grade metamorphism. These rocks comprise mainly chlorite and sericite schists and garnetiferous quartz-mica schists, and quartzite. To the south, and in fault contact with the Mount Ida Group, is the Cache Creek Group. The Cache Creek Group comprises mainly argillite, andesite lava and limestone. Minor occurrences of Tertiary lavas are also to be seen (Fig. 1 - Pocket of Report).

3.2 Structure

"Faults illustrated on the map represent some of the latest deformation in the Vernon map-area.... The amount of movement on these faults is not known...and the irregular fault boundaries between major rock groups signify that movements are mainly vertical rather than horizontal" (Jones, 1959). An important system of faults trends northwest from Armstrong and they appear to exert a strong tectonic influence on the bedrock gradient of the thalweg for the main valley. This results in either a steep gradient between test holes C42 TH2 and C42 TH3, or of a generally uniform gradient interrupted by a definite fault. The former interpretation is preferred for the course of the old stream bed to allow for subsequent erosion within the bed following faulting. A fault is shown trending northwest near Kendry Creek and probably crosses the valley just north of C42 TH2. However, its direction is obscured by the surficial deposits within the main valley and by the above mentioned Tertiary lavas (Fig. 1).

3.3 Surficial Deposits

The references used in this report for describing the surficial geology (Fig. 1) of the Okanagan region are maps by Fulton, R. (1969, Maps 1244A and 1245A) and a report with maps by Nasmith, H. (1962). The foregoing maps show areas of mainly bedrock about 2,500 feet or probably thin morainal deposits over bedrock above about 1,500 feet. The morainal deposits are chiefly till, which is a deposit of unsorted sand, silt, clay and boulders. Below elevations of 1,500 feet, and predominantly on the east side of the valley, occur numerous fan or fan-delta deposits of gravel and sand. Coarse sand and gravel deposits on the west side of the main Okanagan Valley are to be found associated almost entirely with the O'Keefe tributary valley and the "lower part" of Deep Creek valley before it enters the main valley. The deposits of the main valley to be seen at ground surface are commonly silt and some clay.

At this point in the description of the surficial deposits attention is drawn to the north-south (Fig. 1) and east-west (Fig. 1) cross sections for the north end of the main valley. An important result of the test drilling conducted under Task 40, is the regional picture which can be constructed of the surficial deposits of the main valley. These can be divided into two parts -- lower and upper parts. The lower part of the sediments shows an alternating sequence of till, clay and silt, sand and gravel zones divided into units A to F. This sequence ranges from about 300 feet thick in the north at C43 TH5 to about 750 feet thick in the south at C42 TH1. The till zones range from about 40 to 100 feet thick; silt, sand and gravel zones are about 80 to 220 feet thick, and a clay-silt zone is about 100 feet thick. Facies changes within these layers may be due to non-deposition in some parts of the valley, or to removal and subsequent replacement by later glaciations. The uppermost of these silt, sand and graval zones is the one in which most of the deep test holes were completed as observation wells. The units A to F have been denoted in ascending order.

Overlying the succession of tills and sands, and comprising the upper part of the main valley deposits, is 500 to 1,000 feet of sediments that are mainly silt. There are some sand beds in the upper part of the sequence, and of particular importance to this study are the thick sands occurring in the Maid Creek area south of Armstrong. The sands in the upper part of the surficial deposits are commonly fine to medium-grained, angular sands.

Considerable local variations are anticipated within the upper part of the surficial deposits. Local deposits of gravel and sand on the east side of the valley are attributed to meltwaters from tributary valleys, and sands on the west side of the Maid Creek cross section may have been derived in association with meltwaters discharging to the south from Deep Creek (Fig. 1). It may also be observed that there is down-valley thickening of both the upper and lower parts of the valley-fill deposits.

4. SEISMIC EXPLORATION (TASK 39)

4.1 Objective

The purpose of the seismic work was to obtain information on the depth to bedrock across several sections in the Okanagan and O'Keefe Valleys, to try to determine the nature of the valley-fill deposits, to help to reduce the number of test holes required to locate the thickest section of overburden, and to help select the type of drilling equipment required to accomplish test drilling.

4.2 The Seismic Program

During the month of June 1970, reconnaissance field trips were made to evaluate the feasibility of running seismic lines as chosen during the office planning stages of the groundwater program. These trips were also essential to gain permission to run seismic lines across privately-owned land. Adjustments subsequently made proved to be minor. The program was directed by a consulting geophysicist, and an independent seismic company ran the profiles during the month of July. Four profiles were run in the north and two in the south part of the Okanagan River Basin.

The initial results showed the longitudinal bedrock valley profile, along the deepest parts of the cross sections, increased in depth below ground surface from about 800 feet at Enderby to about 1,600 feet at Armstrong. The depth to bedrock decreased to 800 feet in the south end of the valley at Okanagan Falls. Surface elevations of the bedrock-valley floor relative to sea level were about +300 feet at Enderby, about -600 feet at Armstrong and about +500 feet near Okanagan Falls. These elevation readings show the bedrock valley floor to be dipping rapidly towards Okanagan Lake at the north end of the lake, and to be rising at the south end of the lake. The table (Appendix A) compares predicted and actual depths to bedrock, and figures 1 and 2 of Appendix A show the initial seismic interpretation made prior to test drilling and the revised interpretation following test drilling. The valley-fill deposits were considered to be primarily silt and sand with some gravel. However, test drilling at the south end of the valley (C42 TH4, Fig. 4, Appendix A) penetrated almost all sand, gravel and boulders.

4.3 An analysis of the Seismic Program

The initial impression gained by Groundwater Division Staff during a preliminary field trip with Mr. R. Lundberg was that a fast, efficient and effective seismic program was feasible in the Okanagan Valley.

Results bore out prior opinions. Obviously, to form correct value judgements of the seismic program, this analysis concerns interpretations made prior to test drilling.

Predicted depths to bedrock made by the seismic consultant were stated to be within ± 10%. Of five holes drilled towards the middle of the valley, the percentage errors ranged up to 13% for three holes and 17% and 25% for two more. However, test holes drilled close to valley walls show considerable errors of 110% and 500%. Predicted depth for an anomalous layer in the middle of the valley had an error of only 2%.

Significant observations to be made were that the valley was filled mainly with silt and sand. Bed thicknesses, except as in the special case of the thin silt layer for part of seismic line 1, are hard to determine due to lack of velocity contrasts between the silt and sand. Even during test drilling it is sometimes difficult to pick lithologic changes especially as sands or silts are often thinly interbedded and much of the sand is of very fine grain size. Mr. Lundberg drew an interesting conclusion regarding seismic line 4 in that he expected the water level to be about 200 feet below ground surface. Available evidence from examination of drilling samples, suggested an oxidized zone 200 feet thick, and the depth to the water level recorded in test hole C43 TH4 was 193 feet below ground surface.

The seismic survey proved to be a very valuable technique for enabling the Groundwater Division to pick the deepest parts of the valley for test-drilling. The seismic results were the key factor in selecting the capacity of drilling equipment necessary to penetrate the full thickness of the overburden and drill on into the bedrock. Similar surveys would appear to be well worth while in future deep-valley groundwater exploration programs in the Province of British Columbia. A copy of Mr. Lundberg's revised final report is given in Appendix A. Copies of the earlier final report are available at the office of the Groundwater Division, Water Investigations Branch, Department of Lands, Forests and Water Resources, Victoria, British Columbia and at the office of the Director, Canada-British Columbia Okanagan Basin Study Agreement, Penticton, British Columbia. Mr. R. Lundberg's work has since been presented at the 41st International Meeting of the Society of Exploration Geophysicists, November, 1971 and was published under the title "Seismic Techniques Applied to Groundwater Research in the Okanagan Valley, British Columbia".

5. ROTARY TEST HOLE DRILLING PROGRAMS (TASK 40)

5.1 Objective

Beginning in late September 1970 and continuing on into early November, two rotary test hole programs were conducted under Contracts 42 and 43. The purpose of the test hole drilling was initially designed to drill through the overburden to the bedrock, and to provide information on the type, thickness and continuity of the valley-fill deposits, to study geologic structure of the main valley, and also to check on the value of preliminary seismic exploration work. In addition to this planned objective, the test holes were left cased to be used as observation wells. Later, these wells, after cleaning and development, were used for short pumping tests to make estimates of well yields and obtain transmissivity values for some of the aquifers.

5.2 Achievements

Nine holes were drilled under the above contracts, four with a 3,500 foot capacity Failing rig to depths ranging from 850 to 1,900 feet for a total cost of $102,000, and five with a 2,000-foot 'Con-Cor' rig to depths ranging from 120 feet to just over 900 feet, for a total cost of $35,000.

Observation wells were completed in these test holes mostly with 10 feet of four-inch diameter pipe-size screens, washdown bottom and four-inch casing. The deepest well screen is set at 1,215 feet deep. The construction of some deep 4- to 7-inch diameter water wells and successful drilling of test holes to bedrock using the rotary method under sometimes very difficult drilling conditions, marked a major step forward in deep-valley groundwater exploration programs in the Province.

The rotary technique proved to be quite successful due to the adoption of a mud program newly-tried in the Okanagan Valley. This mud kept holes open for up to 25 hours, and withstood artesian pressure conditions until development was begun. In the interval between the end of drilling and running casing, four geophysical borehole logs were run in eight of the nine holes. Composite drilling logs are submitted with this report, one set being derived mainly from Mr. E. Livingston's work on the deep test holes (Appendix B). Very thick permeable deposits, up to about 800 feet of sand, gravel and boulders, were encountered in the Okanagan Falls test hole. An interpretation of the hydrogeological information obtained from the test drilling programs is presented within this report and has been used in the compilation of maps and cross sections.

6. HYDROGEOLOGY

6.1 General Statement

Prior to a more detailed discussion of the north end of the valley, reference will be made to figure 2 contributed to the study by Mr. E. C. Halstead. This shows a diagramatic cross section presenting a conceptual representation of groundwater flow in relation to surface drainage for the Okanagan River Basin. The stream discharge measurements at the south end of the valley, for the year 1967, are designed to illustrate that some of the water contributed by tributary streams is added to groundwater or is lost in consumptive use (that is by evapotranspiration and diversion). The increment to groundwater of 16,500 acre feet from Vaseaux Creek is not recorded by the difference in flow between the two gauging stations at Okanagan Falls and at Oliver. Whatever quantity is not lost to consumptive use must be passed through the basin as groundwater flow (personal communication E. C. Halstead, 1972).

6.2 Basic Water-Well Data

Basic information, mainly water-well data submitted by water-well drillers and that collected from well inventories, was plotted on topographic maps of a suitable scale. The most suitable topographic maps available are at a scale of 1 inch to 1,000 feet. Results of analysis and synthesis of this data and of data from test hole drilling and pump testing supervised by the Groundwater Division have been used in the compilation of figure 1 and in writing this section on hydrogeology. Many of the control points are shallow wells commonly less than 50 feet deep recording only well depth and the depth to the non-pumping water level.

6.3 Aquifers in the Surficial Deposits

Based on available data, an attempt has been made to show the areal extent and thickness of some of the aquifers in the surficial deposits (Fig. 1). For aquifer Units B, D and F in the lower part of the surficial deposits their possible extent and thickness is shown by the cross sections N-S and W-E. Units D and F may occur throughout the entire north end of the Okanagan Valley, the former ranging from about 85 to 140 feet thick and the latter from about 125 to 150 feet thick. Unit F is considered to be composed mainly of sand and gravel with some silt, the silt content sometimes being locally predominant as in C42 TH3. Unit D shows a change from sand and gravel in the north to clay, silt and sand in the south. Unit B, up to 150 feet thick, is composed of sand and silt. As Unit B is the deepest aquifer it is of smaller areal extent being absent to the north where the bedrock gradient steepens and is further limited by the narrower width with increasing depth between the V-shaped bedrock valley walls. The only major aquifer in the upper part of the surficial deposits occurs in the Armstrong area and locally has a known thickness of about 800 feet. Water level measurements in wells completed in both the lower and upper parts of the surficial deposits show the aquifers are confined, the heads rising above the top of the aquifer. In some cases the aquifers are artesian.

Locally important aquifers of more limited areal extent are the numerous fan deposits of sand and gravel flanking the east valley wall. These occur for a limited distance toward the centre of the valley beneath or interfingering with the Upper Lake Beds. Close to the valley wall these aquifers are unconfined but beneath the Upper Lake Beds they are confined aquifers.

The most important unconfined (water-table) aquifer in the study area occurs in the O'Keefe Valley. The map of the surficial geology shows sand and gravel deposits occur throughout the entire length of the valley (Fig. 1). These deposits are known to be 575 feet thick (C43 TH4) at the south end of this valley and to have a saturated thickness of 350 feet. Similar data is not available for the north part of the valley. However, the water levels in the wells, and the lake levels can be mapped as a continuous water-level surface. It is therefore considered the water in the valley-fill deposits forms one continuous aquifer and for the purposes of this report is named the O'Keefe Valley aquifer.

Another unconfined aquifer occurs about 4½ miles to the north of Armstrong. It is composed of sand and gravel occupying a narrow bedrock channel. This aquifer trending from southwest to northeast is about 4 miles long and ½ mile wide with a saturated thickness of up to 200 feet. It has been reported by a local resident that in very dry weather (1970) permanent flow in Deep Creek occurs only where this creek cuts through the surficial deposits occupying this bedrock channel.

6.4 Groundwater Movement, Recharge and Discharge Areas

Figure 1 integrates the salient findings of this hydrogeological study of the north end of the Okanagan River Basin. The water level contours portray a well known concept that the water table is a subdued replica of the topography. The flow of groundwater is normal to the water-level contours and from the map it can be seen the movement of groundwater is towards the centre of the valley. At the water table, in the vicinity of Deep Creek and Fortune Creek groundwater flow will be to the north and to the south from the topographic divide between these creeks.

From water level or pressure readings in deep wells completed in Units D and F groundwater flow occurs to the north and south from a groundwater divide located between wells C42 TH3 and C43 TH5. Also, from seismic work, it is known that there is a divide in the bedrock valley profile between these same two wells. This bedrock divide will also create a barrier to groundwater flow from the Enderby area to the south near the bedrock valley floor. From the available data it can be shown that deep groundwater flow does take place to the south from the Fortune Creek valley beneath the forementioned topographic divide and towards Okanagan Lake.

The areas of recharge to deep and shallow aquifers are the valley sides with the main parts probably being associated with the fan deposits of sand and gravel flanking the east side. The methods of recharge are directly by precipitation, and indirectly by underflow from tributary creeks flowing into the fan deposits.

The discharge areas occur in the valley bottom and can be divided into regional and local categories. The local discharge areas occur within the fan deposits and are indicated by such discharge phenomena as flowing wells and springs. Springs and flowing wells occur about 1½ and 3 miles south of Armstrong (Fig. 1). The regional discharge area (an area of potential artesian flow) is delineated as occurring within a narrow zone bordering Fortune and Deep Creeks. It is considered that the area of artesian flow occurs approximately below elevations of 1,220 feet above sea level near Enderby to 1,175 feet above sea level south of Armstrong. Evidence for this interpretation is based on locations of flowing wells, and on water level measurements in non-flowing wells. In well C42 TH3 at an elevation of about 1,215 feet above sea level, the water level has risen as close as 1½ feet below ground surface. Evidence of extension of the area of regional artesian flow into the Shuswap River valley is given by well C43 TH5, which flows, and also by a well (Hruschak, J., personnel communication) about 4 miles up this valley from which water flows from a depth of 600 feet.

Groundwater temperatures taken under Task 41 for the deep wells in the Armstrong-Enderby area show one anomalously low reading of 11½°C, C42 TH2, compared to the other 3 wells with warm waters of about 17 to 20°C (Table 1). The occurrence of a narrow zone of warm waters comparable with that of the regional discharge area is possible but not proved. However, the low temperature reading from C42 TH2 suggests the close proximity of the well to recharge groundwaters. Further, this well water had the lowest total dissolved solids content of the deep groundwater sampled. Located only 3,500 feet from the entry of Glanzier Creek into the main valley, it offers some evidence that fan deposits may be a source of recharge. However, it must not be ignored that fault zones could locally be an important medium of recharge. This may be the case for well C42 TH2 which occurs only about 700 feet from the point of termination in the buried bedrock-valley wall of a fault cutting across Kendry and Glanzier Creeks (Fig. 1).

The nonpumping water level of 101 feet in well C43 TH2 was about 40 feet deeper than expected. The original purpose of the test hole was to determine the nature of an anomolous lens detected by seismic work along the Maid Creek cross section (Fig. 1). The cause of the low water level may be the result of the location of this well in relation to a lens of less permeable material (silt) in more permeable surrounding deposits (fine- to medium-grained sand) as explained by Tóth (1962). Near the upstream part of a lens the difference between the original undisturbed potential field and the new one gives rise to a negative effect on the water levels. Therefore the deeper depth to the nonpumping water level than was anticipated is believed to be due to the occurrence of the well in the vicinity of the upstream part of the lens.

6.5 Transmissivity Values

There is very limited information concerning transmissivity values for aquifers in the study area. The data are obtained mainly from Task 41 (Le Breton, 1972).

Transmissivity values (Table 1) for aquifers in the lower part of the surficial deposits are available for units D and F. For wells C42 TH1 and TH3 in unit F the values are comparable, 1980 and 1132 igpd/ft (imperial gallons per day per foot). The pump test graphs for both wells (Figs. 3 and 5) are partly comparable showing a period of stabilized water levels after one log cycle of drawdown. In both cases stabilization may be due to partial penetration which is similar to that of recharge (Hantush, 1961). The transmissivity values shown in Table 1 are different from those on the graphs because corrections have been made for partial penetration in wells C42 TH1 and TH3. The information from these two wells is comparable (Table 1) with regard to aquifer thickness, transmissivity, permeability, water temperature and water quality.

The transmissivity value for well C42 TH2 in Unit F is 34,300 igpd/ft. A similarly high figure, 26,400 igpd/ft was obtained for C43 TH5 in unit D. The transmissivity value from well C42 TH2 contrasts with that for the other two wells in unit F to the north and south. Its considerably higher transmissivity suggests the areal extent of clean sand and gravel deposits in the zone is limited. From figure 4 a very definite discharge boundary condition became evident towards the end of the pump test. This is denoted by the steep change in slope of the drawdown graph. The effect of the discharge boundary is very important because the lower transmissivity of 2,090 igpd/ft will result in a

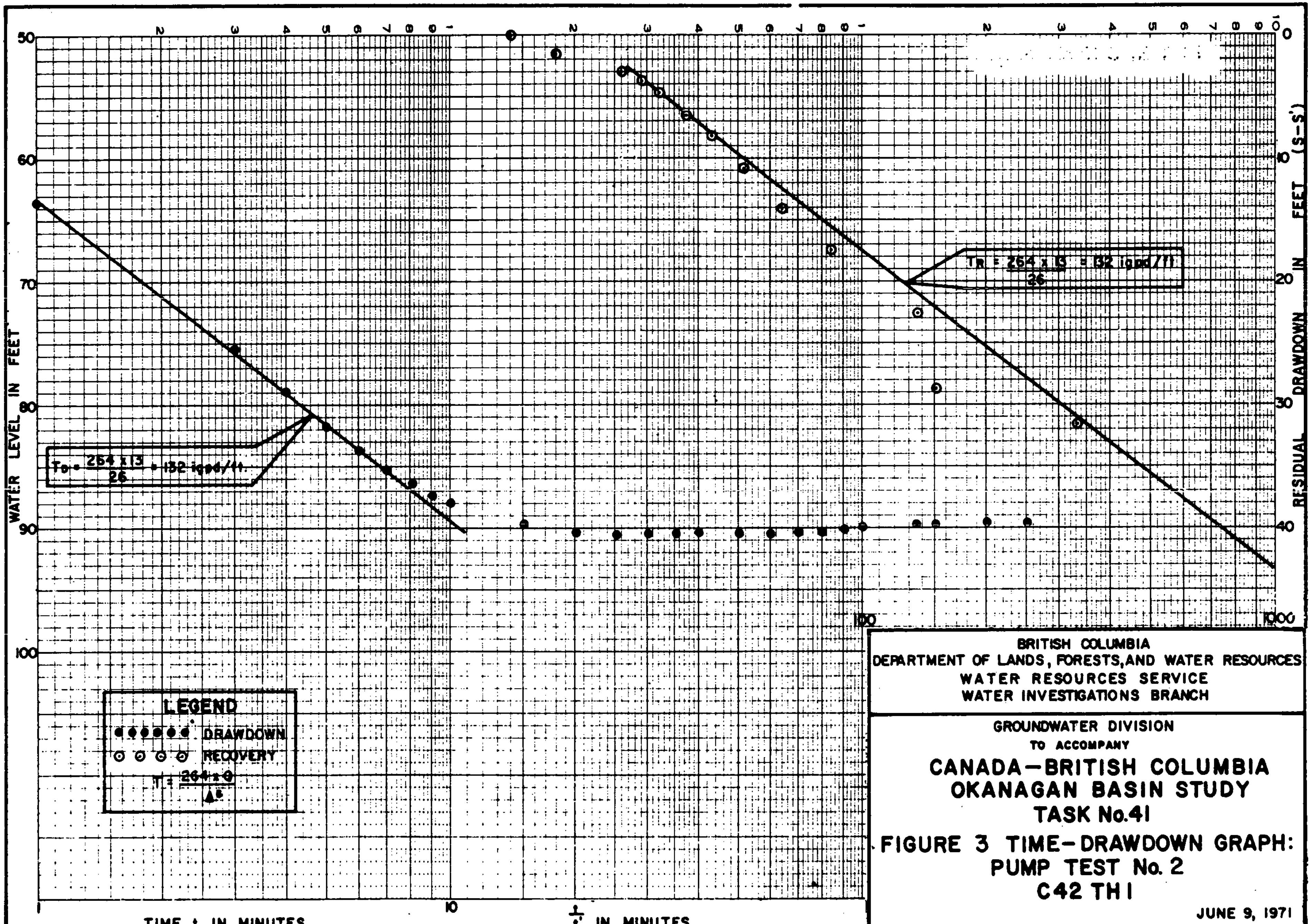
Table 1: Table of Pumping Test Information

		CONTRACT 42			CONTRACT 43			
		TH1	TH2	TH3	TH2	TH3	TH4	TH5
1	Depth* to top of aquifer (feet)	1,140	1,000	700	220	320	192	790
2	Depth to base of aquifer (feet)	1,290	1,140	840	430	330	548	875
3	Aquifer thickness (feet)	150	140	140	210	10	356	85
4	Depth to nonpumping water level (feet)	53	48	4	101	24	192	+20
5	Available drawdown (to top of aquifer) (ft)	1,087	952	696	119	296	178	810
6	Available drawdown (pump set at 200 feet)	147	152	196	99	176	8	220
7	Screen (pipe size: same ID as casing)							
	(a) diameter (inches)	6½	4	4	4	4	4	4
	(b) slot size (No.)	40	40	40	15	40	40	6,15
	(c) length (feet)	10	10	10	10	10	10	20
	(d) depth to top (feet)	1,215	1,016	720	270	320	527	825
8	Transmissivity, T (igpd/ft)	**1,980	34,300	**1,132	27,700	100	-	26,400
9	Permeability, K (igpd/ft^2)***	13.2	245	8.1	130	10	-	300
10	Length of pump test (minutes)	250	3,000	300	1,750	750	300	300
11	Stabilized pumping level (feet)	90	-	-	118.4	-	194.7	-
12	Stabilized drawdown (feet)	37	-	-	17.4	-	2.7	-
13	Specific capacity (igpm/ft)	0.35	-	-	2.4	-	16	-
14	Safe yield (specific capacity estimate)							
	(a) drawdown to top of aquifer (igpm)	265	-	-	200	-	2,850	-
	(b) drawdown to pump setting of 200 feet (igpm)	36	-	-	183	-	90	-
15	Safe yield (Q_{19} estimate)							
	(a) drawdown to top of aquifer (igpm)	-	1,540	37	-	13	-	5,300
	(b) drawdown to pump setting of 200 ft (igpm)	-	250	10	-	8	-	1,250
16	Well loss in feet per igpm after 1 min of pumping	0.77	0.14	5.0	0.37	1.0	-	0.08
17	Temperature °C	20	11.5	18.5	10.5	13.5	13	16.5

* All depths measured from top of casing

** T value corrected for partial penetration

*** equivalent to hydraulic conductivity, the field coefficient of permeability



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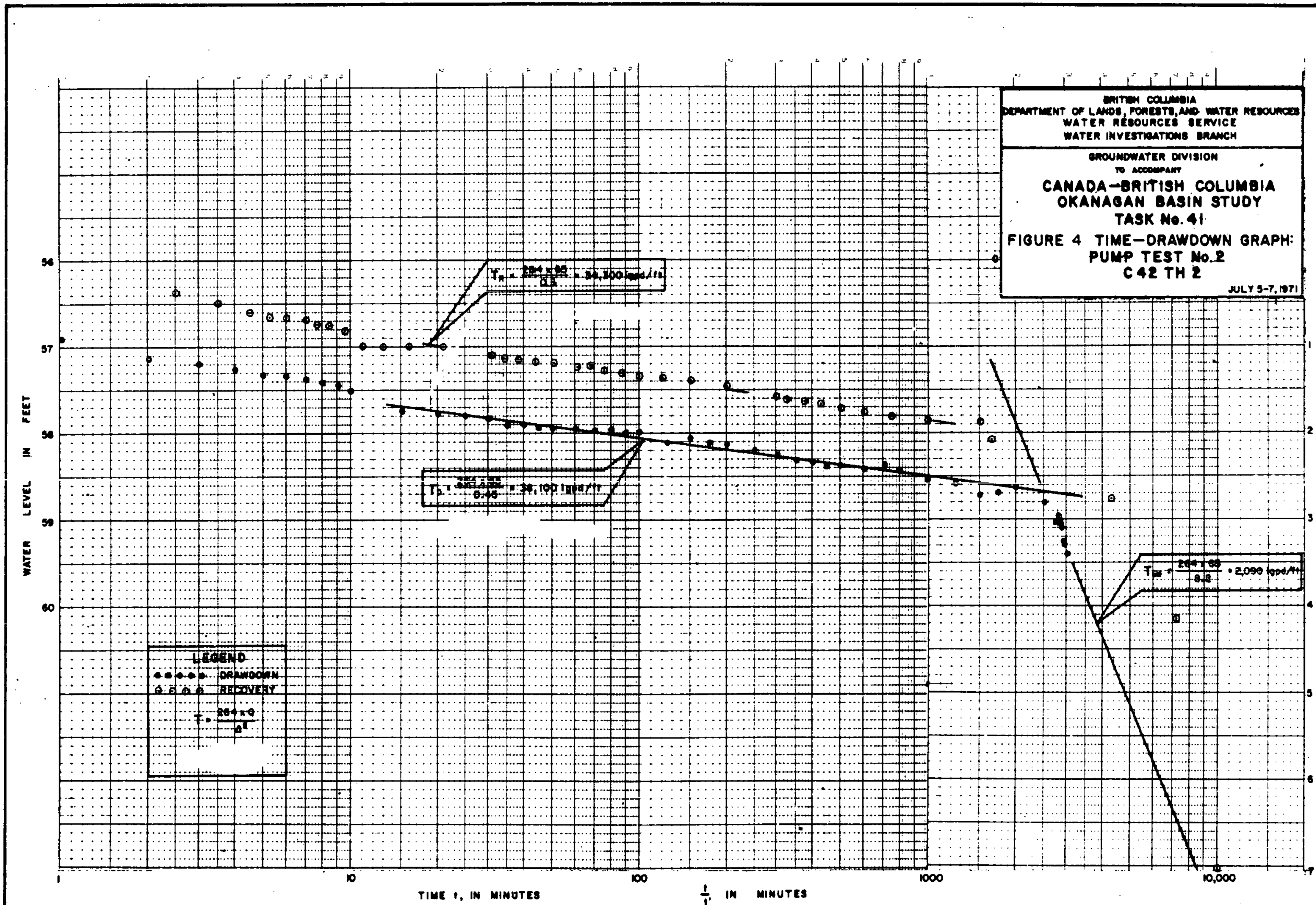
CANADA–BRITISH COLUMBIA OKANAGAN BASIN STUDY
TASK No. 41

FIGURE 3 TIME–DRAWDOWN GRAPH: PUMP TEST No. 2 C42 TH I

JUNE 9, 1971



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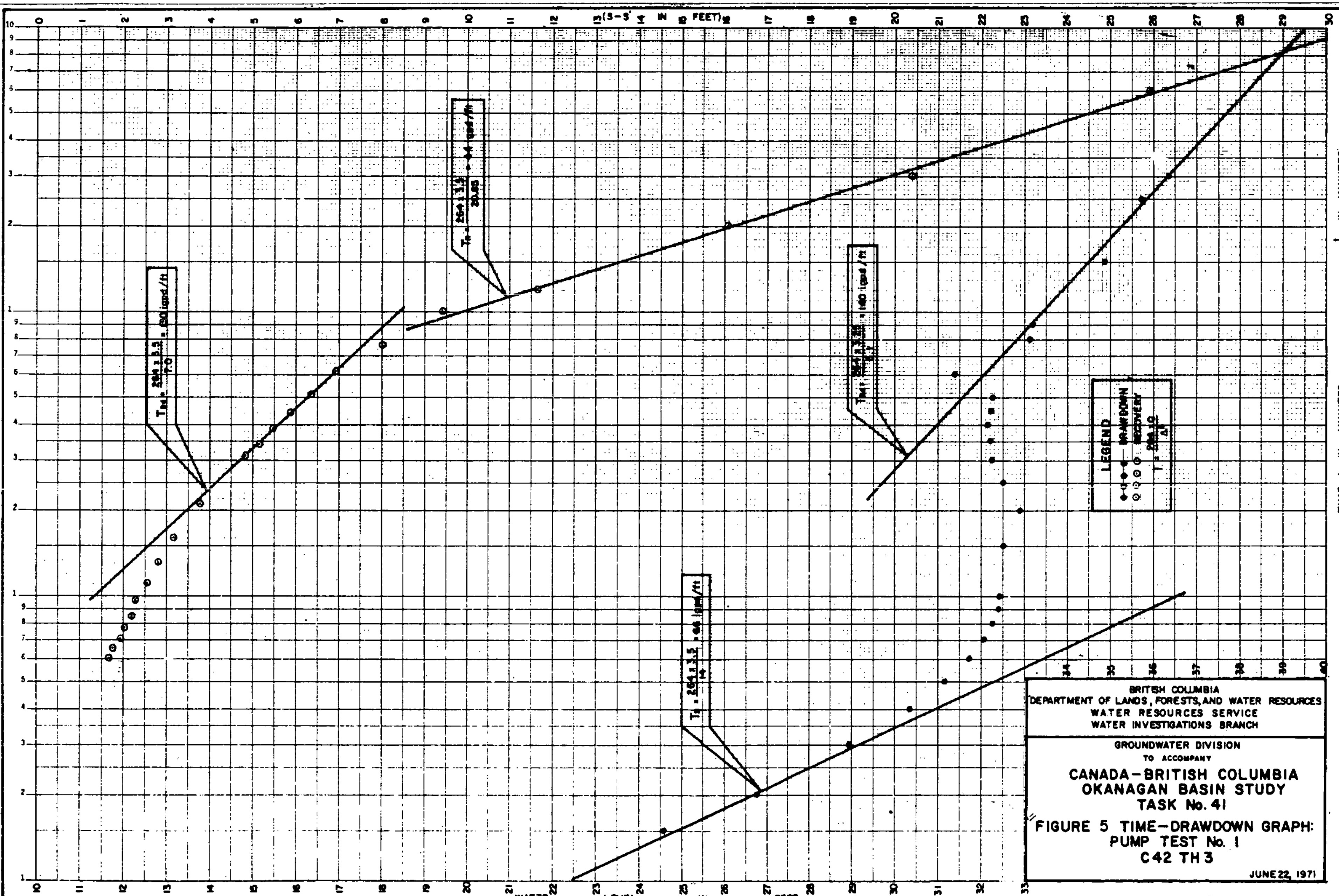
OKANAGAN BASIN STUDY
TASK No. 41
FIGURE 4 TIME-DRAWDOWN GRAPH:
PUMP TEST No. 2
C 42 TH 2
JULY 5-7, 1971
LEGEND
DRAWDOWN
RECOVERY
WATER LEVEL IN FEET
TIME t, IN MINUTES
t/t', IN MINUTES
= 34,300 igpd/ft
= 38,100 igpd/ft
= 2,090 igpd/ft



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TASK No. 41

FIGURE 5 TIME–DRAWDOWN GRAPH:
PUMP TEST No. 1
C42 TH3

JUNE 22, 1971

considerably lower well yield.

Two transmissivity figures were obtained under Task 41 for the upper part of the surficial deposits. A transmissivity of 27,700 igpd/ft for C43 TH2 (Fig. 6) is obtained for the part of the aquifer 210 feet thick above the silt lens. This figure is quite comparable with that of 85,400 igpd/ft for the same aquifer 600 feet thick encountered in well C26 TH2 put down prior to this study. A transmissivity of 100 igpd/ft was obtained from the pump test in well C43 TH3.

Data for transmissivity acquired from work under Task 41 considerably increases knowledge of the hydrogeology of the study area.

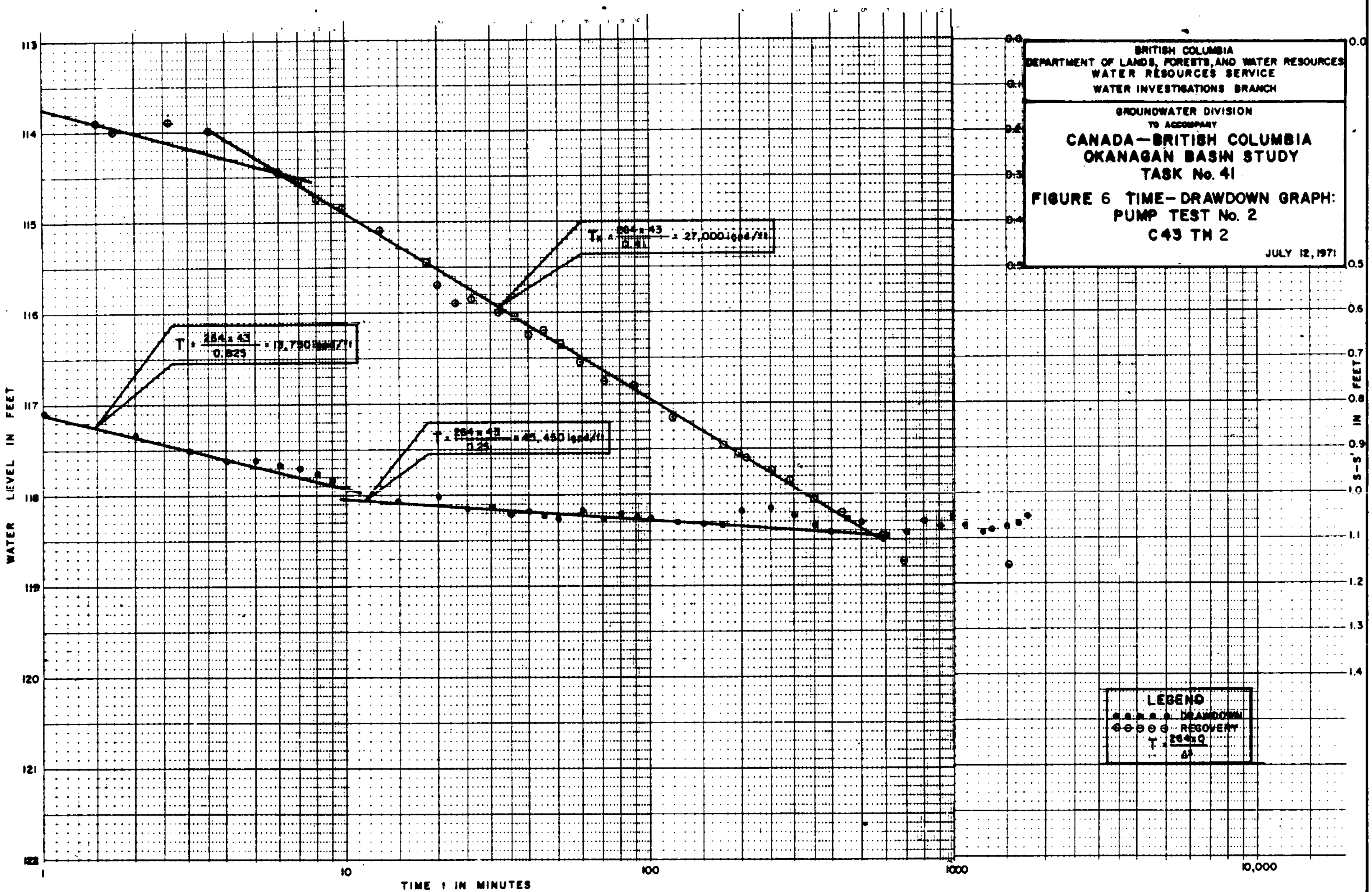
6.6 Water-Well Yields (Task 41)

The estimated well yield calculations given in this section are intended to replace earlier estimates given in previous reports.

In the main Okanagan River Valley deep well pumping test data commonly indicate low well yields (Table 1) from wells about 700 to 1,200 feet deep. Yields range from 10 igpm (imperial gallons per minute) for pumping depths of 200 feet below ground surface to 265 igpm to the top of the aquifer for wells C42 TH1 and TH3 in Unit F. Also completed in Unit F, well C42 TH2 has a higher estimated yield of 250 igpm to the top of the aquifer. However, the only really favourable locality for further development is that indicated by C43 TH5. The very short period of free flow from this well, associated with well development lasting for about 5 hours, is insufficient to indicate declining flow or discharge boundaries. However, for pump settings of 200 feet, this is the only site where well yields of up to 1,000 igpm may be obtained. Further testing is essential to substantiate this statement.

Well yields from aquifers in the upper part of the surficial deposits may locally be high, as in the Armstrong area. For a pump setting of 200 feet a well yield of 183 igpm for C43 TH2 has been calculated from Task 41 data. This yield was derived from a specific capacity of 2.4 igpm and includes a 30 percent safety factor. The safety factor is introduced to allow for declining water levels which occur in reality in conjunction with constant pumping rates. From data for a production well, C26 TH2, of a prior study it is stated a yield of about 850 igpm is possible. This estimate is made for the well as designed by Mr. E. Livingston. The specific capacity is about 38 igpm at a pumping rate of 328 igpm. Based on specific capacity a theoretical yield is obtained of 3,400 igpm which includes a 30 percent safety factor. This yield is for drawdown to the top of the aquifer at a depth of 180 feet below ground surface (Fig. 1).

The significant differences in yield between the two wells is primarily due to design. The calculated yield from C43 TH2 is obtained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TASK No. 41
FIGURE 6 TIME-DRAWDOWN GRAPH:
PUMP TEST No. 2
C43 TH 2
JULY 12, 1971
WATER LEVEL IN FEET
S-S' IN FEET
TIME t IN MINUTES
LEGEND
DRAWDOWN
RECOVERY

from a test hole completed for observation-well use and to obtain preliminary groundwater information. The other well C26 TH2 was completed as a production well and designed to operate at a high efficiency. This comparison is made to show that higher yields may be obtained from better designed wells. Thus well yields calculated from Task 41 data may actually be considered as minimum values.

The "capped" well near the east end of the Maid Creek cross section (Fig. 1) had a free flow of about 320 igpm from 220 feet. The specific capacity of this well is 9 igpm/ft of drawdown giving a theoretical yield of about 1,600 igpm to the top of the aquifer.

The figures for the above wells do not take into account the effects of hydrogeological boundaries, the effects of which will be to reduce well yields. Thus well-yield estimates of up to 500 igpm may prove to be more realistic.

As very limited information is available for the O'Keefe tributary valley (Fig. 1) little reference has been made to this valley so far. On the basis of specific capacity data (Table 1) it would appear that high well yields are obtainable from the O'Keefe Valley aquifer. As specific capacity declines with yield (Todd, 1959, p. 111) and no data is available concerning discharge boundary conditions it is suggested that yields of 500 igpm may be obtained, and possibly 1,000 igpm.

In the narrow southwest-northeast trending bedrock channel aquifer extending about 4 miles to the northeast from Parkinson Lake, 4½ miles northwest of Armstrong, well yields of up to 50 igpm may be obtained. A short tributary creek 2,000 feet long draining from this aquifer into Deep Creek about 4½ miles north of Armstrong is supplied mainly by one spring flowing at an estimated rate of 150 igpm (Fig. 1).

6.7 Groundwater Flow Calculations

The following calculations for groundwater flow are based on the data obtained from Task 41 and replace previous calculations (Le Breton, 1971). The reader should first be made aware of the limits of accuracy of the following flow estimates. It would be misleading if it were suggested that the accuracy of these estimates was any better than one order of magnitude. By this definition it is meant the value of each figure is unlikely to be either 10 times as small or 10 times as large as the figure cited, but might lie somewhere between these 2 extremes. The figures presented below apply to the Maid Creek (W-E) cross section (Fig. 1). This is the section for which most information on geology and groundwater hydrology is available.

Groundwater flow was calculated by using the formula:

$$Q = KIA$$

in which Q = rate of flow (in cfs and ac.ft/yr)
K = permeability (hydraulic conductivity) (in $igpd/ft^2$)
I = hydraulic gradient (in ft/ft)
A = cross-sectional area (in sq.ft)

Permeability values have been derived from transmissivity figures given in Table 1 and were obtained by dividing transmissivity by the aquifer thickness; the hydraulic gradient is derived from differences in water level readings in wells divided by the distance between wells; and the cross-sectional area is the product of aquifer thickness multiplied by the possible aquifer width.

Groundwater flow for the lower part of the surficial deposits was calculated for the cross-sectional area "CD" of Unit F (Fig. 1) allowing for an aquifer thickness of 125 feet. This is the zone within which groundwater flow is considered to be the most significant. It has the largest cross-sectional area and is considered to be the zone with the highest permeability comprising sand and gravel with some silt. It was previously assumed Unit F would have a permeability of 1,000 $igpd/ft^2$ (imperial gallons per day per square foot), but subsequent pump testing showed a figure of only 13.2 $igpd/ft^2$.

Using the formula:

$$Q = KIA$$

where $K = 1.32 \times 10^{1}$ $igpd/ft^2$
$I = 1.4 \times 10^{-3}$ ft/ft
$A = 1.25 \times 10^{6}$ sq ft

the total underflow is calculated as 4.3×10^{-2} cfs (cubic feet per second).

Underflow for the upper part of the surficial deposits was previously calculated using a permeability of 300 $igpd/ft^2$ derived for the screened protion of the aquifer of well C26 TH2. However, after obtaining data from well C43 TH2 giving a permeability of 130 $igpd/ft^2$ this figure is used for revised groundwater flow calculations. This figure for that portion of the aquifer overlying the silt lens compares favourably with a figure of 140 $igpd/ft^2$ from well C26 TH2 having an aquifer thickness of about 600 feet.

Using the formula:

$$Q = KIA$$

where $K = 1.3 \times 10^{2}$ $igpd/ft^2$
$I = 1.4 \times 10^{-3}$ ft/ft
$A = 7.2 \times 10^{6}$ sq ft

total groundwater flow for the cross-sectional area "AB" is 2.44 cfs (1,780 acft/yr).

The combined total groundwater flow for the aquifers for which data is available is 2.48 cfs. The actual total cross-sectional area through which flow occurs is larger than that used in the above calculations, but the remaining sediments are almost certainly less permeable. Based on the presently available data, a rate for groundwater flow of about 2½ cfs (1,825 acft/yr) is likely to be a reasonable figure.

Total groundwwter flow toward Okanagan Lake includes that from the O'Keefe tributary valley which enters the main valley at a point south of the Maid Creek cross section. No permeability values could be obtained from pump tests for the O'Keefe Valley aquifer under Task 41. Calculations for groundwater flow for this aquifer have been revised on the basis of existing data only.

In a previous calculation a K value of 6,000 igpd/ft^2 was used for the screened portion of the aquifer from the first pump test on a well 5,000 feet south of C43 TH4. A lower figure of about 1,000 igpd/ft^2, for the permeable section of the deposits of this well and obtained from a later pump test, is used in the revised calculations given below.

Applying the formula:

$$Q = KIA$$

where
$K = 1{,}000$ igpd/ft^2
$I = 3.7 \times 10^{-3}$ ft/ft
$A = 1.26 \times 10^{6}$ sq ft

groundwater flow is 0.86 cfs (625 acft/yr).

Summing the groundwater flow for the main valley and the O'Keefe Valley, total underflow toward Okanagan Lake is 3 1/3 cfs (2,370 acft/yr).

6.8 Theoretical Calculation of Recharge

As some indications concerning well yields and underflow have been given, so too will a theoretical evaluation be made of recharge to the water table. This will be made with regard to the map of the water-table contours, average annual precipitation for the weather station near Armstrong and the possible area of recharge along the west and east sides of the main Okanagan Valley.

The average annual precipitation for the weather station near Armstrong is 17.18 inches. This figure is considered an average for the area between Okanagan Lake and the Shuswap River as the site is roughly centrally located. The water-table contours reflect the topography of the land surface and as the direction of groundwater flow is normal to the contours, recharge is from the valley sides. With the existing steep gradients, commonly 1,000 to 2,000 feet per mile much of the valley slopes are considered to be recharge areas. For the purposes of this report, for the 17 mile distance between Okanagan Lake to the Shuswap River, a recharge width of 3 miles is taken for the east side of the valley and of 1 mile on the west side of the valley, giving a recharge area of 68 square miles. For calculation purposes, 70 square miles is used. Also 1 inch of precipitation is assumed to reach the water table, a not unreasonable assumption as 1 inch of recharge is only 6 percent of the average annual precipitation.

To calculate the volume of 1 inch of water per square mile:

A 1 sq mi = 27,878,400 sq ft

1 inch of water per sq mi = 2,323,200 cu ft of water

B Number of seconds per year = 31,536,000

C Quantity of recharge of 1 inch per sq mi = 0.0736 cfs

D Quantity for 70 sq mi = 5.152 cfs

Some interesting conclusions may be drawn from comparison of the groundwater flow calculations in relation to recharge from precipitation. The groundwater flow of 2½ cfs (1,825 acft/yr) at the Maid Creek cross section for the north end of the main valley is well within the range of 5 cfs (3,650 acft/yr) derived from precipitation given a recharge of 1 inch of water to a recharge area of 70 square miles. There is then an adequate quantity of recharge to the water table to account for the total underflow.

Similar calculations for the recharge area of the O'Keefe Valley aquifer which is estimated to be 10 square miles is 0.74 cfs (540 acft /yr) or slightly less than the calculated underflow of 0.86 cfs (625 acft/yr). However, this is acceptable for there seems to be a definite possibility of hydraulic continuity between the Salmon River and groundwater at the north end of the O'Keefe Valley aquifer. The northernmost lake has a water-level elevation of 1,480 feet which is about 20 feet below the elevation of the Salmon River occurring, 2,200 feet further north. There is a definite prospect of movement of groundwater from the Salmon River Valley into the O'Keefe Valley. There is no information at the north end of this valley regarding cross-sectional area and lithology of the deposits to calculate the rate of groundwater flow into this valley. Therefore in this report no estimate will be made of flow from the Salmon River Valley to the O'Keefe Valley even though it seems to be a definite possibility.

The total groundwater flow towards Okanagan Lake is about 3 1/3 cfs (2,370 acft/yr). This stands in contrast to an initially calculated figure of 12 cfs (8,750 acft/yr). However, it lies within a range of accuracy of one order of magnitude as considered likely in the Groundwater Review Board's appraisal of an earlier progress report (Le Breton, 1971).

6.9 Hydrogeochemistry

The addition of eight more chemical analyses of groundwater for the study area permits some understanding of the regional picture of the groundwater chemistry. These data combined with water-temperature data also appear to provide some supporting evidence concerning sources of groundwater recharge.

Completely new information was gathered under Task 41 from 4 deep wells concerning groundwaters from 2 aquifers in the lower part of the surficial deposits. Three of these wells are completed in the upper unit, Unit F, of these deposits and show the water is low in total dissolved solids content, about 200 to 500 ppm (parts per million). The water is primarily calcium and magnesium bicarbonate with minor amounts of sodium sulfate. Well C42 TH2 with the freshest water quality, calcium and magnesium bicarbonate-type water of 200 ppm total dissolved solids content and quite cool water temperature, 11½°C, provides strong indications of receiving recharge water. The other two wells are sited in areas where similarly deep groundwaters have undergone warming influence with temperatures from 18½° to 20°C. Similarly warm water 16½°C and water quality data were obtained for the well completed in the middle unit, Unit D, of the lower part of the surficial desposits. These warm waters suggest a narrow zone of warm regional discharge area groundwaters occurs in the middle of the main valley.

Wells in the upper part of the surficial deposits are commonly very low in total dissolved solids content, 150 to 180 ppm, with calcium and magnesium-bicarbonate type water. The water temperatures are quite cool from 10½°C to about 13°C. The very low total dissolved solids content of water from the private "capped" well, Maid Creek (W-E) cross section (Fig. 1), indicates the close proximity of the well to a source of groundwater recharge. Both this "capped" well and well C42 TH2 may receive water by underflow from tributary creeks through fan deposits near the mouths of these creeks. It is also possible that well C42 TH2 may alternatively be close to a source of recharge coming from a bedrock fault zone.

Two chemical analyses of groundwaters are available near the south end of the O'Keefe tributary valley. One well shows water of calcium and magnesium bicarbonate type with a total dissolved solids content of 361 ppm from a depth of 192 feet. The second well shows calcium and magnesium bicarbonate and sulfate water with a total dissolved solids content of 588 ppm from a depth of 527 feet. This increase in dissolved solids content with depth is consistent within the writer's limited experience of such information.

In summary, it may be stated that the groundwaters are of calcium and magnesium bicarbonate type, low in total dissolved solids content, commonly less than 500 ppm. The water is considered fit for human consumption and commonly suitable for irrigation use. For industrial purposes the water is of very good quality and should require only limited treatment, treatment varying according to the process for which the water is used. For washing clothes the water will require some softening as the hardness commonly ranges from 120 to 160 ppm.

7. EVALUATION OF RESULTS

There is very limited test hole control, including pump-test data, in the study area. This is especially so for deep test holes, which is due to the high costs and difficulties of conducting deep-valley groundwater exploration programs. However, the quantity and quality of the information available is just sufficient to enable a regional hydroeological evaluation of the area to be carried out.

There is just sufficient water-level data for determination of hydraulic gradients for some deep and shallow aquifers, thus permitting a regional interpretation of groundwater movement and an understanding of recharge and discharge areas. From the distribution of the pump-test data, it is possible to distinguish aquifers which locally may be suited to high-yield wells about 1,000 igpm, but lower yields less than 100 to 200 igpm are commonly anticipated. The permeability values obtained from pumping tests make groundwater flow calculations possible. These flow values can be compared with theoretical recharge estimates. Estimates have also been made for the determination of groundwater resources available from water mining. Possible time periods required to recharge depleted resources have also been calculated. It is thought that reasonable conclusions concerning groundwater resources and well yields have been reached.

Information gathered on water quality show groundwaters, though commonly hard, are suitable for human consumption and irrigation, and requires only limited treatment for industrial purposes, and for laundering.

The results obtained directly from the siesmic program (Task 39) from test drilling (Task 40) and pumping tests (Task 41) were good. It has been demonstrated that seismic programs are a valuable preliminary phase in deep-valley groundwater exploration studies for planning test drilling. Test drilling alone is inadequate without subsequent pumping tests for aquifer evaluation.

It can be stated that the importance of groundwater resources relative to surface water resources or surface water development programs can be readily assessed. This can be done even though the actual quantity of groundwater available for development on an annual or water-mining basis may have been considerably underestimated. However, it becomes apparent that groundwater resources are not a feasible alternative to large scale development of surface water resources.

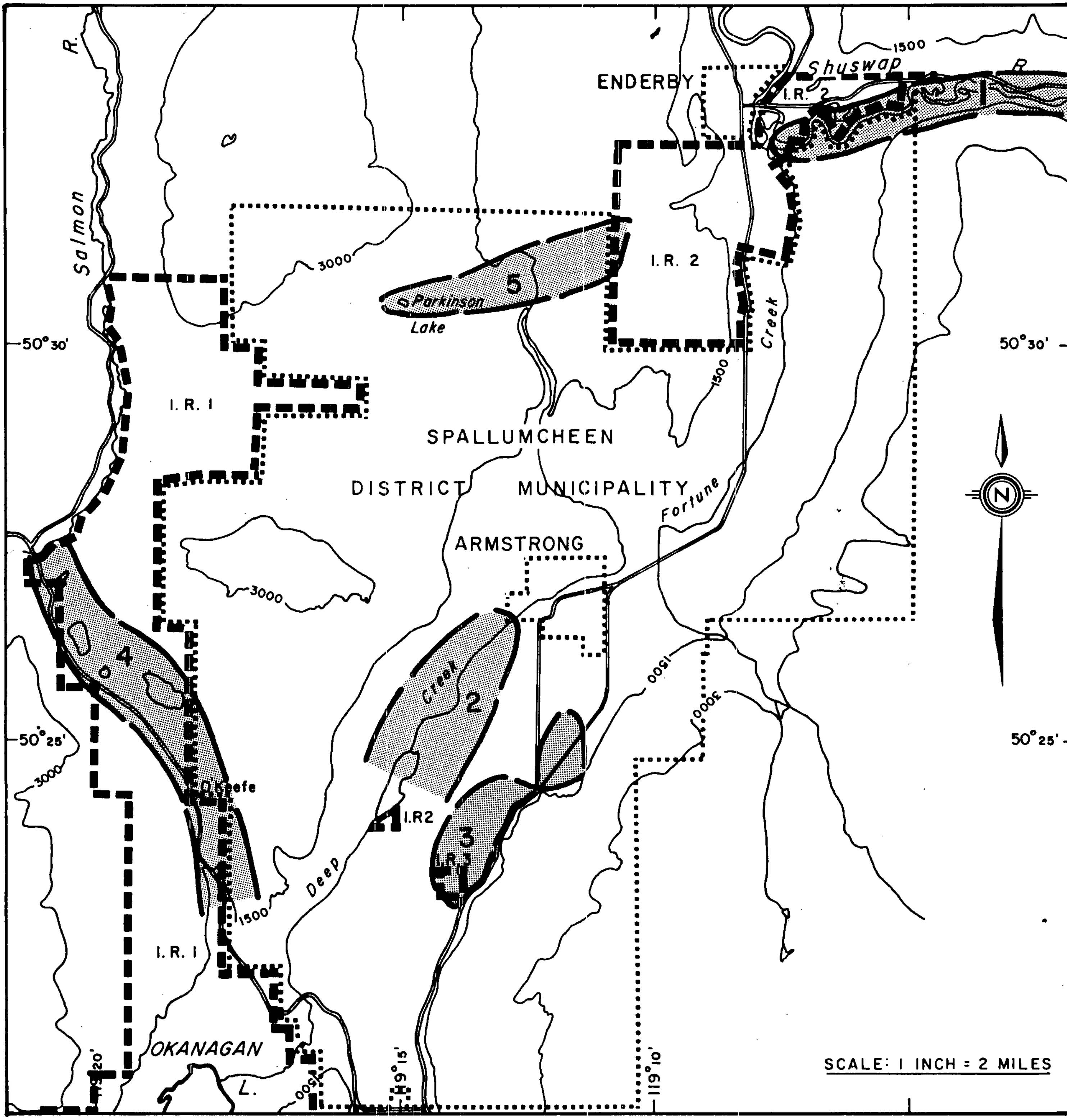
8. POTENTIAL GROUNDWATER DEVELOPMENT

From groundwater flow calculations and a theoretical calculation of groundwater recharge from precipitation, the potential groundwater resources available for development without depleting groundwater resources range between 3 1/3 and 6 cfs (2,370 to 4,380 acft per year). This is equivalent to wells continuously producing a total of 1,120 to 2,240 igpm. It is very unlikely that groundwater withdrawal takes place in the study area at this rate as the number of high producing wells, in excess of 100 igpm, is very small. On this basis alone there is scope for limited increase of groundwater resources.

8.1 Lower Part of the Surficial Deposits

From the existing pump-test data, there appears to be little prospect for considerable development of groundwater supplies from deep wells, that is, about 1,000 feet deep. The exception is the aquifer encountered about 800 to 875 feet deep (C43 TH5) near Enderby. This part of the study area probably falls entirely within the hydrologic regime of the Shuswap River Valley Drainage Basin, and is not considered as part of the Okanagan River Basin hydrologic budget. The potential for groundwater development increases slightly when the Enderby area is considered, but the scope for development here is not known. Of some promise is an area of artesian flow extending about 4 miles up the Shuswap River Valley from Enderby (Fig. 7). However, the two control points upon which this statement is based are two wells 4 miles apart. One of these wells is C43 TH5 over 800 feet deep and the other is reported to be 600 feet deep. It is not known whether these two wells both terminate in the same or in different aquifers. In order to more fully evaluate groundwater potential in the vicinity of Enderby, further information is required concerning the areal extent of deep aquifers. This information must be supplemented by deep test-production wells including observation wells, so that adequate aquifer tests can be conducted for the purpose of determining not only well yields but well spacing. It is the writer's opinion that well yields of up to 1,000 igpm are a possibility in this part of the study area. However, the lack of information on the proximity of less permeable boundaries and their attendant effect in reducing well yields is unknown. The locality is certainly one in which further groundwater exploration is definitely justified.

Elsewhere in the main Okanagan River Valley it appears that well yields from deep aquifers is disappointingly low, less than 250 igpm for pump settings of 200 feet. Progressively higher yields would be obtained to the top of the aquifer. Though minimum well yields are believed indicated by data collected from deep aquifer pumping tests, there is insufficient evidence to believe that groundwater potential occurs for



LEGEND

5	PARKINSON LAKE BEDROCK CHANNEL AQUIFER
4	O'KEEFE VALLEY AQUIFER
3	UPPER PART OF SURFICIAL DEPOSITS — FAN DEPOSITS
2	UPPER PART OF SURFICIAL DEPOSITS — VALLEY CENTRE
1	LOWER PART OF SURFICIAL DEPOSITS
▬ ▬	AREA BOUNDARIES, APPROXIMATE
▪▬▬	INDIAN RESERVE BDY.
········	DISTRICT MUNICIPAL BOUNDARY

FIGURE 7 AREAS INDICATED FOR GROUNDWATER EXPLORATION

little more than domestic and farm livestock water supply requirements. Again test production wells including one observation well are necessary to improve on present knowledge of the study area. However, well design problems and costs of 1,000 feet deep wells are a deterrant to further evaluation of apparent low yield areas.

8.2 Upper Part of the Surficial Deposits

The chief source of groundwater supply in the main Okanagan River Valley is the area to the south of Armstrong (Fig. 7). Within this locality well yields of up to 850 igpm can definitely be otained near the centre of the valley and possibly higher yields. However, conditions imposed by well design problems and costs will limit yields in practice, though figures of 3,500 igpm seem to be a theoretical possibility. These calculations do not take into account limitations due to impermeable boundaries which will reduce well yields. The extent of the aquifer, mainly fine grained sand with some silts is not known but it ranges in depth from about 200 to 800 feet below ground surface. The aquifer is therefore about 600 feet thick. Task 41 data suggest minimum well yields of about 200 igpm (C43 TH2) from this aquifer.

Within the same area to the south of Armstrong (W-E cross Section Fig. 1) near the east side of the valley are two flowing wells. The well designated as CW (capped well) had a free flow of 320 igpm and a theoretical yield of about 1,600 igpm is a possibility. Again the effect of discharge boundaries is unknown. However, an estimated well yield of 500 igpm may be reasonable. The aquifer, a sand and gravel deposit believed to be associated with fan deposits flanking the east valley wall, is known to be at least 50 feet thick. Its areal extent (Fig. 7) is not known, but probably does not extend far to the west beyond the 1,300 feet contour line. The convex shape of the topographic contours probably indicates much of the areal extent of the fan deposits flanking the east valley wall. Their westward extent may not always be delineated in terms of topographic expression and there is insufficient drill hole control to determine their actual extent.

About 3 miles south of Armstrong are 2 other flowing wells capable of producing about 100 igpm or possibly more. These are associated with a fan deposit of larger areal extent than that of the fan deposit discussed above. Well data for the 2 fan deposits give an idea of possible yields which may be anticipated from wells associated with these fan deposits. What is unknown in terms of groundwater potential is the significance of recharge by underflow to these fan deposits from tributary creeks flowing into them.

It can be seen from a study of the inset map of the surficial geology (Fig. 1) and topographic contours that fan deposits occur along much of the east valley wall. Prospecting for groundwater within these deposits followed by test pumping is encouraging as denoted by well yields for a very few wells.

There are also some thin, minor or local ? sand deposits contained in the commonly thick silt deposit which comprises the majority of the upper part of the surficial deposits of the main valley. Thick local sands shown on the north-south cross section (Fig. 1) are presumed to be of importance as only supplying small water supply requirements for domestic or livestock purposes.

8.3 O'Keefe Valley Aquifer

Information regarding potential groundwater resources is very limited and available only for the south end of the valley. It does indicate high capacity wells from sand and gravel deposits up to 576 feet deep with a saturated thickness of about 350 feet. Theoretical well yields of up to 2,850 igpm seem to be a possibility. Because of the influence of discharge boundaries, about which there is no data available at present, well yields are estimated to be in the range of 500 to 1,000 igpm.

There is no information regarding the areal extent and saturated thickness of the sand and gravel deposits throughout the valley. However, from the map of the surficial geology and apparent continuity of the water levels in wells with that of lake levels to the north end of the valley, it is believed the aquifer is continuous from the Salmon River Valley to Okanagan Lake (Fig. 7).

On the basis of present knowledge of the hydrogeology of the O'Keefe Valley, it is definitely justified to conduct further groundwater exploration programs within this valley.

8.4 Parkinson Bedrock Channel Aquifer

The only remaining locality of significance in terms of groundwater potential is a narrow, sand and gravel aquifer about 4 miles long extending to the northeast from Parkinson Lake (Fig. 7). It occurs at an elevation just below 1,700 feet above sea level. The sand and gravel is about 250 feet thick with a saturated thickness of 200 feet. Well yields based on pump test data from one well are estimated to be 50 igpm or slightly higher. Spring discharge, from a point 4½ miles north of Armstrong, forming a very short permanent tributary to Deep Creek has a discharge of about 150 igpm. At the point where Deep Creek flows from its course across this bedrock channel aquifer, its flow is reported to be permanent. In "drought" years such as 1970 Deep Creek is dry above this bedrock channel aquifer, according to one local resident.

The above information suggests that there is limited scope for groundwater development in this part of the study area. Groundwater flow within this bedrock channel aquifer a short distance west of Parkinson Lake is considered to flow into the Salmon River and so falls outside the hydrologic regime of the Okanagan River Basin.

In summary, the main sources for groundwater withdrawal in the study area are aquifers in the upper part of the surficial deposits and the O'Keefe Valley aquifer. These aquifers occur mainly in the central part of the Maid Creek cross section, as fan deposits along the east valley wall, and probably throughout the entire length of the O'Keefe Valley. There is also a sand and gravel bedrock channel aquifer 4½ miles north of Armstrong with limited potential for groundwater development, and locally as at Enderby, there is some prospect for high yield wells from deep aquifers.

8.5 Groundwater Mining

A total groundwater withdrawal capacity of 2,240 igpm without depleting the resources seems to be low. This is equivalent to one inch of precipitation reaching the water table over the entire recharge area. However, the quantity of recharge by underflow from tributary creeks into fan deposits is not known. There is evidence to suggest that moderate quantities of runoff water may be lost to underflow along the porous and permeable sand and gravel beds of tributary creeks, such as Vaseaux Creek (Fig. 2). The calculation of recharge to groundwater from precipitation does not include any additional increments to groundwater resulting from infiltration from stream runoff. Also an unknown factor is the amount of water moving from the Salmon River into the O'Keefe Valley. If both the latter methods of recharge should prove to be significant, the potential for groundwater development would increase.

If the concept of groundwater mining is considered the following recoverable water quantities have been estimated to be available for withdrawal. The reader is reminded, as in the case of groundwater flow calculations, that the limits of accuracy are anticipated to be no closer than one order of magnitude.

Aquifers	Acre feet
Upper Part of Surficial Deposits (south of Armstrong only)	5,000
Lower Part of Surficial Deposits	1,500
O'Keefe Valley	60,000
	66,500

In arriving at the quantities of water available for mining the following figures were used:

Aquifer	Length (ft)	Width (ft)	Thickness (ft)	Effective Porosity %
Upper part of Surficial Deposits	34,000	10,000	600	0.1
Lower part of Surficial Deposits				
Unit F	54,000	6,000	125	0.1
Unit D	30,000	5,000	125	0.1
Unit B	30,000	3,500	125	0.1
O'Keefe Valley	30,000	3,000	200	15

The above figures for groundwater mining are estimates based on limited information of the geology of the area. The problem is to determine the physical dimensions of an extensive 3-dimensional body, to estimate the proportion of its volume occupied by aquifers and to arrive at values for the hydrologic properties of these aquifers, utilizing a few rather widely spaced test holes and some seismic information. To further improve knowledge of the geology and consequently of the extent, thickness and lithology of individual aquifers considerably more test drilling is essential.

As an example of the limits of accuracy of groundwater available for mining if the figure of 5,000 acre feet for the upper part of the surficial deposits is considered, the quantity of recoverable water ranges from 500 to 50,000 acre feet. This is the range for one order of magnitude. The exception to the above figures is the O'Keefe Valley aquifer where the estimated upper limit for recoverable groundwater supplies may be considerably less than one order of magnitude.

Based on an annual rate of recharge from precipitation of 1 inch which is equivalent to 5 cfs (3,600 acft per year) for the main valley it would take about 2 years to replenish the quantity of water taken from storage by mining aquifers in the lower and upper parts of the surficial deposits. If recharge to the lower and upper parts of the surficial deposits are considered separately it would take 3 years to replenish the upper part based on a groundwater flow rate of 2.44 cfs (1,780 acft per year), but very many years to replenish the lower part.

In the O'Keefe Valley with a recharge rate of about 0.74 cfs, equivalent to about 540 acre feet per year, it would require 110 years to replenish groundwater resources taken from storage. However, with the possibility of limited underflow from the Salmon River Valley the period of time necessary for recharge would be reduced.

9. ECONOMICS OF GROUNDWATER DEVELOPMENT

The economics of groundwater development fall into 2 main categories. One is preliminary exploration, the other is the capital costs of production wells. Actual costs given below might range 20% upwards or downwards due to varying geologic conditions etc.

9.1 Costs of Groundwater for High-Yield Wells

Preliminary exploration costs for a specific locality may include costs for both seismic and test drilling. A seismic survey comprising one or two profiles including consultant's fees are estimated to cost about $5,000 to $10,000. Costs of 2 rotary test wells about 1000 feet deep including 24 hour pumping tests are estimated to be about $35,000 but these costs do not include consulting fees. Total preliminary groundwater exploration costs could be about $45,000.

The costs of production wells are estimated separately for the O'Keefe and the Okanagan Valleys. The capital costs of production wells, including pump and well housing, to produce groundwater supplies at 4 acft/day (acre feet per day) for 90 days could range from about $25,000 for a well 225 feet deep near the north end of the O'Keefe Valley to about $36,000 for a well 425 feet deep near the south end of the valley. These costs do not include bringing power to the site, water treatment, nor consultant's fees. Estimated annual costs at the well head for the foregoing production wells, with a power cost of 60.5¢ per acft/day for the former well and of $2.45 per acft/day for the latter well, are given below. These annual costs do include interest and amortization, and operation and maintenance costs over a period of 25 years at interest rates of 5%, 7% and 9%.

(A) $25,000 well

	Interest rates for 25 years		
	5%	7%	9%
Amortization costs per annum	$ 1,770	$ 2,145	$ 2,510
Power costs for 4 ac ft per day for 90 days	$ 218	$ 218	$ 218
Operation and Maintenance	$ 1,250	$ 1,250	$ 1,250
Total annual costs for one well producing 4 ac ft per day for 90 days	$ 3,238	$ 3,613	$ 3,978
Total 25 year costs	$80,900	$90,200	$99,400

(B) $36,000 well

	Interest rates for 25 years		
	5%	7%	9%
Amortization costs per annum	$ 2,555	$ 3,090	$ 3,600
Power costs for 4 ac ft per day for 90 days	$ 882	$ 882	$ 882
Operation and Maintenance	$ 1,860	$ 1,860	$ 1,860
Total annual costs for one well producing 4 ac ft per day for 90 days	$ 5,297	$ 5,832	$ 6,342
Total 25 year costs	$132,500	$145,800	$158,500

The total annual costs per acre ft per day including power costs, interest and amortization costs over a period of 25 years at interest rates of 5%, 7% and 9% are estimated to be within the following limits:

	Interest rates for 25 years		
(A) Lower Limit	$ 8.87	$ 9.89	$10.90
(B) Upper Limit	$14.52	$15.98	$17.37

Production well costs in the Okanagan Valley lying north of Okanagan Lake can be expected to vary considerably depending upon depth, conditions encountered during well drilling and upon well construction. Capital costs for a well approximately 1000 feet deep producing 4 acft/day for 90 days are estimated to range from $25,000 to $50,000. Again these costs include pump and well housing, but do not include those of bringing power to the site, water treatment, nor consultant's fees. Estimated annual costs for the above wells at the well head covering power costs of $2.45 per acft/day, interest and amortization costs for a period of 25 years at interest rates of 5%, 7% and 9% are given below.

(A) $25,000 well

	Interest rates for 25 years		
	5%	7%	9%
Amortization costs per annum	$ 1,770	$ 2,145	$ 2,510
Power costs for 4 ac ft per day for 90 days	$ 882	$ 882	$ 882
Operation and Maintenance	$ 1,250	$ 1,250	$ 1,250
Total annual costs for one well producing 4 ac ft per day for 90 days	$ 3,902	$ 4,277	$ 4,642
Total 25 year costs	$97,500	$106,900	$116,000

(B) $50,000 well

	Interest rates for 25 years		
	5%	7%	9%
Amortization costs per annum	$ 3,540	$ 4,290	$ 5,020
Power costs for 4 ac ft per day for 90 days	$ 882	$ 882	$ 882
Operation and Maintenance	$ 2,500	$ 2,500	$ 2,500
Total annual costs for one well producing 4 ac ft per day for 90 days	$ 6,922	$ 7,672	$ 8,402
Total 25 year costs	$173,100	$193,800	$210,000

The total annual costs per acre ft per day including power costs, interest and amortization costs over a period of 25 years at interest rates of 5%, 7% and 9% are estimated to be within the following limits:

	Interest rates for 25 years		
	5%	7%	9%
(A) Lower Limit	$10.69	$11.70	$12.71
(B) Upper Limit	$18.96	$21.02	$23.00

The foregoing figures represent approximate costs of water in acre feet per day. However, well costs may vary considerably from those given above. Ultimately the costs of groundwater supplies will be determined by well yield, the demand for water made upon a given well according to its use (for irrigation supplies for part of a year, or for industrial supplies that are continuous year round) in relation to the actual costs of a well.

9.2 Cost of Groundwater for Low-Yield Wells

Costs for water supply requirements up to 10 igpm for private domestic and livestock purposes will be considerably lower. However, the costs of developing groundwater from deep aquifers would make such wells very uneconomic.

Low yield wells completed in the depth range from 100 to 250 feet are estimated to cost about $4,000 to $6,000. These costs include those for the pump and well housing but exclude power installation etc.

10. CONCLUSIONS

The surficial deposits in the north end of the Okanagan River Basin are primarily fine grained, low permeable materials, mainly silt and fine-grained sands. There are some coarser grained, high permeable deposits of sand and gravel. The fine-grained materials are expected to have permeability values of less than 10 $igpd/ft^2$ and the coarser grained materials permeability values commonly of 100 to 300 $igpd/ft^2$.

Well yields for aquifers in the study area are commonly expected to be less than 200 igpm for pump settings of 200 feet. Locally higher yields of up to 500 igpm or possibly 1,000 igpm may be obtained. Aquifers with well yields in the 200 to 500 igpm range, are considered to occur in the O'Keefe valley; and in the main valley in a locality just south of Armstrong and in parts of fan deposits along the east valley wall. Well yields of up to 1,000 igpm may possibly be obtained near Enderby and also in the O'Keefe valley, but more adequate testing is essential to verify these high yields.

The quantity of groundwater available from water mining is estimated to be about 66,500 acre feet, most of which would be obtained from the O'Keefe Valley aquifer. Groundwater flow towards Okanagan Lake for the more permeable materials is calculated to be about 3 1/3 cfs (2,370 acft/yr). This figure is considered to be a reasonable estimate when compared to total theoretical recharge rate of 6 cfs (4,380 acft/yr) obtained from 1 inch of precipitation for a recharge area of about 80 square miles. At this rate of recharge it would take about 100 years to replenish the water supplies that could be mined from the O'Keefe Valley and only 2 years to replenish supplies in the main valley aquifers. However, the possibility of higher recharge to the above aquifers by underflow from tributary creeks to the main valley and from the Salmon River into the O'Keefe Valley is a distinct possibility.

The potential for groundwater development without depleting the resources is estimated to be from 3 1/3 to 6 cfs. It is unlikely that total groundwater withdrawal is close to the lower value, so there is limited scope for increasing the use of groundwater resources in the study area. If the potential of the Enderby area, which occurs in the adjacent Shuswap River Basin is considered, then the potential for groundwater development increases. The possible extent of the increase is unknown.

Analyses of groundwaters sampled in the study area show the chemical quality of the water is very good. The total dissolved solids content of water is commonly in the range of 200 to 500 ppm and the water is primarily calcium and magnesium bicarbonate. The water is quite suitable for human consumption and for irrigation use and should require only very little treatment for industrial purposes.

The hydrogeological study comprising this report has been confined almost entirely to the north end of the valley, the exception being a deep test hole and seismic work near Okanagan Falls in the south end of the valley and some sub-basin studies. To bring other parts of the Okanagan River Basin to the same stage of knowledge as that of the north end would require implementing some or all of the following work items. The detail involved would depend on the scope of the projects involved and the funds available:

1. Collection, tabulation, study and plotting of available data.

2. Review of relevant groundwater and geological maps and reports of the area.

3. Synthesis of this data into preliminary hydrogeological maps.

4. Hydrogeological mapping and well inventories to fill important gaps lacking information.

5. Collection of water samples for hydrogeochemical studies.

6. Geophysical studies: seismic and gravity meter studies.

7. Rotary test hole drilling to evaluate geophysical results; case the holes for preliminary groundwater information and for use as observation wells.

8. Cable tool test production wells and pump tests.

Long range studies to further evaluate groundwater resources, movement and recharge are a natural follow-up to the present preliminary studies conducted prior to and as part of the joint Canada-British Columbia Okanagan Basin Study Agreement.

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APPENDIX A

OKANAGAN VALLEY

SEISMIC SURVEY

REVISED FINAL REPORT

FEBRUARY 1, 1971

R.M. LUNDBERG P. Eng.

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OKANAGAN VALLEY
SEISMIC SURVAY
REVISED FINAL REPORT
R. M. LUNDBERG, P. Eng.

INTRODUCTION

This revised report was prepared in order to incorporate the new data available as a result of the nine hole drilling program carried out in the autumn of 1970.

The seismic data has been reviewed and in places re-interpreted to provide a combined geological-geophysical picture which is compatible with all the data. For this purpose, revised seismic refraction profiles and reflection sections have been prepared. A table of percentage error in prognoses is presented. Predicted bedrock depths based on the Geologic Survey of Canada program are indicated on the seismic refraction profiles.

DISCUSSION OF RESULTS OF 1970 TEST HOLE PROGRAM

The seismic profiles have been revised on the basis of the following criteria:

1. New test hole data.
2. Revised refraction interpretation.
3. Revised reflection interpretation.

Table Number 1 was prepared to focus attention on problem areas. The limit of error expected on this project was ± 10%. Where this is exceeded, it is likely that the basic assumptions made in the calculation are incorrect. In all cases, a review of the data has provided a reasonable explanation. In particular, the new test hole data allowed a more detailed reflection interpretation which was a major factor in revising the seismic refraction profiles.

TABLE No. 1

PERCENTAGE ERROR IN PROGNOSES

HOLE	CONTACT	PREDICTED	ACTUAL	% ERROR
Deep Hole 1	Bedrock	1,645	1,884	+13%
Deep Hole 2	Gravel	880	950	+ 7%
	"Quartzite" (Base of till)	1,227	1,230	0%
Deep Hole 4	Bedrock	800+	800+	0%
Test Hole 1	Gravel	105	85	-24%
	Bedrock	475	95	-500%
Test Hole 2	Silt	430	440	+ 2%
Test Hole 3		880	415 ?	-110% ?
Test Hole 4	Base oxidized zone	200	200	0%
	Bedrock	510	548	+ 7%
Test Hole 5	Bedrock	650	872	+25%

The following brief discussion of each profile should serve to explain the basis for revision in each case.

LINE 1

Three test holes drilled on this line showed a wide range of accuracy in the seismic prognosis. Test Hole No. 1, at Station 5, encountered gravel only 20 feet shallower than predicted, but an incorrect seismic interpretive assumption together with an inaccurate extrapolation of surface dips of the valley wall led to a large error in bedrock depth calculation.

In Test Hole No. 2, a silt layer correlated very well with the 6,000 ft/sec. layer noted on the seismic refraction profile. The initial report postulated a thin layer which seems to be the case as the log reverts to sand after 70 feet of silt.

Deep Test Hole No. 1 encountered a hard shale or till at the predicted bedrock level. It is likely that this bed is a refracting interface which masks the true bedrock. A deeper event on the reflection section shows the bedrock to be 230 feet deeper if an average seismic velocity of 7,500 ft/sec for the 230 foot interval is used (a reasonable assumption from the hole log). A strong reflection not interpreted previously ties to the gravel. One observation that gives credence to this gravel reflection is its absence at Station 102, in proximity to C23 TH 1. north of Station 98. No gravel was logged in this well, implying that a discontinuous sand-gravel interface does exist as shown on the seismic refraction profile.

LINE 2

Two test holes were drilled on this line. Deep Test Hole No. 2 at Station 40 verified the predicted gravel-sand sequence and hit bedrock below the deepest refracting interface as predicted. The "quartzite" logged in the Enderby No. 1 Well likely is the white sand and silty sand reported below the till. As was the case on Line 1, it is likely that the till at 1,150 feet is a refractor which masks the bedrock refraction in the deeper part of the valley. A deep reflection at Station 35 correlates with the bedrock.

Test Hole No. 3 hit bedrock 440 feet above the predicted level. A review of the refraction plots reveals good evidence for a high velocity (10,000 ft/sec) layer extending from Station 101 to 67. The plots from Station 69 west are atypical for the area but with no reflection or geological data, a simplified interpretation was made initially. Whether the bedrock logged is a thin stringer or detrital or a mound-like mass of detrital and gravel is not determinable, however, there is a good chance that it is not the true bedrock.

LINE 3

Test Hole No. 5 found the bedrock 220 feet deeper than predicted. In this instance, a recomputation of the bedrock depth using the criteria used in recalculating the east end of Line 1, provides a tie with the bedrock which is confirmed by a deep reflection.

Note that this line was shot by the G.S.C. and that their prognosis was 140 feet low, or -16%. I think the relative inaccuracy of both surveys at this point is related to the fact that this is the deepest, narrowest portion of the valley surveyed.

The main reason I do not attribute the error to a masking effect by the till logged is that, unlike the data on Lines 1 and 2, the seismic data on Line 3 can be reinterpreted to yield a deeper bedrock. Where this is the case, I think it more likely that the bedrock is indeed the refracting interface.

LINE 4

Test Hole No. 4 (Station 16) verified the seismic interpretation very well. The 200 foot thick low velocity determined at the nearest control point (Station 22) correlates with the oxidized sand. The bedrock was found within the expected limit of error.

LINE 5

Deep Test Hole No. 4 hit conglomerate 40 feet below the predicted bedrock. With the hole drilled off the seismic line and the various extrapolations that are possible from surrounding control points, it is likely that the bedrock is very close to the predicted level.

CONCLUSIONS

The seismic survey appears to have been reasonably accurate on the central portions of Lines 1 and 2, Line 4, and Line 5. On the flanks of the valley, steep dips, erratic gravel deposits and poorer seismic control combine to make interpretation more hazardous. However, we are likely more concerned with the deeper sections of the valley for purposes of the total program.

By carefully combining geological and seismic data the seismic interpretation is fortified. It can be anticipated that additional drilling in the area would show more overall accuracy in the revised profiles than was found in the initial program. In particular the reflection sections are more understandable and yield more predictive information.

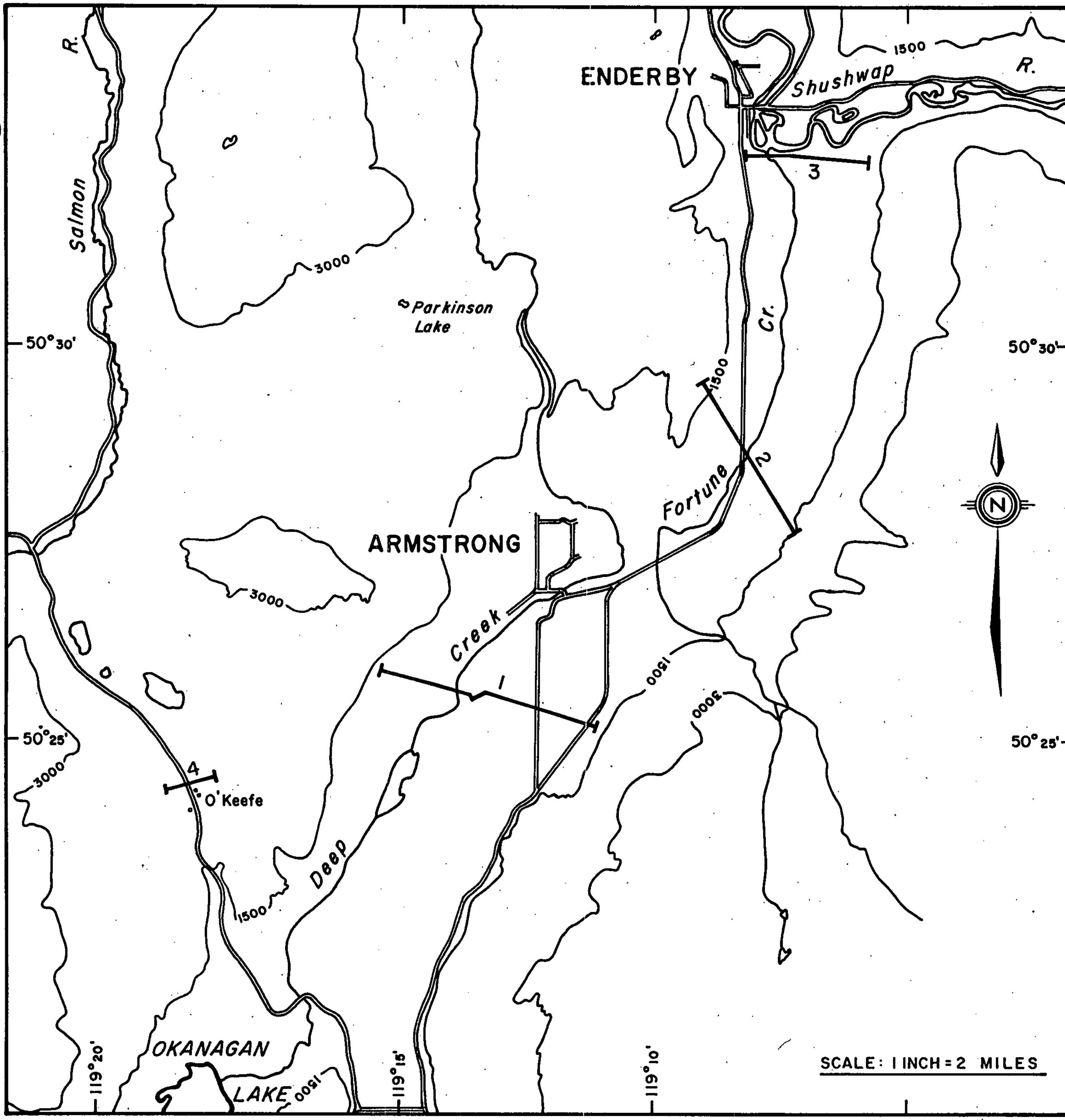
The degree to which the program has been a success and the advisability of using more seismic in the future must be defined in terms of the objectives of the program. With the exceptions noted above, the bedrock valley profile was in general successfully predicted. The other aim, to determine the lithology of valley fill deposits, was achieved in some places. The silt lense detected by Line 1 refraction data and verified by Test Hole No. 2; the gravel-sand sequence predicted by Line 2 reflection data and verified by Deep Test Hole No. 2; and the deep 200 foot weathered sand interpreted on Line 4 refraction data, verified by Test Hole No. 4 are examples of the ability of the program to achieve, to some extent, this more demanding objective.

The possibilities of detailed gravity work have been investigated. Gravity work would not help in determining valley fill lithology and would not help in making depth determinations where the bedrock profile is relatively smooth, but ridges, terraces and channels would be observable and would permit a depth to bedrock calculation where they occurred. Thus gravity may detect the bedrock terrace indicated by seismic underlying the west half of Line 4. It would resolve the problem on the northwest end of Line 2 where the "bedrock" encountered in Test Hole No. 3 may be a detrital stringer, thick detrital lense or a bedrock terrace. The bedrock highs underlying Lines 2 and 5 would be discernable even without the proximity of large outcrops.

Note that the total cost of last year's seismic program was about $1,600 per mile. The cost of a small gravity survey would not exceed $100 per mile.

Regarding the seismic operations, I would in future recommend an increased effort to obtain reflection data by shooting additional holes. It appears the slight extra expense would yield a rewarding amount of data. This should of course only be attempted in areas where satisfactory record quality can be anticipated.

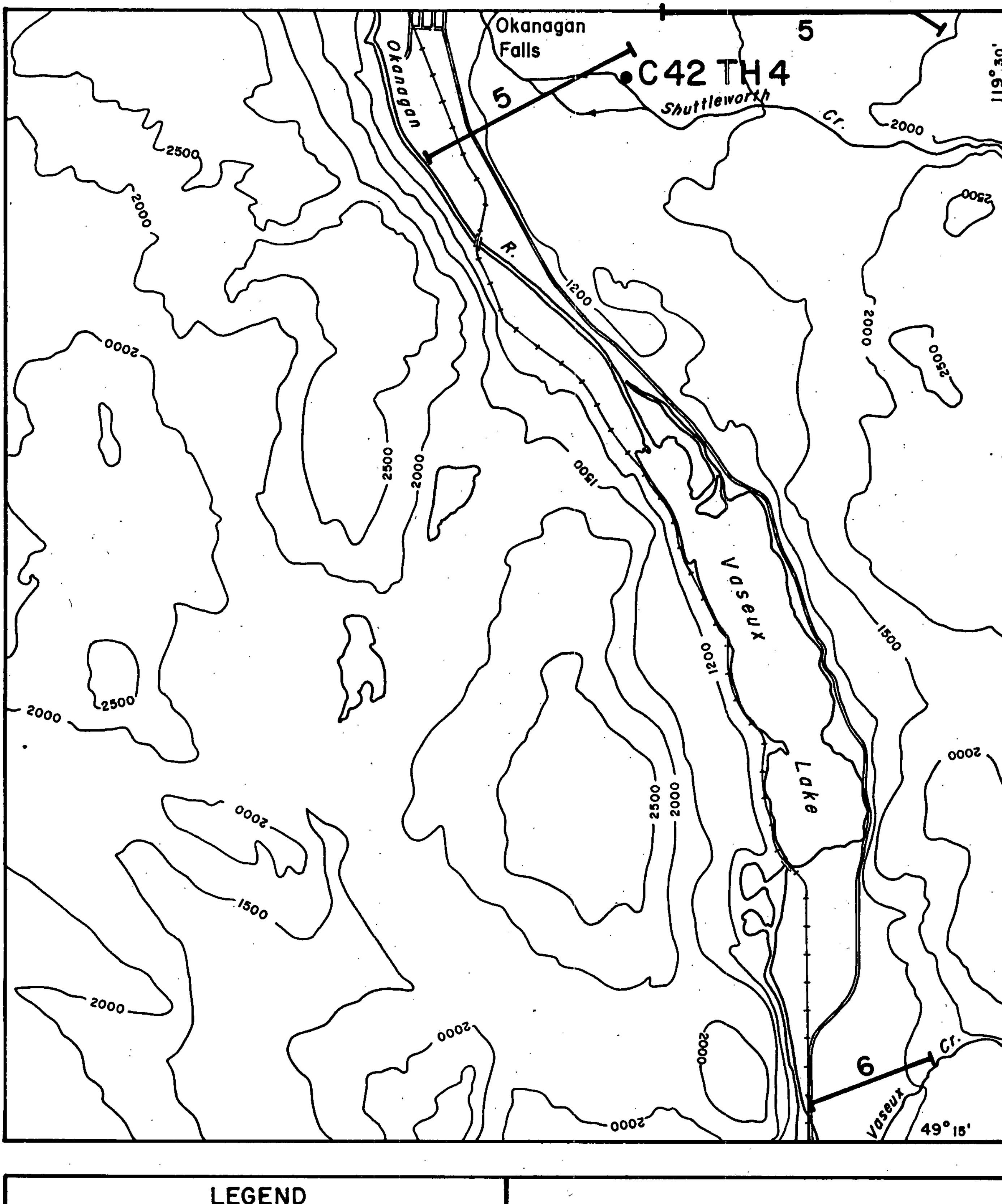
If it is necessary to define the valley lithology and configuration in more detail, I think seismic has a role to play. The knowledge obtained from each test hole can be extrapolated over a larger area more economically than by drilling. It is possible that gravity will solve some specific problems of bedrock configuration. Incorporated with seismic and geological data there is a good chance that meaningful gravity results can be obtained.



LEGEND

SEISMIC LINE 4

FIGURE 3
LOCATION OF SEISMIC LINES
NORTH END
OKANAGAN RIVER BASIN



LEGEND

SEISMIC LINE	6
WELL LOCATION	•
CONTRACT NUMBER	C
TEST HOLE NUMBER	TH

FIGURE 4
LOCATION OF SEISMIC LINES,
SOUTHEND OF
OKANAGAN RIVER BASIN

APPENDIX B - COMPOSITE TEST HOLE LOGS - CONTRACTS 42 & 43

C42 TH1

Elevation (map): 1225 feet
Location: 3,800 feet south of Lat 50°26'15" N and 5,500 feet east of Long 119°15'00" W.

Depth (in feet)	Log
0 - 160	silt
160 - 200	sand
200 - 810	sand; some silt
810 - 1140	silt; some sand
1140 - 1290	sand and gravel, some silt white and gray
1290 - 1510	silt, sand; some clay, gray
1510 - 1650	clay, silt, sand, blue-gray
1650 - 1740	clay, gray-blue
1740 - 1830	sand
1830 - 1884	till; clay, silt, sand, gravel
1884 - 1892	bedrock

C42 TH2

Elevation (map): 1260 feet
Location: 12,600 feet north of Lat 50°26'15" N and 1,300 feet west of Long 119°07'30" W.

Depth (in feet)	Log
0 - 340	silt, gray
340 - 380	sand, gray
380 - 630	silt, gray
630 - 1000	silt; some sand; some sand and gravel 940 - 960 feet
1000 - 1140	sand and gravel
1140 - 1220	till, gray and white
1220 - 1290	silt, sand and gravel
1290 - 1390	silt, gray
1390 - 1480	sand and silt, gray and white
1480 - 1540	till
1540 - 1570	bedrock

C42 TH3

Elevation (map): 1215 feet
Location: 2,800 feet north of Lat 50°30'00" N and 600 feet west of Long 119°07'30" W.

Depth (in feet)	Log
0 - 230	silt, gray
230 - 500	silt; some sand, gray
500 - 520	sand
520 - 700	silt, gray
700 - 840	silt, sand, pebbles
840 - 880	till
880 - 940	silt, gray
940 - 1040	sand and gravel; some silt
1040 - 1046	bedrock

C42 TH4

Elevation (map): 1,300 feet
Location: 10,600 feet south of Lat 49°22' 30" N and 8,900 feet west of Long 119°30'00" W.

Depth (in feet)	Log
0 - 190	gravel and boulders
190 - 290	sand and gravel; occasional silty sand
290 - 510	gravel and sand
510 - 580	sand and gravel
580 - 670	gravel and sand, severe lost circulation problem from 578 to 590 feet
670 - 710	sand and gravel
710 - 760	gravel and sand
760 - 770	sand and gravel
770 - 800	gravel and till
800 - 822	gravel, lost circulation 800 - 818 feet
822 - 848	bedrock

C43 TH1

Elevation (map): 1325 feet
Location: 6,000 feet south of Lat 50°26'15" N and 14,000 feet west of Long 119°07'30" W

Depth (in feet)	Log
0 - 20	clay, pale brown
20 - 40	silt, clay, pale yellowish brown
40 - 60	silt, pale yellowish brown and light gray, oxidized to 50 feet
60 - 85	silt, gravel, light olive gray and yellowish gray
85 - 95	gravel
95 - 120	bedrock

C43 TH2

Elevation (map): 1265 feet
Location: 4,200 feet south of Lat 50°26'15" N and 7,800 feet east of Long 119°15'00" W.

Depth (in feet)	Log
0 - 90	clay, oxidized to 50 ft, pale yellowish brown, light gray and light olive gray
90 - 180	silt, light olive gray
180 - 190	clay, light olive gray
190 - 200	silt, light olive gray
200 - 220	clay, light olive gray
220 - 310	sand, fine to medium grained
310 - 350	sand, very fine grained
350 - 400	sand, fine to medium grained
400 - 410	silt, light olive gray
410 - 430	sand, fine grained
430 - 500	silt, light olive gray
500 - 540	sand, fine to medium grained
540 - 590	sand, very fine grained; some silt light olive gray

C43 TH3

Elevation (map): 1270 feet
Location: 6,300 feet south of Lat 50°30'00" N and 3,800 feet west of Long 119°07'30" W.

Depth (in feet)	Log
0 - 20	clay, light brownish gray
20 - 40	clay; some silt, light olive gray
40 - 110	silt, oxidized to 50 feet, light olive gray, light gray and yellowish gray
110 - 150	sand, fine grained
150 - 160	silt, yellowish gray
160 - 200	sand, very fine grained; some silt, yellowish gray
200 - 245	till-sand, gravel and silt, oxidized, pale yellowish brown and very pale orange
245 - 295	sand, gravel and silt, yellowish gray
295 - 320	till, yellowish gray
320 - 330	pebbles, sand, gravel and clay
330 - 415	till-clay, silt, sand and gravel; some gravel, oxidized 370-400 ft, pale yellowish brown
415 - 450	bedrock

C43 TH4

Elevation (map): 1570 feet
Location: 11,200 feet south of Lat 50°26'15" N and 13,300 feet east of Long 119°22'30" W.

Depth (in feet)	Log
0 - 10	gravel
10 - 50	sand, medium to coarse grained, some gravel, pale yellowish brown
50 - 70	silt, sand, very fine grained, some coarse sand, light brown
70 - 140	sand, fine to medium grained; pale yellowish brown
140 - 170	sand, medium to coarse grained, yellowish gray
170 - 200	sand, fine to coarse grained, oxidized to 200 ft, grayish orange pink
200 - 230	sand, very fine grained, light gray
230 - 290	sand, fine to medium grained, pinkish gray
290 - 350	sand, coarse grained to fine gravel, light olive gray
350 - 390	gravel
390 - 470	sand, coarse and very coarse grained, some gravel
470 - 510	sand, medium to coarse grained
510 - 548	gravel, some sand
548 - 576	bedrock

C43 TH5

Elevation (map): 1,180 feet
Location: 8,100 feet south of Lat 50°33'45" N and 1,500 feet east of Long 119°07'30" W.

Depth (in feet)	Log
0 - 20	clay, oxidized, pale brown
20 - 50	silt, some clay, oxidized to 50 feet, light olive gray
50 - 370	silt, light gray, light olive gray and yellowish gray
370 - 400	sand, very fine grained; some silt, light olive gray
400 - 430	sand, fine and very fine grained, light olive gray
430 - 450	sand, very fine grained, light olive gray
450 - 550	silt, light olive gray
550 - 640	sand, fine and very fine grained, light olive gray
640 - 690	sand, fine and very fine grained; some silt, light olive gray
690 - 790	till, silt, sand fine to very coarse grained sand, and fine gravel; some oxidized zones, light olive gray
790 - 860	sand, medium to very coarse grained, light olive gray, grayish orange pink
860 - 875	sand, gravel, silty, light olive gray
875 - 912	bedrock

HYDROLGEOLOGY OF VASEUX CREEK AND VERNON CREEK SUB-BASINS BRITISH COLUMBIA

by

E. C. Halstead

HYDROGEOLOGY OF VASEUX CREEK AND VERNON CREEK SUB-BASINS BRITISH COLUMBIA

by E. C. Halstead

Hydrologic Sciences Division

Inland Waters Branch

The purpose of the Canada-British Columbia Okanagan Basin Agreement is to develop a comprehensive framework plan for the development and management of water resources for the social betterment and economic growth in the Okanagan Basin. The terms of reference suggest that the studies be broad in scope so as to examine possible alternatives for the efficient utilization and provision of an adequate quantity and quality of water in the basin and in those areas likely to be affected by diversion. The hydrology task force is responsible for water quantity studies as required to evaluate the existing hydrologic regime in the basin, including studies of run-off, lake levels, flows, groundwater and geological structure; climatology and meterology; to evaluate means of regulating flows through storage diversion; and to evaluate means of augmenting water supplies within the Okanagan Basin.

Changes in a hydrologic regime are due to snowmelt, precipitation, evaporation and groundwater discharge and recharge. Investigations are underway, the purpose of which, is to examine and evaluate each of these parameters. This report deals with the preliminary investigation of groundwater in sub-basins. The upland area rimming the Okanagan drainage basin provides the headwaters for some 35 tributary drainage basins of which 6 have been chosen for inclusion in this study. The 6 are, on the east side listing from south to north, Vaseux Creek, Penticton Creek, Pearson Creek and Vernon Creek; on the west side Lambly Creek and Greata Creek (a tributary of Peachland Creek). The object of the reconnaissance investigation was to determine whether or not the groundwater component of the sub-basin is in sufficient volume to warrant the expenditure of more time and funds to provide as complete as possible an assessment of its contribution to the hydrologic regime. Preliminary investigations were carried out in each basin in September 1970 and the results together with any available hydrologic data are presented on the accompanying hydrogeological maps and brief notes. Existing data was not consistent, and as mapping was limited to logging roads, the presentation on each map differs but nevertheless the maps reflect an environmental pattern and serve a useful purpose to inform and support further planning.

VASEUX CREEK

Vaseux Creek (Fig. 1) includes a drainage area of some 97 square miles above a gauging station situated at a point about 5 miles upstream from the mouth of the creek where it joins Okanagan River. Vaseux Creek drainage basin rises to elevations of more than 6,500 feet and more than 75 square miles lies above an elevation of 4,500 feet. Vaseux Creek is the trunk stream for 5 major tributaries.

GEOLOGY

Vaseux Creek drainage basin is underlain by the Shuswap terrane that comprises a group of metamorphic rocks but younger intrusive granitic and granodiorite rocks are exposed at the surface over much of the area. During Pleistocene time the area was ice covered and erosion of the bedrock, in particular the granitic rocks provided material for the deposition of grey silty stony clay and till and meltwaters left ice-contact and outwash gravel and sand to form extensive areas of surficial deposits within the plateau-like uplands between elevations of 4,000 and 5,000 feet (see map, distribution of surficial deposits). These surficial deposits not only provide a soil (Fig. 2) for the stands of timber covering the area but also provide a medium for the storage and movement of groundwater contributed by snowmelt seepage.

HYDROLOGY

No climatological stations or snow courses exist in the basin. A gauging station on Vaseux Creek, at an elevation of about 1,500 feet, has been in operation since 1958 providing continuous records (Fig.3). A bar graph chart shows the runoff (see map) for the 1966 water year and its monthly distribution. The 1966 water year was below normal but the graph illustrates the distribution of the discharge which reaches a peak in May following the near disappearance of the season's snowmelt.

The study of groundwater flow systems in crystalline rocks under a similar geological environment was undertaken by D. W. Lawson* in the

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*Lawson, D. W., Groundwater flow systems in the crystalline rocks of the Okanagan Highland, British Columbia. Canadian Journal of Earth Sciences, Volume 5, 1968.

Trapping Creek drainage basin tributary to the West Kettle River and about 20 miles northeast of Vaseux Creek basin. The quantitative flow net for that basin depicts local flow systems superimposed on an intermediate flow system that in turn overlies a regional flow system. Lawson concluded that flow through the combined regional and intermediate flow systems is at most less than 2 percent of the flow through the local flow system and the local flow system adjacent to the creek supports the groundwater component of baseflow. In Trapping Creek the local flow systems in the crystalline rock complex contributes from 10 to 17 imperial gallons a day per foot thickness of aquifer. In the Vaseux Creek basin a local flow system exists in the permeable surficial deposits and the intermediate and regional flow systems are confined to the massive bedrock in which flow is negligible and hence these systems can be discounted as providing any significant volume of water to the overall regime. The local flow systems during the 1967 water year contributed a baseflow in the order of 3 cfs during the months of August and September and it is assumed that discharge during those months was entirely groundwater. Groundwater discharge at this rate during the year provided a little more than 10.5 percent of the total discharge of 43,110 acre feet.

Water samples were collected from 7 points in the basin to assess by geochemical means any groundwater contributions to the creek discharge. The chemical analyses are presented in Table I and bar diagrams on the accompanying map show the total of dissolved solids at sampling points. Discharge from the Fish Creek tributary has the highest concentration of total dissolved solids and this represents groundwater discharge that had been stored in the unconsolidated deposits primarily of a granitic provenance hence the higher concentration of the cations calcium, magnesium, sodium and potassium. The samples collected on Vaseux Creek below the entrance of McIntyre Creek have a lesser concentration of cations because the discharge from this creek is in part snowmelt and surface runoff from Baldy Mountain which rises to an elevation of more than 6,500 feet at the drainage divide. The sample, taken at the gauging station where discharge at the time of sampling was in the order of 3.0 cfs shows the result of mixing of Fish Creek and McIntyre Creek discharge and compared with the analyses of the sample collected near the creek mouth there is no real change indicating no groundwater contribution in the canyon below the gauging station.

CONCLUSION

A regional pattern shows up in this watershed and similarly snow accumulation and snowmelt above elevations of 4,000 feet are the major sources of runoff and annual groundwater recharge and discharge. Although the groundwater component is significant and provides for a base flow of at least 3.0 cfs daily during the late summer months it is recommended that the above assessment is valid for present planning. Climatological stations should be established in the drainage basins to give precipitation and snow accumulation data and if funds are available it is recommended that an observation well is installed near a snow course and fluctuations of the water table observed in that well can be correlated with the snow course data to provide accurate forecasting. A. Pipes, U. B. C. Civil Engineering Division is presently preparing a paper to provide results of his research in Carr's Landing IHD basin regarding groundwater levels and snowmelt recharge.

TABLE I

Analyses of water samples (in parts per million)

Station / Constituent	Fish Lake	Venner Creek	Fish Creek	Mile 22	Vaseux Creek at wier	Vaseux Creek at gauge station	Vaseux Creek at mouth	Vaseux Creek
pH	6.5	8.3	7.9	7.4	7.5	7.8	7.9	7.3
chloride	nil	0.5	0.3	0.3	0.3	0.5	0.5	0.5
alkalinity $CaCO_3$	nil	nil	nil	nil	nil	nil	nil	nil
alkalinity total	10.5	69.5	99.0	38.0	38.0	78.5	85.5	33.5
hardness	15.6	62.1	95.6	36.6	37.6	76.3	84.6	34.6
conductance	28	142	200	81	82	168	185	78
calcium	3.4	18.4	22.2	10.8	9.2	20.1	22.0	9.0
magnesium	1.7	3.9	9.7	2.3	3.6	6.4	7.2	2.9
sulphate	1.0	3.7	5.5	7.6	3.5	7.5	9.5	5.3
sodium	1.4	3.6	3.4	2.2	2.4	3.6	3.6	2.0
potassium	0.5	1.2	1.4	0.9	0.8	1.2	1.6	1.0
fluoride	0.23	0.18	0.32	0.24	0.31	0.38	0.35	0.1

Analyst: Division of Laboratories, British Columbia Health Services.

VERNON CREEK

Vernon Creek drainage basin (Fig. 4) occupies an area of about 52 square miles of which more than 35 square miles are above an elevation of 4,000 feet. Long Mountain, the highest point in the basin reaches an elevation of more than 5,400 feet. Lake basins cover more than 1.66 square miles of the upland area and provide basin storage for snowmelt runoff. Discharge from the lakes system flows through Vernon Creek to empty into Ellison Lake some 8 miles distant at an elevation of approximately 1,400 feet. One tributary, Clark Creek, drains an area below the 4,250 ft. contour and discharges into Vernon Creek at an elevation of about 1,500 feet.

GEOLOGY

The basin is underlain by metamorphic rocks of the Shuswap terrane that commonly occupies much of the eastern upland area adjacent to the Okanagan drainage system. Overlying these metamorphic rocks and occupying an area west of Swalwell Lake including Wrinkly Face Cliff are some shales and lavas that at most are not more than 500 feet thick. The lavas flowed out over an erosional surface on the Shuswap terrane during the Tertiary period and it is inferred that the lake depressions could be remnants of this erosional surface. Thereafter glacial ice covered the area and with the disappearance of the ice the upland area was covered with a thin mantle of silt and silty till whereas below 3,000 feet the bedrock is covered in general with morainal deposits washed and channelled by meltwater overlain at lower elevations by poorly sorted gravel, sand, silt and clay that form the delta of the present Vernon Creek.

The mantle of silty sandy clay and till supports a cover of immature timber above an elevation of 3,500 feet (Fig. 5).

HYDROLOGY

Climatological stations have not been established in the drainage basin but beyond its eastern limit and at an elevation of 4,300 feet a snow course has been in operation for more than 30 years. The water equivalent on April 1st at this point is commonly in the order of 5 inches. The volume of meltwater from this snowpack is the recharge for basin storage in the lakes, soil moisture and groundwater storage in the underlying soils and rocks and provides for runoff that typically reaches a peak in May. Records for the years 1966, 1967 and 1968 indicate the 3 year average storage from the snowmelt in the Vernon watershed amounted to 8,057 acre feet for Swalwell Lake (Fig. 6) and 2,226 acre feet for Crooked Lake. The discharge of this lake storage is controlled by dams at the west end of both lakes (Figs. 7 and 8) and therefore flow through Vernon Creek is regulated. Groundwater recharge and discharge within the basin supports the vegetative cover but its contribution to base flow of Vernon Creek is not considered sufficient to warrant further investigation. Discharge of groundwater was noted in September at a spring line at an elevation of about 2,700 feet at the contact of permeable silts overlying a till section at least 200 feet thick. Collective discharge of these springs was less than 3 gallons a minute and supported a growth of cedars and aspens. Below the spring line groundwater continued to seep through a fracture in the till and at the cutbank on Vernon Creek amounted to an immeasurable volume (Fig. 9). Clark Creek was dry below about 2,750 feet elevation but discharge above that point was sufficient to supply water to a logging operator and the volume was in the order of less than 0.2 cfs.

A sample of water was collected at a point at an elevation about 2,250 feet and below present construction for a storage dam (Fig. 10). The quality of the water, Table 1, reflects that of surface water in storage in the lakes and hence confirms the inference that groundwater discharge is minimal.

CONCLUSION

The regional pattern also shows up in this watershed where at elevations of more than 4,000 feet snow accumulates and its meltwaters contribute to the storage of surface water and runoff providing the typical annual discharge pattern. Following the peak discharge, flow through Vernon Creek is controlled. Further groundwater investigations are not recommended for the Vernon Creek drainage basin.

A HYDROGEOLOGICAL RECONNAISSANCE STUDY

OF THE

PENTICTON CREEK DRAINAGE BASIN

by P. L. Hall

A HYDROGEOLOGICAL RECONNAISSANCE STUDY OF THE PENTICTON CREEK DRAINAGE BASIN

by P. L. Hall

SUMMARY

The following points are made in the report and are based on existing data, which is somewhat limited, and may be modified when more data is available.

For Penticton Creek

1. Area some 62.7 square miles.
2. Elevation 1100' to 7000'.
3. Mean annual precipitation varies from approximately 15" to 35".
4. Approximately 100,000 acre feet of precipitation falls on the basin of which nearly:

   90% occurs above 4,000 ft.
   80% occurs above 4,500 ft.
   70% occurs above 5,000 ft.

   and some 55% falls in the October - March period.
5. Water Balance:

   Approximately 40% of precipitation goes to surface runoff.

   Approximately 60% is lost as evapotranspiration.

   Actual groundwater outflow is probably only 1 or 2% of total input, (1 to 5 cfs) while baseflow is probably in the order of 5 - 15% of surface runoff.
6. A theoretical model could be developed to simulate groundwater movement within this basin.

   Three groundwater zones are postulated:

   (a) Surficial zone of local flows, this zone is often dry in the summer.
   (b) There is an intermediate (1) zone in the lower part of the Pleistocene and upper part of fractured bedrock. Most water probably moves in this zone.
   (c) An intermediate zone (2) down to depths of 200 - 300 feet with flow becoming negligible (½ us gpd/ft^2) at depth.

(d) There is probably very little groundwater movement between drainage basins.

7. Instrumentation could be installed to monitor groundwater movement at a cost of $5,000 - $10,000 per piezometer nest and probably $50,000 would be needed to install a groundwater network.

8. The effect of groundwater movement on the shape of the discharge hydrograph could be determined from hydrograph records or perhaps by installing more weirs.

9. In view of the fact that say a 5% error in precipitation measurement would probably result in the same quantitative error as a 500% error in groundwater measurement, it is thought best not to proceed with groundwater instrumentation unless a very detailed study is made of one basin.

10. High level observation wells may give some indication of surface runoff during the snowmelt period. These wells should be carefully sited in a closed flow system, or one with a limited subsurface inflow/outflow, possibly in surficial materials on the plateau area. Careful mapping of such a site should preceed the installation of the observation well. The well should be carefully designed and instrumented.

GENERAL

Penticton Creek drainage basin is located on the east side of the main Okanagan Valley near the City of Penticton. The drainage basin covers some 67 square miles and extends from latitude $49^\circ 30'$ to $49^\circ 40'$ and longitude $119^\circ 35'$ to $119^\circ 20'$. The elevation ranges from approximately 1,100' at the City of Penticton to some 7,000' at Greyback Mountain.

MORPHOLOGY

Geology

The bedrock is comprised of gneisses and schists of the Shuswap Complex and is associated with the late Mesozoic Okanagan intrusives. The bedrock is exposed in numerous places and is covered by a thin veneer of Glacial deposits, mainly till and ice-contact material.

It appears that Penticton Creek is structurally controlled, as can be seen on the photo mosaic, there is a NNE-SSW lineation, which is approximately parallel to Penticton Creek. There are seven tributary creeks to the main creek, all are at right angles to the NNE-SSW trend, the tributaries to the tributary creeks are again at right angles, i.e. parallel to the NNE-SSW trend. Of the seven tributary creeks, five are on the east side of the basin.

Elevation

The following table shows the areas between different contours:

Contour Interval	Area in Square Mile	% of Total Area			
> 2500	4.15	6.18			
2500 - 3000	2.05	3.05			
3000 - 3500	2.36	3.51			
3500 - 4000	3.10	4.62			over
4000 - 4500	5.50	8.20		over	4000 ft
4500 - 5000	8.90	13.25	over	4500 ft	
5000 - 5500	16.52	24.60	5000 ft		
5500 - 6000	16.29	24.25	61.17%	74.42%	82.62%
6000 - 6500	7.67	11.40			
> 6500	0.65	0.97			
	67.19	100.03			

HYDROLOGY

Precipitation

Records are available from Penticton for the period 1907 - 1953, later records are probably available but the following averages are based on these figures:

Mean Annual Precipitation	11.31"
Minimum 1928 - 1929	5.73"
Maximum 1948 - 1949	18.47"

Monthly Averages:

	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
Precip.in.	0.94	0.94	1.12	1.03	0.80	0.67	0.77	1.10	1.33	0.86	0.86	0.89
% of total	8.31	8.31	9.9	9.12	7.07	5.92	6.81	9.73	11.76	7.60	7.60	7.87

The Hydrology Division of the Water Investigations Branch has developed the following multiple regression equations to calculate precipitation in the Okanagan from elevation, latitude and longitude.

The equations are given below:

$$Y_1 = 0.46\,X_1 + 4.29\,X_2 - 206.3$$
$$Y_2 = 0.267\,X_1 + 2.574\,X_2 - 124.49$$
$$Y_3 = 0.238\,X_1 + 2.098\,X_2 - 101.61$$

Where X_1 = elevation in hundreds of feet

X_2 = Latitude e.g. $49^{\circ}20'$

and Y_1 = Mean annual precipitation in inches

Y_2 = Oct. March mean precipitation in inches

Y_3 = Nov. March mean precipitation in inches

Penticton Creek extends from latitude $49^{\circ}30'$ to $49^{\circ}40'$ which gives an approximate increase of half an inch of mean annual precipitation in the north of the basin.

Limitation of the Equations

The equations are based on data from below 4,000' and so are not verified above this.

The confidence limits of the values are not calculated here, as the main purpose of using them is to show the areal distribution of precipitation over the basin. More detailed studies of the hydrology and meteorology are being carried out by other task forces.

Mean Annual Precipitation

Contour Interval	Mean Elev.	Area in sq. miles	Mean Annual in in.	Precip. acre feet
2500	2100	4.15	14.86	3,288
2500 - 3000	2750	2.05	17.85	1,951
3000 - 3500	3250	2.36	20.15	2,535
3500 - 4000	3750	3.10	22.45	3,711
4000 - 4500	4250	5.50	24.75	7,259
4500 - 5000	4750	8.90	27.05	12,838
5000 - 5500	5250	16.52	29.35	25,856
5500 - 6000	5750	16.29	31.65	27,494
6000 - 6500	6250	7.67	33.95	13,886
6500		0.65	36.02	1,248
		67.19		100,066

over 5000'	over 4500'	over 4000'
68,484 = 68%	81,322 = 81%	88,581 = 88%

The table shows that less than 5% of the precipitation falls below 3000' mainly due to the small area below 3000' (10% of total area). Yet 88% of the precipitation is derived from 4000' and higher, 81% from 4500' and higher and 68% from 5000' and higher, Fig. 1.

Y_2 October - March Precipitation

Mean elevation between controus	Oct-March inches.	Precip. acre-feet	Cumulative Total
2100	8.02	1,774	55,901
2750	9.75	1,066	54,127
3250	11.09	1,395	53,061
3750	12.42	2,053	51,666
4250	13.76	4,035	49,613
4750	15.09	7,163	45,578
5250	16.43	14,471	38,415
5750	17.76	15,430	23,944
6250	19.10	7,811	8,514
6700	20.30	703	
		55,901	

As can be seen, just over half of the mean annual precipitation falls from October to March. It should be borne in mind that a large part of the October - March precipitation occurs as snow and remains on the ground until the spring thaw.

Surface Runoff

A P.F.R.A. Report of 1963 (Ref. No. 5) indicates that the 25 year average runoff (prior to 1963) is some 43,000 ft. or approximately equivalent to 12" over the whole basin (Fig. 2).

If the total precipitation over the basin is in the region of 100,000 acre-feet, as calculated from the regression equation, then approximately half of the precipitation is lost in evaporation, it will be shown that groundwater outflow from the basin is negligible. Of course, both the estimates of runoff and precipitation are subject to considerable error, but will be refined as the study continues.

One of the problems on Penticton Creek is the number of man-made storage schemes.

The Upper Penticton Creek storage reservoir consists of two dams, #1 dam capable of storing 1,200 acre-feet and #2 dam storing 10,240 acre-feet. The catchment area is approximately 12.3 square miles and the estimated average runoff (Ref. No. 5) is 8,900 acre-feet or 13.6". The minimum estimated runoff is 2,000 acre-feet or 3.1".

The average runoff of 13.6" appears low if the estimate of precipitation of 30" or so, for 5000' and higher, is correct. There is a much thicker Pleistocene cover over this area and it could be that the groundwater runoff from this area is much higher than the rest of the basin.

In addition to the Upper Penticton Creek reservoir, there is 100 acre-feet of storage on Howard Lake and 150 acre-feet on Corporation Creek.

It is thus quite difficult to estimate the natural flow. Stream gauges are being installed on the Upper reservoir, to determine reservoir storage, below the upper dams to determine flow released from them and just above the dam at Campbell Mountain, to measure the flow going into the lower storage area and diversion tunnel.

The spring snowmelt generally begins in April and proceeds upwards at an approximate rate of 500' per week until the snow melts on the 7000' peaks in late June.

The peak runoff generally occurs in late May and is in the order of 200-300 cfs. According to reference No. 5, the natural flow in July, August and September is 20 acre-feet per day or 10 cfs with flows as low as 5 acre-feet per day (2.5 cfs).

If we take the low flows as being mainly groundwater discharge, then say groundwater discharge is 7 cfs or approximately 5000 acre-feet per year and assuming the value of 43,000 acre-feet is correct for average natural discharge, then the groundwater component of the discharge (baseflow) is in the order of 11.5%.

Groundwater Flow

As has already been mentioned, the groundwater component of the hydrograph is possibly in the 5% - 15% range of total flow. In addition to this, there will be a certain amount of groundwater flow out of the basin. There are thus two factors to consider:

1. The effect of groundwater flow within the basin, this will generally affect the shape of the discharge hydrograph and be a major influence on low flows.

2. The amount of water actually leaving the basin as groundwater flow.

Amount of Groundwater Leaving the Basin

As the Pleistocene deposits are only a thin veneer over the bedrock, we will consider the hydraulic properties of the bedrock.

The bedrock is generally highly metamorphosed (gneiss, granodiorite) and so the hydraulic conductivity will be dependent on structure i.e. joints, fissures and sheer zones. There appears to be a pronounced joint system running approximately parallel to the main creek (NNE-SSW) and at right angles to this; both are nearly vertical. In addition, there appears to be a smaller system associated with a foliation structure dipping generally to the SW.

These joints have been opened to several centimeters by surface weathering and undoubtedly close up with depth. Test drilling for the diversion tunnel at Campbell Mountain indicated fine fissures up to 140' below the surface with inflows of up to 1 gpm in the test holes. No detail was given on the diameter of the hole or depths at which water came up (Ref. No. 6).

It thus appears that the hydraulic conductivity, k, could probably be expressed as a function of depth and would probably be insignificant below depths of say 500 - 1000'. So there would be very little groundwater outflow from the basin, other than near the mouth of the creek and possibly minor amounts near the topographic divides.

The P.F.R.A. drilled a test hole in the valley bottom near the site of the diversion tunnel and dam. This test hole indicated there was some 70 feet of overburden above bedrock, although it may be that the hole was terminated in a large granitic boulder.

Field permeability tests gave values in the range of 0.06 to 0.3 ft/min., which is approximately 5.5×10^2 us gpd/ft.^{2} to 2.8×10^3 us gpd/ft.^{2}.*

The authors of the report assume a hydraulic head differential of 25' at the dam, a flow path of 250 feet and a cross-sectional area of 13,000 square feet.

From this, they derive an underflow of from 2-10 cfs.

Using D'Arcy's Law

$$Q = KIA$$

Where Q = flow in us gpd
K = hydraulic conductivity us gpd/ft.^{2}
I = hydraulic gradient
A = Cross sectional area

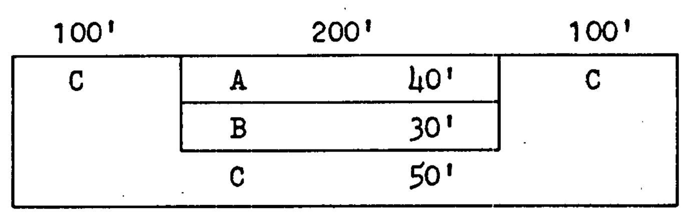
$$Q = 5.5 \times 10^2 \times \frac{25}{250} \times 13{,}000 = 7.1 \times 10^5 \text{ us gpd/ft.}^2$$

$$Q = 2.8 \times 10^3 \times \frac{25}{250} \times 13{,}000 = 3.6 \times 10^6 \text{ us gpd/ft.}^2$$

Dividing by 6.46×10^5 to obtain flow in cfs, we have:

$$Q = 1.1 \text{ to } 5.5 \text{ cfs.}$$

To make a rough estimate of the natural flow through the channel above the dam, where the new weir will be sited, consider the following simplified cross section:



Where: A = coarse gravels and boulders
B = fine sands
C = fractured bedrock

* to convert to us gpd/ft.^{2}, multiply ft/min. by 1.075×10^4.

If we assign the following hydraulic conductivities to each unit:

	Cross sectional area A
$K_A = 10^4$ us gpd/ft^2	$A_A = 8{,}000$ ft^2
$K_B = 10^2$ us gpd/ft^2	$A_B = 6{,}000$ ft^2
$K_C = 10^0$ us gpd/ft^2	$A_C = 34{,}000$ ft^2

And assume a hydraulic gradient of approximately 150 ft/mile (the same as the creek bed).

We have: $Q = KIA$

$$Q_A = 10^4 \times \frac{150}{5000} \times 8000 \text{ us gpd} \quad \text{approx. } 2.4 \times 10^6 \text{ us gpd}$$

$$Q_B = 10^2 \times \frac{150}{5000} \times 6000 \text{ us gpd} \quad \text{approx. } 1.8 \times 10^4 \text{ us gpd}$$

$$Q_C = 10^0 \times \frac{150}{5000} \times 34{,}000 \text{ us gpd} \quad \text{approx. } 1.0 \times 10^2 \text{ us gpd}$$

Total approx. 2.4181×10^6 or approximately 3-4 cfs.

Groundwater Flow Within the Basin

As has already been mentioned, the geology of the basin comprises of a thin veneer of Pleistocene deposits over gneissic bedrock. The Pleistocene deposits vary from silts, sands and till to gravels with extremely rapid lateral variations.

A theoretical groundwater flow pattern is described below, this is based on work by Tóth (1962, 1963) and Freeze (1966, 67a, 67b). Tóth suggests a system of three major flow components: (1) local, (2) intermediate, (3) regional. Due to the decreasing permeability of the bedrock with depth, it is suggested here that the regional flow between drainage basins is negligible or absent. It is further proposed that there be two flow zones for Tóth's local flow system, these are designated K_A and K_B, the term K_C is used for the intermediate flow path.

Local flow Zone K_A

It is proposed that the upper part Pleistocene cover be designated a local flow zone; in places this zone would extend down to bedrock, in others, the lower part of the Pleistocene may be better grouped with zone K_B. The zone K_A is characterized by numerous small flow systems (see diagram (1)). Local springs are caused by variations in topography and lithology, some characteristic situations causing springs are shown in diagram (1).

During August 1970, field examination showed that most of the springs had ceased flowing or were only discharging at 5-10 us gpm, this was due to the low precipitation and high evapotranspiration. This emphasizes the seasonal variations within this zone, much higher flows would be expected after the snowmelt period and also after heavy rains.

Zone K_B

This zone would be an extension of zone K_A, it is shown in diagram (2). This zone would comprise of the lower part of the Pleistocene, the fractured tills and leached zones. It also includes the upper few feet of the bedrock where the joints are opened by weathering, this zone would extend 5-10 or 20 feet below the bedrock surface. The hydraulic conductivity of this zone would be generally higher than that of the overlying zone and would probably be extremely variable, from say, 1 to 100 us gpm per ft^2. This zone will in general, be more uniform than zone K_A and will show smaller water level fluctuations.

To measure the amount of water flowing through this zone, we could use the following elementary formulae.

$$Q = PIA$$

$$Q = VA$$

Where P = Permeability
I = Hydraulic gradient
A = Cross section area
V = Velocity

The hydraulic gradient 'I' could be assumed to be nearly the same as the topographic gradient, pressure tests would give permeability and also a possible depth at which this zone could be terminated. Alternatively velocity, V, could be obtained from injecting tracers.

One feature of this zone is the major spring line at approximately 5000 ft. where there is a distinct break in slope. Above this elevation the topographic gradient is approximately 500 ft/mile while below it is in the order of 1000 ft/mile. This shows that the hydraulic conductivity, K, is such that it will support a hydraulic gradient of 500 ft/mile but not 1000 ft/mile, alternatively there could be a change in hydraulic conductivity at the change of slope, for example, till could be plastered against the lower part of the slope. Most of the groundwater movement probably occurs within this zone.

Intermediate flow Zone K_C

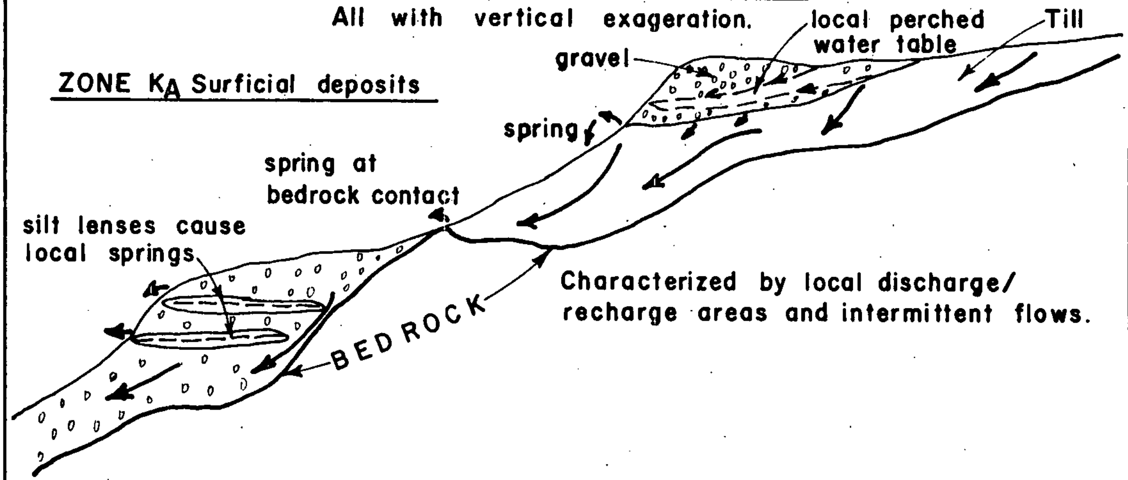
This zone would be entirely within bedrock and would begin at some

A'

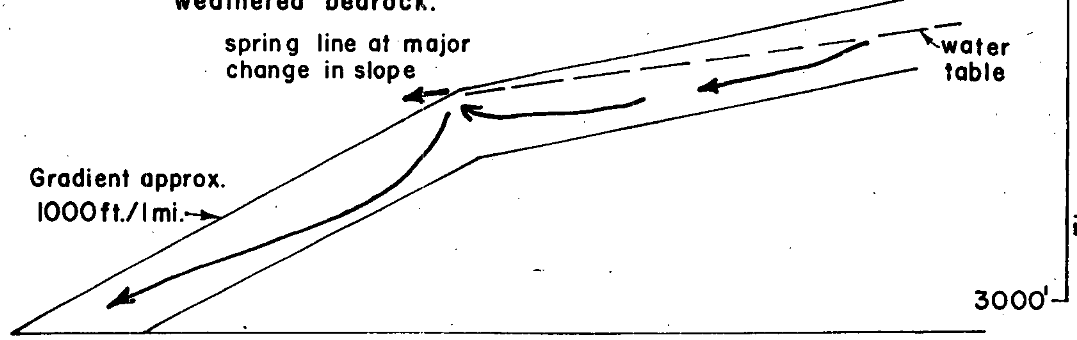
SCHEMATIC FLOW DIAGRAMS

All with vertical exageration.

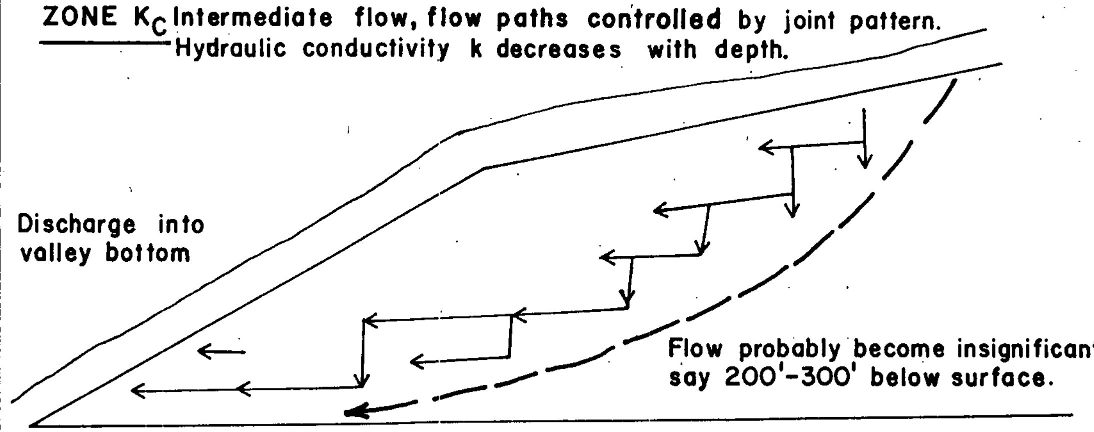
ZONE K_A Surficial deposits



ZONE K_B Base of surfical deposits and upper part of weathered bedrock.



ZONE K_C Intermediate flow, flow paths controlled by joint pattern. Hydraulic conductivity k decreases with depth.



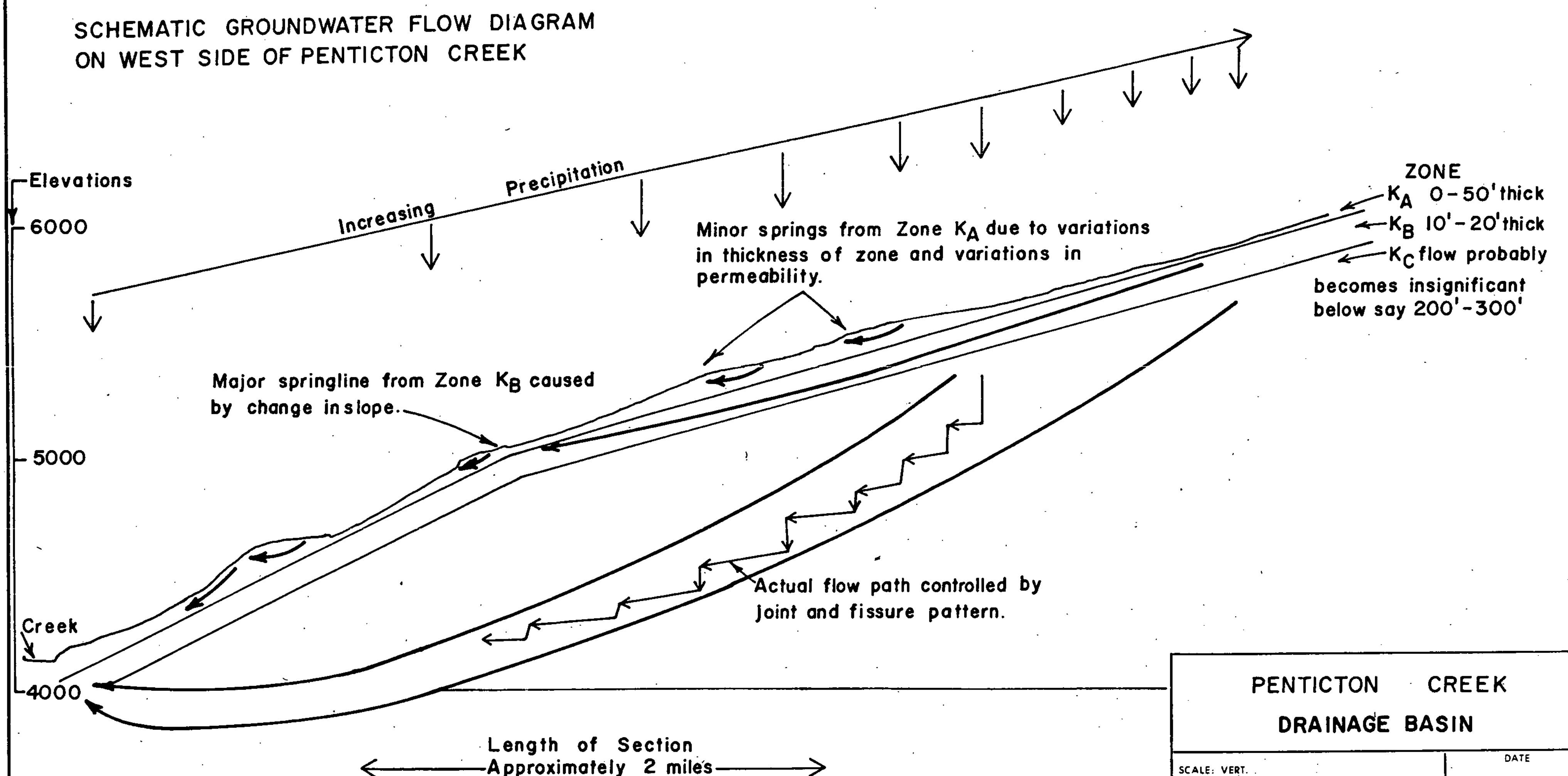
PENTICTON CREEK
DRAINAGE BASIN

SCALE VERT n.t.s.
HOR. n.t.s.

DATE

FILE No.

DWG. No. DIAGRAM 2



PENTICTON CREEK
DRAINAGE BASIN

SCALE: VERT. HOR. n.t.s.	DATE
FILE No.	DWG. No. DIAGRAM 1

BCIL - 870A - W.R.S.

arbitrary depth at which there is a specific decrease in hydraulic conductivity. As has been stated earlier, hydraulic conductivity, K, decreases with depth, a P.F.R.A. test hole at the site of the diversion tunnel found a permeability of ½ us gpd/ft^2 at a depth of 138' below surface. It is thus probable that flow becomes insignificant beyond depths of say 200' and for mathematical simulation an impermeable boundary could be assigned to varying depths, say 200-500 ft. It is thus evident that there would be no significant flows between basins and the groundwater from this zone would discharge into the valley bottom.

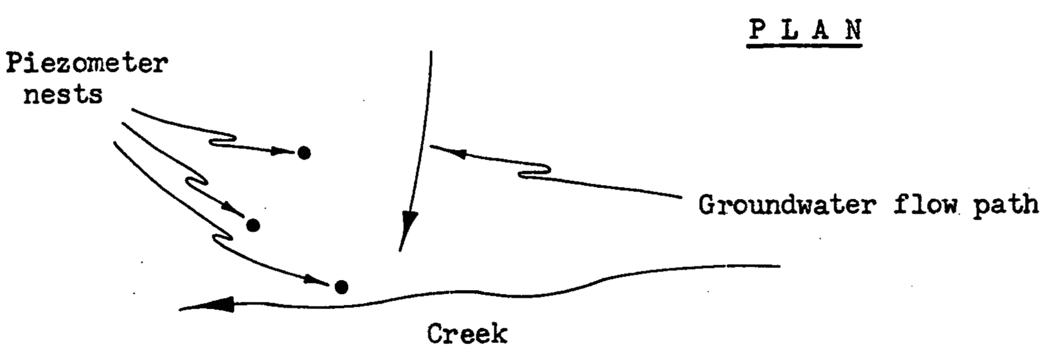
It is proposed that no regional flow component be created, for the above reasons.

Mathematical models developed by Freeze (1966, 67a, b, c,) could be utilized to aid in the interpretation of the groundwater flow system. This would involve assigning <u>relative</u> values of K to a multilayered aquifer system.

To check any theory in the field would be expensive, involving the installation of piezometers. This is discussed under instrumentation.

Instrumentation

In order to measure groundwater fluctuation in the field, it would be necessary to install piezometers, a minimum of three nests in any profile would be necessary to define the water-table plane (see diagram below).



At each nest, at least one piezometer would have to be installed within each of the three proposed flow zones. Due to the steep hydraulic gradients (I) and the relatively high velocities associated with fissure flow, in conjunction with a low storage coefficient (S) water-table fluctuations will be both rapid and relatively large. Consequantly, the water level should be monitored by recorders rather than manually.

It would cost $500 to $2,000 to drill each hole, it may be that nests of piezometers could be completed at different depths within each hole or different holes may have to be drilled for each depth, depending upon conditions and hole diameter.

Recorders would cost approximately $500 for a single channel, with multi channel recorders costing more (for different piezometers) so costs would vary from say $3000 to $6000 per piezometer nest.

There would also be the cost of access roads to each site at a cost of $2000 - $3000 per mile.

As stated, a minimum of three piezometer nests would be required to monitor one section. This, in itself, may not be representative of conditions a short distance away.

In summary, it is concluded that it would not be justifiable to install a piezometer network due to the high capital cost and relatively small returns.

"V" Notch Weirs

One alternative is to install small weirs at numerous strategic points and analyze the hydrograph for the base flow component. Data from these weirs could also be used to simulate surface water runoff using flood routing techniques.

The weirs are described by Hall and Langham (Ref. No. 9) and are constructed of 3/4" or 1" plywood, reinforced with metal angle iron and have a metal lip on the "V" notch to give a sharp crest. The rating curve of the weir will depend upon the angle of the notch, the capacity can be from approximately 7-12 cfs for a two-foot head on a 60^{o} or 90^{o} "V" notch; other angles could also be used. The weirs could be constructed for less than $250, an F-type recorder would cost approximately $450; with installation the weirs would cost approximately $1000.

These weirs could be installed on the tributary creeks and at different elevations on one of the six basins under study.

In the I.H.D. study basin at Carr's Landing, the Hydrology division has reported a good correlation between water-table fluctuations and snowmelt runoff.

One possible explanation is as follows: Apart from the meteorological effects upon runoff from snowmelt, the actual amount of water melting will go partly towards surface water runoff phenomena and partly as groundwater phenomena. This in turn will affect the peak flow and its duration, higher peaks and shorter duration high flows will be experienced when the surface water runoff is more important.

The percentage surface runoff to groundwater will depend upon the permeability of the soil, among other factors. The permeability of the soil will in turn be affected by the amount and type of frost in the soil at the time of snowmelt. The frost seal will depend partly upon soil moisture levels prior to freezing and also upon depth and rate of freezing. The soil moisture levels will depend upon precipitation and evaporation prior to snowfall and the type of frost will depend upon freezing conditions prior to snowfall and the insulating effects of the snowfall. There may also be substantial evaporation/condensation within the soil moisture - snowpack system, depending upon vapour pressures.

Thus monitoring the water-table may give a good index to be used in estimating runoff from snowmelt.

If possible, small closed local flow systems should be instrumented with recording piezometers. If properly designed, the piezometers may also measure evapotranspiration in the summer. Thermistors installed at different depths in the soil may also give useful indexes to the frost seal and would give information on infiltration rates during the spring, summer and fall.

Hydrochemistry

Seven samples of water were collected from Penticton Creek and its tributaries, these were analysed by the Public Health Department. The locations where the samples were taken from are shown on Fig. 1. The analyses are shown in the accompanying table and on the Piper diagram.

As can be seen, the waters are relatively fresh, with less than 100 ppm dissolved solids.

The samples are generally calcium, magnesium, bicarbonate waters and there appears to be no real difference between the samples.

In waters this fresh, the anion/cation epm balance should generally be within 5%, there is up to 10% difference in some analyses, which makes the analyses somewhat suspect.

The Water Balance

If we consider the following simple relationship

(1) $P = ET + R + A_s$ Where P = Precipitation
ET = Evapotranspiration
R = Runoff, surface and subsurface
A_s = Change in storage, surface and subsurface.

From figures available at this time:

P	approx.	100,000 acre-feet per year	
R_s	approx.	43,000 acre-feet per year	(surface)
R_g	approx.	1 - 3,000 acre-feet per year	(groundwater)
A_s	approx.	natural storage prob. small	

Potential ET approx. 20" approx. 61,000 acre-feet.

Thus using equation (1)

100,000 approx. 61,000 + 43,000 + 1 - 3,000 acre-feet

which nearly balances and considering the nature of the data, the balance is quite good.

It can be seen that the groundwater component is quite small even when taking baseflow as 5-15% of runoff (2,000 - 6,000 acre-feet).

Errors within the Water-Balance

1. Precipitation

Errors in catch by the rain gauge caused by location of gauge, height above ground, type of gauge, wind speed, etc., will add some small error say ± 5% for rain and possibly for snow, up to ± 50%.

There is also the problem of extrapolating the gauge catch to the rest of the basin.

Estimating the water equivalent of the snow cover over the basin can also lead to considerable errors.

2. Evapotranspiration

Losses from the snowpack by evaporation and sublimation can be especially high during the snowmelt period. As the snowmelt period extends over several weeks and rises in altitude with time a relatively sophisticated meteorological network would be necessary to estimate losses. Transpiration from the forest cover during summer will also be subject to considerable errors.

3. Runoff

Weirs generally have an error margin of ± 5%, the error margin of the Penticton weirs will be determined by other task forces.

4. Storage

If we assume that each of the Upper storage reservoirs has a surface area of approximately ¼ square mile, or say, 150 acres, then a change of 1/100th of a foot per day will give more than 1½ acre-feet or very nearly 1 cfs inflow or outflow. Thus it will not be possible to measure accurately small changes in storage, especially if one considers the fluctuations due to seiches and winds piling the waters up downwind.

The possible errors in the water-balance have been pointed out to show that many of these errors are of the same or greater magnitude as the groundwater outflow.

CONCLUSION

The main significance of groundwater in this drainage basin is its affect upon the discharge hydrograph. As the groundwater zone is relatively shallow and as gradients are high then there is probably not sufficient temporary groundwater storage to reduce peak flows significantly, yet there is sufficient storage to provide 5-20 cfs runoff during low flow.

WATER SAMPLES FROM PENTICTON CREEK

Sample No.		1			2		
		ppm	epm	%epm	ppm	epm	%epm
A	Cl^-	0.80	0.023	6.50	0.30	0.009	1.39
N	SO_4^{--}	1.20	0.025	7.19	1.00	0.021	3.42
I	* HCO_3^-	18.29	0.300	86.31	35.36	0.580	95.19
O							
N	Sum	20.29	0.347	100.00	36.66	0.608	100.00
S							
C	Ca^{++}	4.2	0.210	49.44	7.0	0.350	48.22
A	Mg^{++}	1.1	0.090	21.34	2.8	0.230	31.79
T	Na^+	2.2	0.096	29.22	2.8	0.122	19.99
I	K^+	1.1	0.028		0.9	0.023	
O							
N	Sum	8.60	0.423	100.00	13.50	0.724	100.00
S							
Total ppm		28.89			50.16		
1 % Anions epm			45			45.6	
% Cations epm			55			54.4	
S.A.R.		0.25			0.22		
pH		6.7			7.2		
Conductivity as micromhos/cm		42			68		
Total hardness as $CaCO_3$		15.0			29.0		
dissolved solids		28.9			50.4		

Alkalinity as CO_3 nil in all samples. Flouride generally less than 0.1 ppm. * HCO_3 value obtained by multiplying $CaCO_3$ by 1.219214.
1 Anion/cation balance should be within:

$\pm$ 5% for total solids 100 ppm.
$\pm$ 3% for total solids 100-250 ppm.
$\pm$ 2% for total solids 250 ppm.

Samples #4 and #6 do not balance within limits. The remaining samples are only just within the limits.

WATER SAMPLES FROM PENTICTON CREEK

		Sample No. 3			Sample No. 4		
		ppm	epm	%epm	ppm	epm	%epm
A	Cl-	0.5	0.014	4.78	0.5	0.014	9.10
N	SO_4--	1.0	0.021	7.06	1.0	0.021	13.44
I	* HCO_3-	15.85	0.26	88.15	7.32	0.120	77.46
O							
N	Sum	17.35	0.295	99.99	8.85	0.155	100.00
S							
C	Ca++	3.2	0.160	48.61	2.0	0.100	47.64
A	Mg++	1.2	0.099	30.04	0.5	0.041	19.63
T	Na+	1.2	0.052	21.34	1.4	0.061	32.73
I	K+	0.7	0.018		0.3	0.008	
O							
N	Sum	6.30	0.328	99.99	4.20	0.209	100.00
S							
Total ppm		23.65			13.05		
1 % Anions epm			47.4			42.6	
% Cations epm			52.6			57.4	
S.A.R.		0.145			0.229		
pH		6.6			6.5		
Conductivity as micromhos/cm		27			17		
Total hardness as $CaCO_3$		13.0			6.0		
dissolved solids		23.7			13.0		

WATER SAMPLES FROM PENTICTON CREEK

	Sample No.	5			6		
		ppm	epm	%epm	ppm	epm	%epm
A	Cl^-	0.3	0.009	3.69	0.3	0.009	2.74
N	SO_4^{--}	1.0	0.021	9.09	1.0	0.021	6.74
I	HCO_3^-	12.19	0.200	87.22	17.07	0.28	90.52
O							
N	Sum	13.49	0.229	100.00	18.37	0.309	100.00
S							
C	Ca^{++}	3.0	0.15		3.6	0.180	49.76
A	Mg^{++}	1.2	0.05		0.6	0.049	13.67
T	Na^+				2.8	0.122	
I	K^+				0.4	0.010	36.57
O							
N	Sum				7.4	0.361	100.00
S							
Total ppm					25.77		
% Anions epm						41.3	
% Cations epm						58.7	
S.A.R.					0.36		
pH		6.9			6.9		
Conductivity as micromhos/cm		20			36		
Total hardness as $CaCO_3$		10.0			14.0		
dissolved solids					26.37		

WATER SAMPLES FROM PENTICTON CREEK

Sample No.		7					
		ppm	epm	%epm	ppm	epm	%epm
A	Cl^-	0.50	0.014	3.69			
N	SO_4^{--}	2.70	0.056	14.71			
I	HCO_3^-	19.02	0.312	81.60			
O							
N	Sum	22.22	0.382	100.00			
S							
C	Ca^{++}	3.2	0.160	35.96			
A	Mg^{++}	1.8	0.148	33.33			
T	Na^+	2.9	0.126	30.71			
I	K^+	0.4	0.010				
O							
N	Sum	8.3	0.444	100.00			
S							
Total ppm		30.52					
% Anions epm			46.2				
% Cations epm			53.8				
S.A.R.		0.32					
pH		6.9					
Conductivity as micromhos/cm		35					
Total hardness as $CaCO_3$		15.6					
dissolved solids		30.44					

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APPENDIX 1

Since writing this report, the following paper has been brought to the author's attention by E. C. Halstead.

"Groundwater flow systems in the crystalline rocks of the Okanagan Highland, British Columbia", by D. H. Lawson, Canadian Journal of Earth Sciences, Vol. 4, P. 813, 1968.

This paper deals with a groundwater study in Trapping Creek Basin, some 20 to 30 miles east of Penticton Creek Basin.

Lawson proposes a flow system based on Toth's work and proposes 6 permeability zones, three zones are similar to those proposed in this report and a further three zones of higher permeability are postulated in the valley bottom.

Lawson postulates that piezometers cannot be reliable beyond depths of 175 feet, due to the decreasing and more random frequency of fissures with depth. He further postulates an impermeable boundary at a depth of 1000 feet and suggests most of the groundwater movement (95%) occurs in the local flow system (zones K_A and part of K_B in this report). Lawson reports permeabilities higher than the P.F.R.A. figures in this report, this may be due to differences in geology, there being more permeable tuffs present in Trapping Creek. Lawson gives values of permeability as follows:

Local flow zones (0-150') 10-17 igpd/ft. thickness (zone K_A and part K_B)

Intermediate flow zone (est. at 150') 6.8 x 10^{-3} igpd/ft. thickness

Regional flow zone (est. at 600') 8.0 x 10^{-15} igpd/ft. thickness

A HYDROGEOLOGICAL RECONNAISSANCE STUDY OF PEARSON CREEK SUB-BASIN

by P. L. Hall

A HYDROGEOLOGICAL RECONNAISSANCE STUDY OF PEARSON CREEK SUB-BASIN

by P. L. Hall

Movement within this basin is extremely limited due to lack of logging roads.

There is considerably less data available for this basin than Penticton Basin.

Pearson Creek flows into Mission Creek at an approximate elevation of 3,000 feet, Pearson Creek basin rises to approximately 6,500 feet.

The basin is considerably smaller than Penticton basin, being only approximately 30 square miles in area.

Being further north, precipitation is also slightly higher than Penticton Creek. Estimated precipitation is given below:

Contour Interval	Mean Elevation	Area Sq. Miles	Precipitation Inches	Precipitation Acre-feet
3000 - 4000	3700	4.2	23	5,200
4000 - 5000	4500	9.6	27	13,800
5000 - 6000	5500	11.4	32	19,200
6000	6300	4.9	35	9,200
		30.1		47,400

Calculations were made the same way as on Penticton Creek.

Assuming an approximate mean annual precipitation of 50,000 acre-feet:

less than 10% falls below 4000 ft.
more than 60% falls above 5000 ft.
more than 20% falls above 6000 ft.

GEOLOGY

The area is much the same as Penticton Creek, a Pleistocene veneer over igneous bedrock. Here the main difference is the bedrock type, being basalts and andesites rather than granodiorite.

There is a distinct plateau area above 5,500 feet which is generally poorly drained, due to the low topographic gradients. This area may be suitable for high level observation wells to use as an index of runoff from snowmelt. The wells should be sited in an area not influenced by large surface or groundwater inflows and outflows. The wells should also, if possible be completed in fairly permeable deposits, i.e. the drift or upper few feet of bedrock. Wells completed at depth may be affected by irregular storage within fissure zones. That is, a uniform input of water may not produce a regular rise in the observation well due to zones of large permeability (large fissures) and zones of small fissures at different depths.

It is not possible to estimate the amount of groundwater outflow from the basin at the moment as there is no information on the type and amount of surficial materials in the valley bottom. The quantity is probably in the same order of magnitude as Penticton Creek, possibly slightly higher as there appears to be more surficial material.

The baseflow component can be estimated from the hydrographs obtained from the new weir. There is little or no artificial storage to modify the runoff hydrograph.

Movement within the basin is extremely difficult and it would be extremely expensive to veriiy any theoretical groundwater movement by installing piezometers.

Locations of chemical analyses are shown in figure 1 and results of the water quality analyses are shown on the Piper diagram.

WATER SAMPLES FROM PEARSON CREEK

		Sample No. 1			Sample No. 2		
		ppm	epm	%epm	ppm	epm	%epm
A N I O N S	Cl^-	0.3	0.008	0.71	0.3	0.008	1.26
	SO_4^{--}	4.9	0.102	8.58	2.6	0.054	8.03
	* HCO_3^-	65.84	1.079	90.72	37.31	0.611	90.71
	Sum	71.04	1.190	100.00	40.21	0.674	100.00
C A T I O N S	Ca^{++}	15.6	0.778	64.11	10.4	0.520	76.75
	Mg^{++}	3.6	0.296	24.38	1.1	0.090	13.38
	Na^+	2.8	0.121	11.51	1.3	0.056	9.87
	K^+	0.7	0.018		0.4	0.010	
	Sum	22.7	1.214	100.00	13.2	0.676	100.00
Total ppm		93.74			53.41		
1 % Anions epm			49.5			49.9	
% Cations epm			50.4			50.1	
S.A.R.		0.166			0.102		
pH		7.7			7.3		
Conductivity as micromhos/cm		119			65		
Total hardness as $CaCO_3$		54			30.6		
dissolved solids		83			58		

Alkalinity as CO_3 nil in all samples. Flouride generally less than 0.1 ppm. * HCO_3 value obtained by multiplying $CaCO_3$ by 1.219214.

1 Anion/cation balance should be within
± 5% for total solids 100 ppm.
± 3% for total solids 100-250 ppm.
± 2% for total solids 250 ppm.

All samples balance within limits.

WATER SAMPLES FROM PEARSON CREEK

	Sample No.	3			4		
		ppm	epm	%epm	ppm	epm	%epm
A	Cl-	0.3	0.008	1.20	0.3	0.008	0.44
N	SO_4--	4.0	0.083	11.84	7.0	0.146	7.65
I	* HCO_3-	37.31	0.612	86.96	106.8	1.750	91.91
O							
N	Sum	41.61	0.703	100.00	114.1	1.904	100.00
S							
C	Ca++	10.6	0.529	79.55	27.6	1.377	73.76
A	Mg++	1.0	0.082	12.37	4.5	0.370	19.82
T	Na+	1.0	0.044	8.08	2.4	0.104	6.42
I	K+	0.4	0.010		0.6	0.015	
O							
N	Sum	13.0	0.665	100.00	35.1	1.867	
S							
Total ppm		54.61			149.2		
1 % Anions epm			51.4			50.5	
% Cations epm			48.6			49.5	
S.A.R.		0.079			0.111		
pH		7.3			7.9		
Conductivity as micromhos/cm		62			179		
Total hardness as $CaCO_3$		30.6			87.6		
dissolved solids		58			112		

A HYDROGEOLOGICAL RECONNAISSANCE STUDY OF LAMBLY CREEK SUB-BASIN

by

E. Gordon Le Breton

A HYDROGEOLOGICAL RECONNAISSANCE STUDY OF LAMBLY CREEK SUB-BASIN

by E. Gordon Le Breton

INTRODUCTION

Methods of Investigation

As sub-basins are virtually unsettled, and study of the groundwater regime must first be directed towards qualitative reconnaissance studies of natural phenomena. This involved field mapping of groundwater features such as springs and seepage sites in relation to topography and geology. Air photos were used to supplement field studies.

GEOGRAPHY

Location and Extent of the Area

Lambly Creek drainage basin occurs on the west side of Okanagan Lake, in a direction northwest of the city of Kelowna. The basin lies between parallels of latitude 49°55' and 50°07' north, and meridians of longitude 119°30' and 119°49' west (Figs. 1 and 3). The area of the basin is about 95 square miles. Its elevation ranges from 1,121 feet at Okanagan Lake to 6,134 feet at Whiterocks Mountain.

Drainage

Lambly Creek describes an arcuate course divisible into 3 portions during its flow from Lambly Lake to Okanagan Lake. Upon leaving its source area, it flows northeast in the upper part, slightly south of east along its central portion and turns southeast in its lowest portion. The major tributary is Terrace Creek which rises in the extreme northwest corner of the sub-basin and generally flows southeast before entering Lambly Creek at about the midpoint of the central portion. The other important tributary creeks are North Lambly Creek which rises in Tadpole Lake flowing mainly from northwest to southeast and occurring about 3 miles west of Terrace Creek, and Bald Range Creek flowing mainly from north to south entering the main creek at a point where it turns southeast. The basin is little affected by man made storage, except at Lambly and Esperon Lakes and by a dam on the lower part of Lambly Creek. Precipitation ranges from about 11 inches at Okanagan Lake to an estimated 36 inches at the highest levels.

Vegetation

The area is densely forested preventing access to much of the area. The tree types are mainly Lodgepole pine with some Douglas fir and Spruce at the higher elevations, above about 3,500 feet, with Douglas fir and Yellow pine predominating below 3,500 feet and in areas of east-facing aspect. Locally poplars occur and are found within the elevation range from about 3,000 to 4,500 feet.

GEOLOGY

The bedrock geology is comprised mainly of two rock types, intrusive igneous rocks chiefly granite and granodiorite of Jurassic age, and extrusive igneous rocks, chiefly andesite and basalt of Tertiary age (Fig. 1). These rocks, which have not been subjected to structural influences produced by earth movements can be expected to have fracture patterns formed during natural cooling processes and by weathering. Rectangular type fracture patterns were observed during field work but no particular predominating trend seemed to be apparent from which qualitative inferences may be drawn concerning fracture permeability influences on groundwater movement.

The surficial geology (Fig. 2) most of which has been mapped by R. J. Fulton (1969) consists mainly of till, an unsorted mixture of sand, silt, clay and boulders, commonly less than 25 feet thick. Fluvial deposits of sand and gravel with locally some silt, are commonly found flanking the steep valley faces of Lambly Creek.

HYDROGEOLOGY

Groundwater Mapping

As access roads are well distributed in this sub-basin, it was possible to make observations concerning groundwater features across much of the area. Numerous trips were made into the basin between early summer and fall, permitting observations which give an indication of influence of seasonal variations in temperature and precipitation upon rates of groundwater discharge and storage. Plotting of basic data and its subsequent synthesis resulted in division of the basin into several groundwater zones (Fig. 3). At the highest levels from 4,500 feet to 4,800 feet, zone 1, a zone of thick snow accumulation, spring and summer melting gives rise to water-logged areas, or terrain with many springs and often very widespread seepage. Zone 2, in an elevation range of about 4,000 feet to 4,400 feet is characterized by fewer springs and somewhat less seepage. Zones 1 and 2, the source and near source areas for creeks give rise to permanent runoff and most of the groundwater discharge. These are zones of considerable water surplus. Spring discharges are commonly less than 2 imperial gallons per minute and many of the spring discharges do not become part of the main streamflow.

There appears to be considerable groundwater and surface water that is lost by evapotranspiration so that much of the precipitation is involved in a hydrologic cycle that is complete at these high levels. At successively lower elevations than zones 1 and 2, are zones 3, 4 and 5 with an ever decreasing number of spring discharge sites and seepage features.

Locality 4A was so separated because of the rare occurrence of a permanent, nearly constant flowing spring of about 2 igpm (imperial gallons per minute). This spring observed many times during the field season, showed no noticeable drop in yield in contrast to most springs many of which went dry or nearly dry. Occurring on a steep slope without a particularly large catchment area, its west-facing aspect combined with possible high storage may account for its steady flow.

Water Quantity

There is no information available concerning permeability of the bedrock nor surficial deposits for Lambly Creek sub-basin.

Recourse therefore must be made to texts discussing data on the same rock types occurring elsewhere. For information on granitic and basalt rock types, reference is made to Meinzer (1923, p. 138 to 148). Granitic type rocks are generally poor water bearers and when encountered at several hundred feet, are almost devoid of water. Water is obtained from joint openings which may be expected to close rapidly with depth. The vast majority of wells producing water from granitic rock are less than 300 feet deep, most of the water supply coming from depths of less than 100 feet. Well yields range from 2 to 25 igpm and average about 10 igpm.

Well yields and spring flow from basalts prove this rock type to be a good aquifer in the United States. "The water occurs in large joint openings and other cavities. This rock is so generally traversed by large openings that it takes in surface water very readily." (Meinzer, 1923, p. 138). Frequently, well yields up to 100 igpm may be anticipated. In areas favourable to high well yield, similarly high spring flows are to be expected and do, in fact, occur.

Within the writer's limited field observations, no evidence was found of spring flow from bedrock sources. This may be taken to suggest generally low permeability and low water yield of the bedrock in the basin. Information confirming generally low well yields from bedrock sources within the Okanagan, is given by Halstead, E. C. (1969) and from an observation well drilled into volcanic rocks in Pearson Creek sub-basin in 1970 and supervised by the Groundwater Division. Both programs, examples, from wells to as deep as 270 feet show well yields from several small fractures to be in the range of 1 to less than 10 igpm.

With regard to the surficial deposits these are primarily till, and again are predominantly low permeability materials. The common occurrence concerning groundwater discharge is mainly of spring seepage with some spring flows less than 2 igpm. The fact that there is noticeable decrease in flow, some of which cease entirely and of considerable decreases in size of spring seepage areas from spring to fall suggests generally low groundwater flow from the surficial deposits. This very noticeable decrease in groundwater discharge is evidence of the dependence of storage areas upon replenishment by snowmelt and of the limited storage capacities of the material from which discharge takes place.

As the objective of the sub-basin studies was to assess, even on a qualitative basis, the possible importance of the groundwater component to stream flow, it is believed that most of the groundwater to stream flow originates in the source areas of zone 1. The groundwater is derived mainly from the surficial deposits and possibly from shallow depths in the bedrock. Almost all of the water supply leaving the basin is considered measured by runoff gauges and losses beneath and around gauging sites is thought to be minor.

Water Quality

Numerous conductivity measurements of springs and stream flow were plotted as parts per million (conversion factor 1 ppm = 1.56×10^{6} mho/cm at 25°C, Todd, 1959, p. 328). The plotted results when contoured show a steadily increasing mineral content with increasing flow path. Very high elevation areas, areas of groundwater recharge, have waters low in total dissolved solids and low elevation areas, discharge areas have waters higher in total dissolved solids. Both surface streams and groundwaters (springs) show the same trend. The increase in mineralization is commonly small, further suggesting that groundwater contributions to runoff are small.

REFERENCES CITED

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Meinzer, O. E. (1923): Outline of groundwater hydrology; U. S. Geol. Survey Water Supply Paper 494.

Todd, D. K. (1959): Groundwater Hydrology; John Wiley and Sons, New York.

A HYDROGEOLOGICAL RECONNAISSANCE STUDY

OF GREATA CREEK SUB-BASIN

by

E. Gordon Le Breton

A HYDROGEOLOGICAL RECONNAISSANCE STUDY OF GREATA CREEK SUB-BASIN

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INTRODUCTION

Methods of Investigation

As sub-basins are virtually unsettled, any study of the groundwater regime must first be directed towards qualitative reconnaissance studies of natural phenomena. This involved field mapping of groundwater features such as springs and seepage sites in relation to topography and geology. Air photos were used to supplement field studies.

GEOGRAPHY

General Comments

Greata Creek sub-basin lies between lines of latitude 49°45' and 49°49' north and meridians of longitude 119°51' and 120°0' west. It has a total area of about 12 square miles. This sub-basin is closely comparable with the Lambly Creek sub-basin where Lambly Creek flows within its upper and central portions, in terms of topography, direction of stream flow and aspect. Greata Creek flows from southwest to northeast and turns east to flow into Peachland Creek. The basin has an east-facing aspect (Fig. 1).

GEOLOGY

General Comments

The bedrock geology as shown in Figure 1 taken from G.S.C. Map 538A, Kettle River (west half), geology by Cairnes, C. E. (1936) consists primarily of granodiorite, diorite and quartz diorite rock types.

The surficial geology (Fig. 2) is mainly till, commonly quite thin across much of the area with sand and gravel deposits flanking and underlying Greata Creek. The thickness of these deposits is estimated to be up to 50 feet thick.

HYDROGEOLOGY

As Greata Creek covers a very small area and was mapped during a short time interval in the summer after the influences of snowmelt had largely disappeared, it was possible to observe only a limited number of groundwater features. This basin lies at an elevation range equivalent to zones 3 and 4 of Lambly Creek sub-basin and may earlier in the year exhibit more numerous sites of seepage and spring discharge. Becsause of the time of year at which this basin was mapped, its more southerly location, and the small number of groundwater discharge points actually observed, the basin zones are classified as similar to zones 4 and 5 of Lambly Creek.

Increases in stream flows are generally associated with additional tributary creeks entering the main creek. However, an intermittently appearing stream, the most northwesterly tributary creek, revealed an overall increase in flow, some of which might possibly be attributed to groundwater discharge. However, as in the case of Lambly Creek, there is little evidence to suggest more than minor contributions from groundwater to the increase in stream flow. Again there was some small increase in total mineralization of the streams with increased flow path (Fig. 3) supporting the fact that some increment from groundwater was made to stream flow.

CONCLUSIONS

Conclusions drawn from the study of the two foregoing sub-basins are that most of the discharge of water from the basins is measured as run-off. The amount of groundwater flow which goes unmeasured is probably very small and would form a very small percentage of the total runoff of both basins.

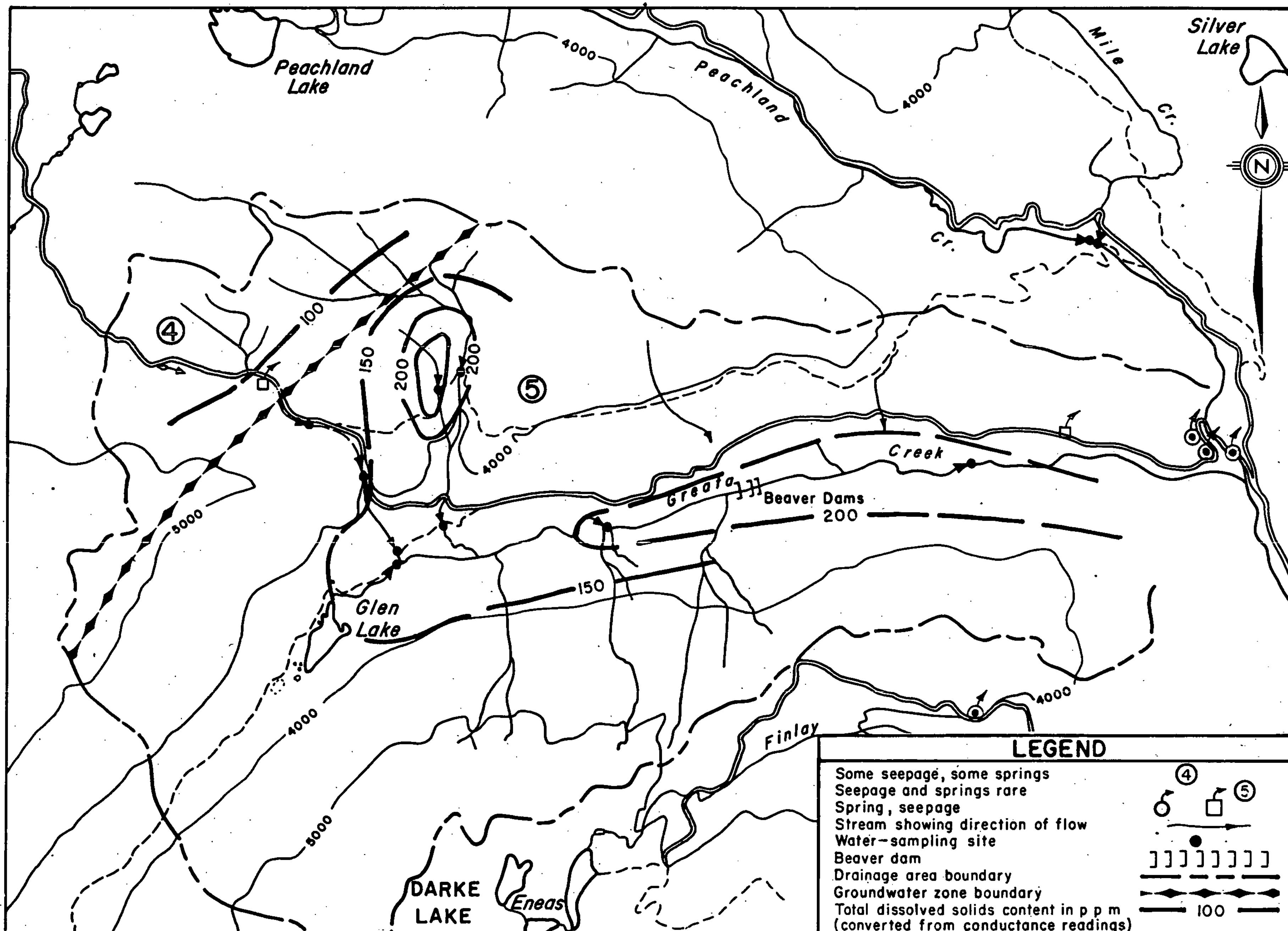


FIGURE 3 GROUNDWATER ZONES
GREATA CREEK SUB-BASIN

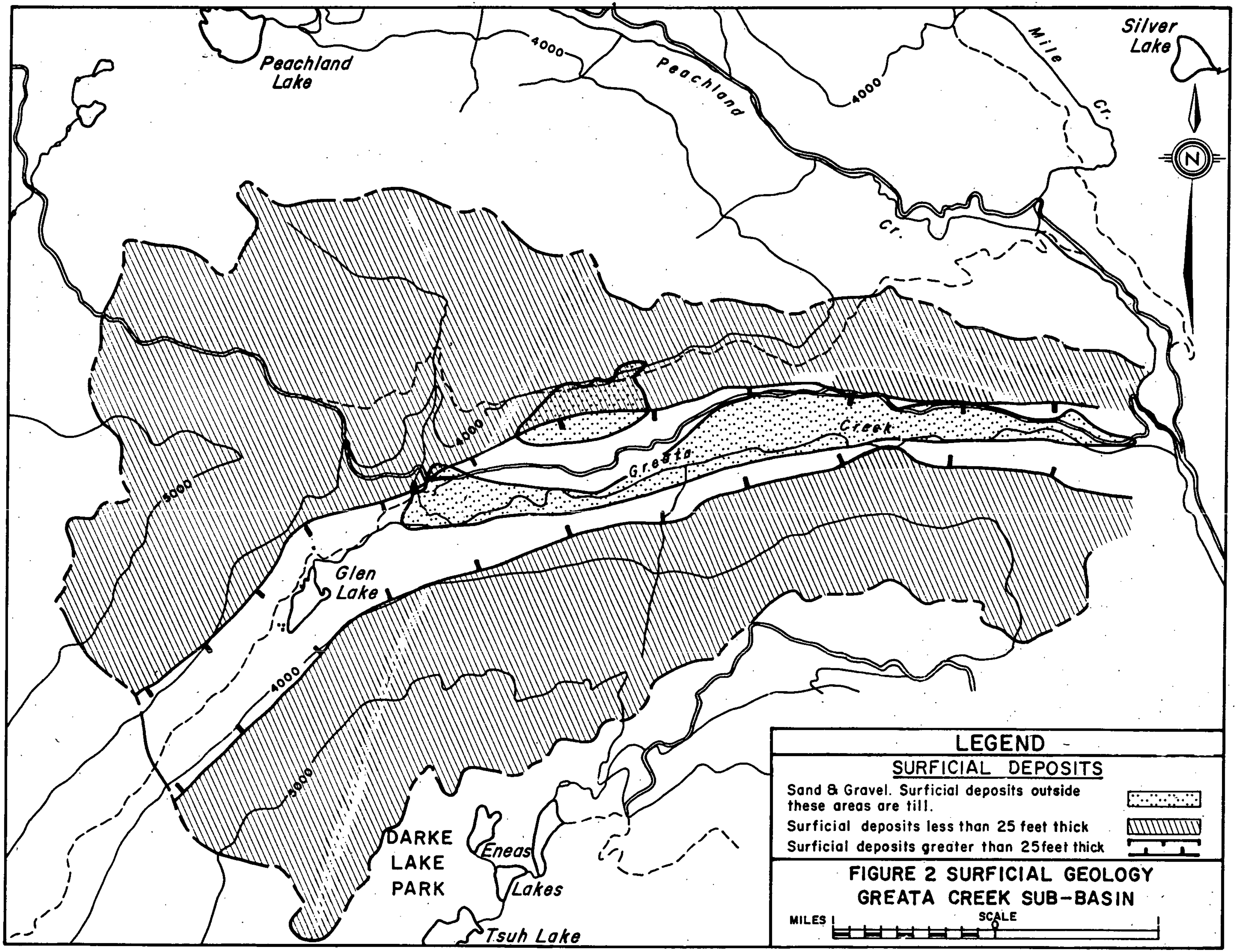


FIGURE 2 SURFICIAL GEOLOGY
GREATA CREEK SUB-BASIN

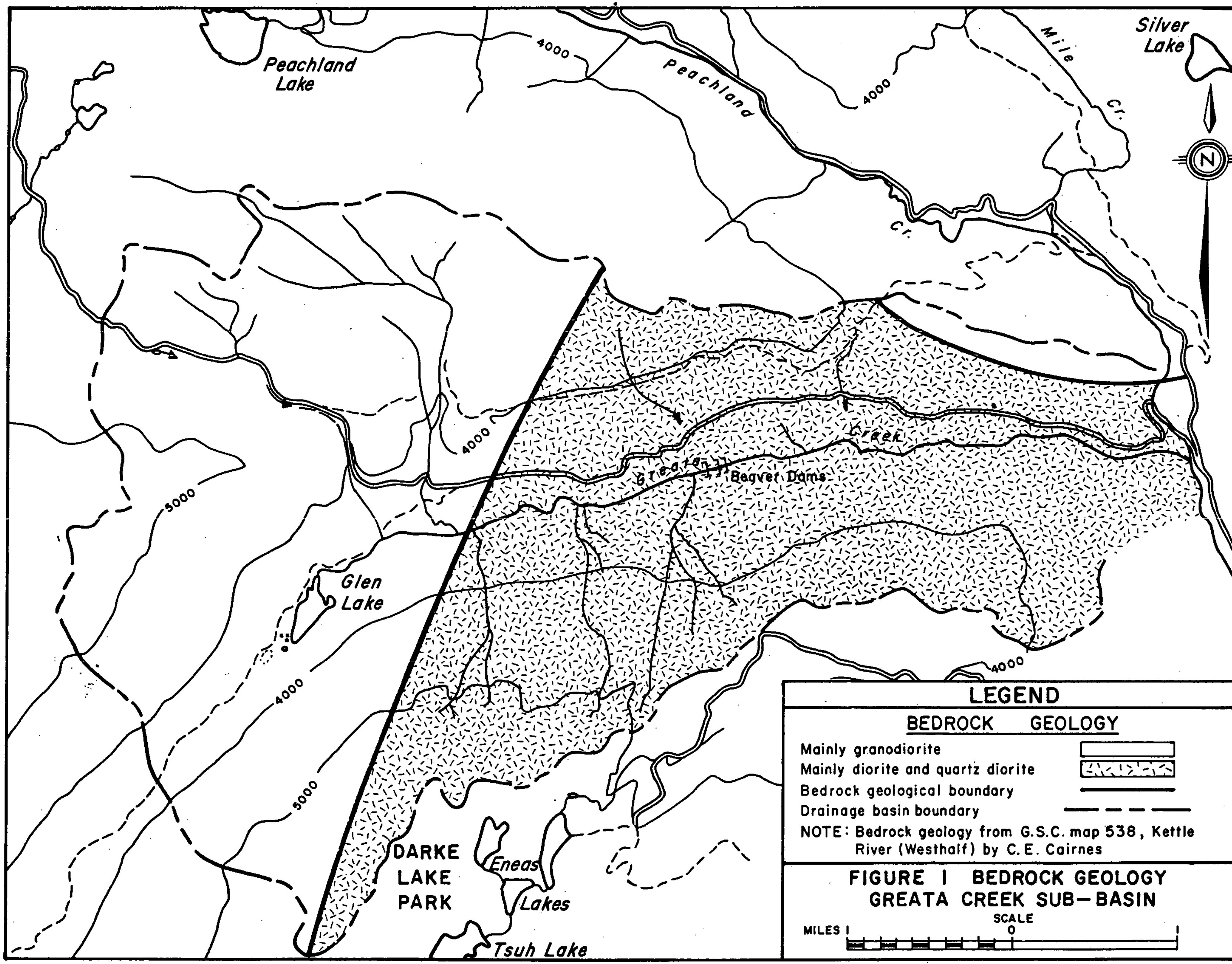


FIGURE 1 BEDROCK GEOLOGY
GREATA CREEK SUB-BASIN

SUB-BASIN STUDY CONCLUSIONS

In summing up the combined findings of the six sub-basin studies, Mr. Halstead's phrasing of the objective will be repeated.

Objective

"The object of the reconnaissance investigation was to determine whether or not the groundwater component of the sub-basin is in sufficient volume to warrant the expenditure of more time and funds to provide as complete as possible an assessment of its contribution to the hydrologic regime."

Certain common factors emerge from three separate investigators:

(1) Geology

The bedrock geology comprises mainly intrusive igneous rocks -- granite and granodiorite; metamorphic rocks -- gneiss and schists; and extrusive igneous rocks -- andesite and basalt.

The surficial geology is primarily till, commonly very thin, with some sand and gravel deposits in each basin. The surficial deposits are the most important medium for storage and movement of groundwater.

(2) Topography

There is generally a sharp change in surface gradient from the mouths of the main creeks to their source areas.

(3) Vegetation

Dense stands of timber prevent access to much of the basin areas. The main tree type is Lodgepole pine with some Douglas fir, Spruce, Yellow pine, Poplar and Cedar.

(4) Hydrogeology

Sharp changes in gradient, and bedrock-drift contacts give rise to the occurrence of many springs in the basins.

Local flow systems primarily occurring within the surficial deposits adjacent to the creeks account for most of the groundwater component of baseflow. Because local flow systems are primarily of limited depth and small areal extent, they are sources of small groundwater storage. Consequently, much of the groundwater discharge will rapidly decline in yield and is very dependent on recharge for maintenance of flow. As recharge is restricted almost entirely to snowmelt, a high and steady rate of groundwater discharge must not be expected from the sub-basins.

Baseflow to the streams is calculated to range from 3 to 20 cfs for Vaseux and Penticton Creek drainage basins. It is considered to be equally small for the other sub-basins with their very similar hydrogeological environments.

(5) Hydrogeochemistry

There is an increase in total dissolved solids content of surface waters and groundwaters from the recharge to discharge areas, but this increase is not very significant.

Only small increases in total mineralization to streams seen in conjunction with only limited increases in stream-flow support early opinions that the nature of the bedrock and surficial geology was such that considerable groundwater contributions should not be anticipated from sub-basins.

(6) Conclusions

Inaccuracies in measurement of precipitation across the basins, the very few precipitation gauges occurring in these areas, combined with general extrapolation of the data across the basins and its divergence from actual precipitation variations, more than offset errors in groundwater flow calculations.

It is generally agreed that instrumentation for further groundwater studies in sub-basins within the rather limited budget for the Okanagan River Basin Study seems unjustified at this time. Instrumentation if carried out in the future should follow that outlined by P. L. Hall. The writer, based on his field observations suggests Terrace Creek as a minor basin for further study (1) because of the many creeks with readily available access, (2) the relative ease with which gauging stations could be reached, (3) the very limited amount of man-made storage in the basin.

In relating sub-basin studies to the groundwater studies in the main valley, it can be observed that subsurface flows into fan deposits at the mouths of tributary creeks, though possibly commonly small, may provide locally important sources of groundwater recharge. There is strong evidence to suggest subsurface flow from tributary valleys augments stream flow in Okanagan River at the south end of the valley.

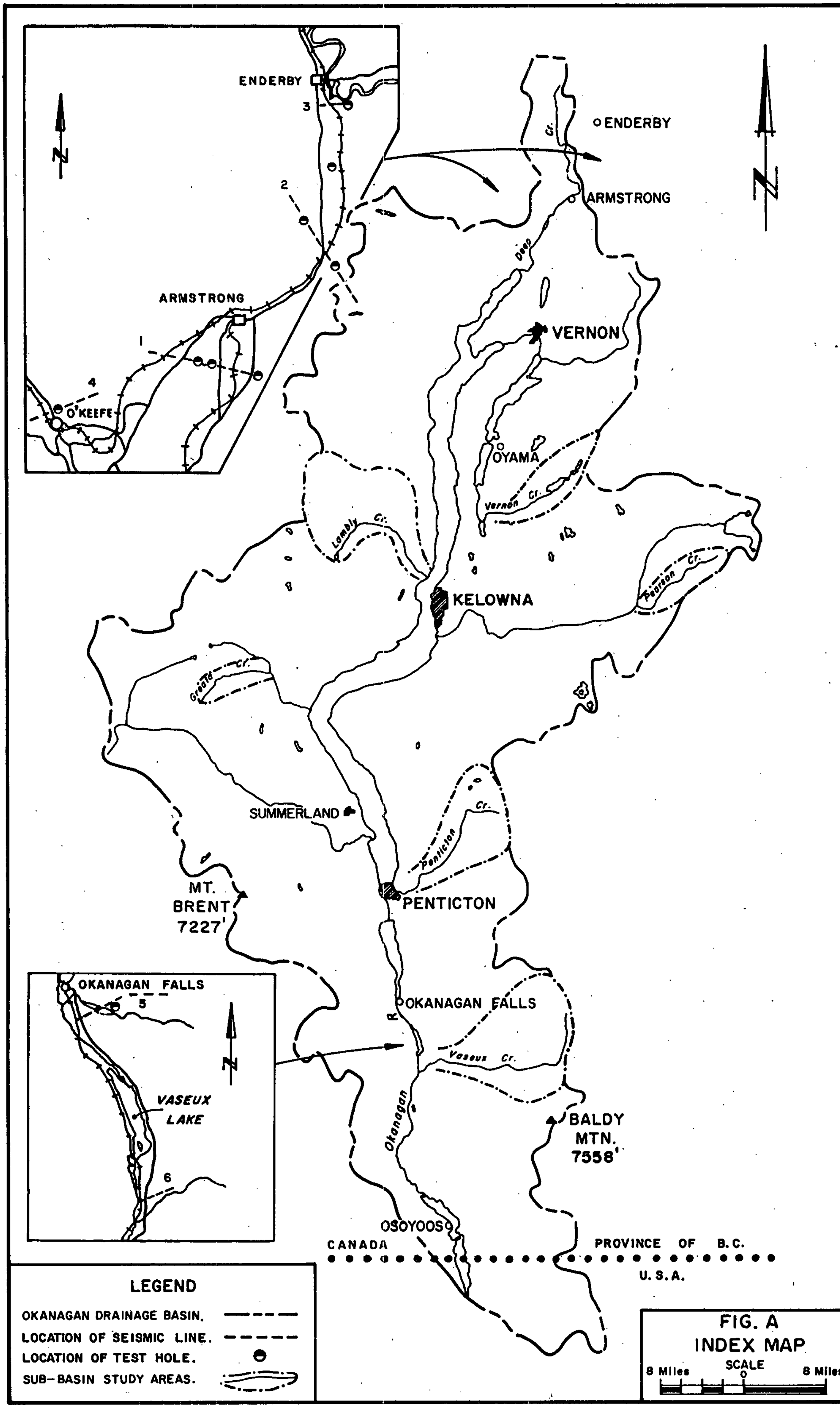


FIG. A
INDEX MAP

Aug. 9/91

#1,2 maps were missing from this report. These 2 are copies of maps found at back of blue-covered Report entitled "Tech. Supplement # I to Final Report" which appear (Dave J. agrees) to be the correct ones to go with this report too.

Bart T.

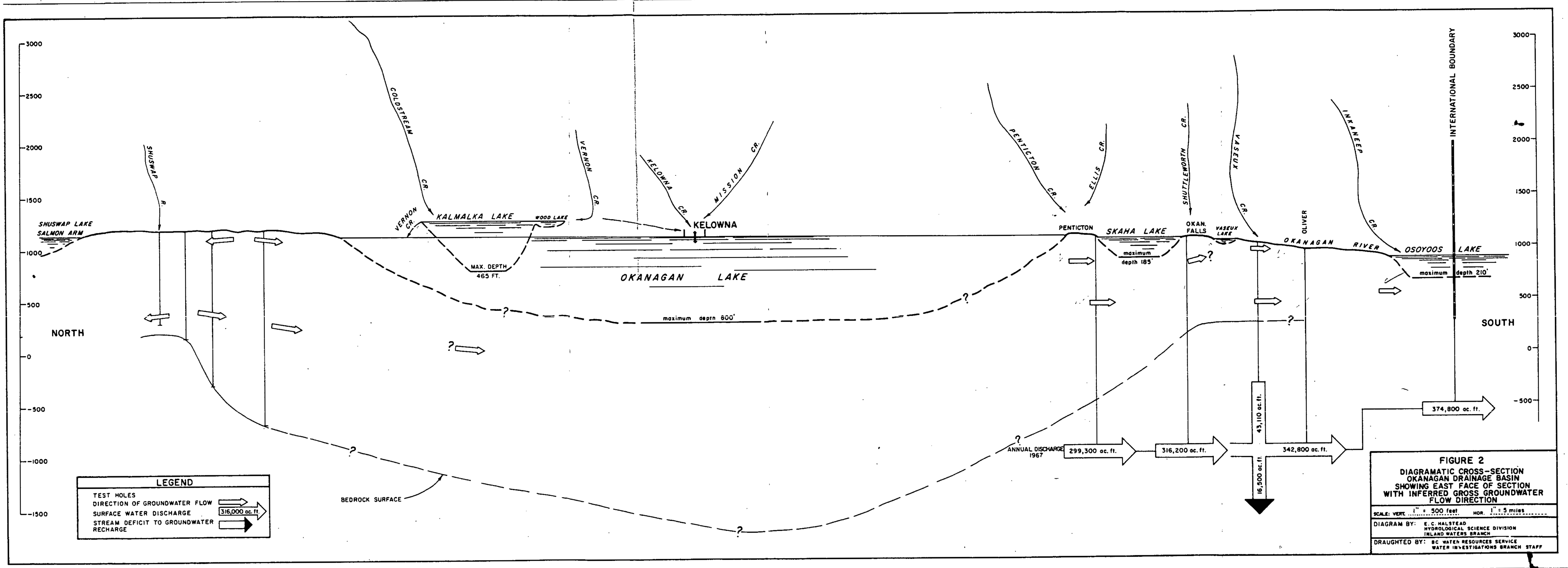


Figure 2
Cross-Section
Okanagan Basin

4.6.0

BRITISH COLUMBIA
DEPARTMENT OF LAND, FORESTS, AND WATER RESOURCES
WATER RESOURCES SERVICE
WATER INVESTIGATIONS BRANCH
GROUNDWATER DIVISION

FIGURE 1 HYDROGEOLOGICAL MAP NORTH END, OKANAGAN RIVER BASIN

TO ACCOMPANY CANADA-BRITISH COLUMBIA OKANAGAN BASIN STUDY-TECHNICAL SUPPLEMENT II

SCALE: 1 inch = 2000 feet	Date: August 1972
ENGINEER: E. GORDON LE BRETON	

NOTE

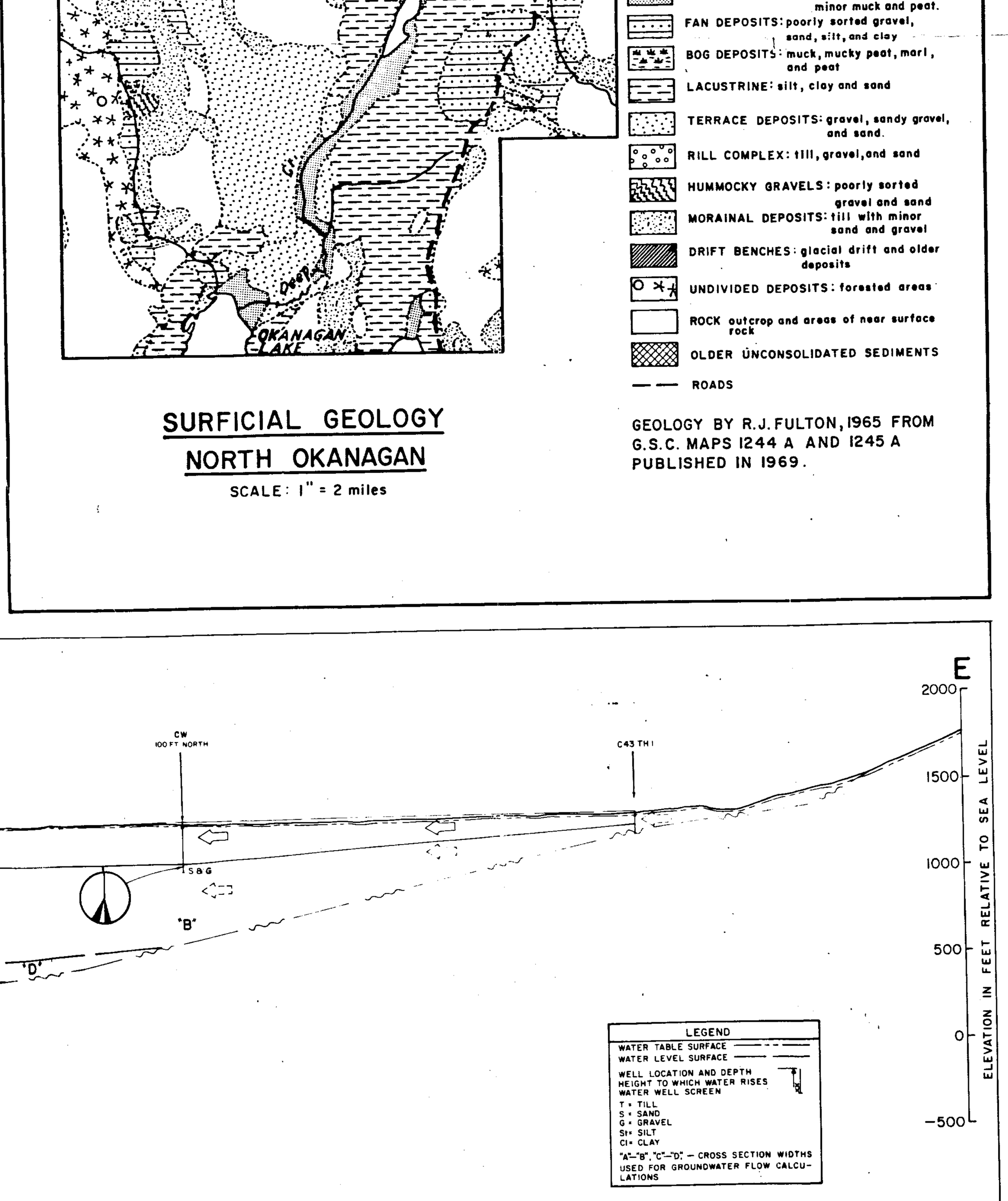
BASE MAP AND LEGEND BY THE

BRITISH COLUMBIA
DEPARTMENT OF LANDS, FORESTS, AND WATER RESOURCES
SURVEYS AND MAPPING BRANCH
TOPOGRAPHIC DIVISION
(* FIELD OPERATIONS DIVISION)

BASE MAP LEGEND

TRIANGULATION STATION	HASS I.P. 2852'	CREEK INDEFINITE	
BENCH MARK	B.M. 24 J 1368.24'	SWAMP	
GROUND CONTROL POINT	ART 277.8'	CONTOURS & ELEVATIONS	1000
AIR PHOTO POINT	F. 28 2939'	CLIFF	
AIR PHOTO CENTRE & FL. No.	BC5002 207	CUT	
ROAD MAIN – HARD TOP		FILL	
ROAD SECONDARY – HARD TOP		FENCES	
ROAD – OTHER		GRAVEL PIT	PIT
TRAIL		CONTOURS INDEFINITE	
POWER LINE		BUILDINGS	
CREEK		CULTIVATED	C
CREEK INTERMITTENT		ORCHARD	ORCH.
		WOODED AREA	

*CURRENT DIVISION TITLE (1972).



GEOLOGY BY R.J. FULTON, 1965 FROM G.S.C. MAPS 1244 A AND 1245 A PUBLISHED IN 1969.

SURFICIAL GEOLOGY
NORTH OKANAGAN

SCALE: 1" = 2 miles