PART III
GROUNDWATER STUDIES

CHAPTER 15

Hydrogeological Study of the North End of the Okanagan River Basin.

15.1 Introduction

The purpose of this study was twofold, first to try to determine the ground-water 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 second, to determine the ground-water component of six selected sub-basins to more fully understand the hydro-logic budget of the Okanagan River Basin.

15.1.1 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 Canadian 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 B.C. Water Resources Service 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 Also used were data obtained from other Government agencies and local unpublished areal groundwater investigations.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 1/12,000 and 1/50,000 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. Seismic investigations were conducted as important preliminary work on which to base the far more expensive groundwater-test drilling programs. A well development and test pumping program was conducted for the purpose of estimating well yields in the test holes completed.

15.1.2 Previous Investigations

Local areal investigations were previously carried out by the staff of the Groundwater Division. 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).

15.2 Geography

15.2.1 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 3,170 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 (bottom 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-basin studied 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).

15.2.2 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 Kalamalka 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.

15.3.3 Climate

The climate of the area, according to Koppen'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.

15.3 Geology

15.3.1 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 (Figure 15.1- Pocket of Report).

15.3.2 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 above mentioned Tertiary lavas (Figure 15.1).

15.3.3 Surficial Deposits

The references used in this report for describing the surficial geology (Figure 15.1) of the Okanagan region are maps by Fulton, J. (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 of 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 (Figure 15.1) and east-west (Figure 15.1) 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. Fades 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 gravel 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 Main 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 (Figure 15.1). It may also be observed that there is down-valley thickening of both the upper and lower parts of the valley-fill deposits.

15.4 Seismic Exploration (Task 39)

15.4.1 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.

15.4.2 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 (Figure 15.2 5.2), and to be rising at the south end of the lake. The table (see Table 15.4) compares predicted and actual depths to bedrock, and Figures 15.3 and 15.4 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, Figure 15.5) penetrated almost a11 sand, gravel and boulders.

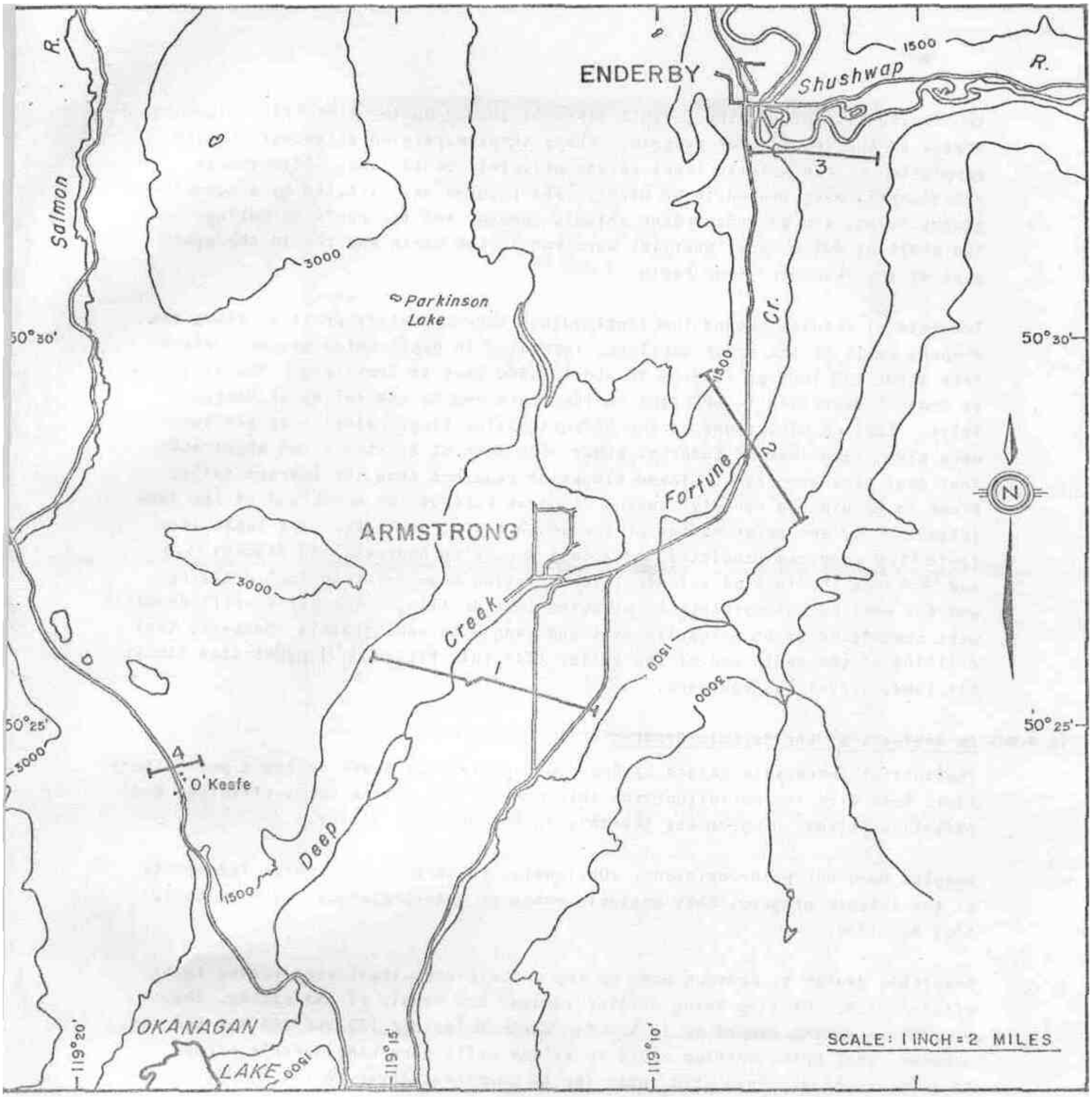
15.4.3 An Analysis of the Seismic Program

The initial impression gained by Groundwater Division Staff during a preliminary field trip with the consultant for this program 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%.

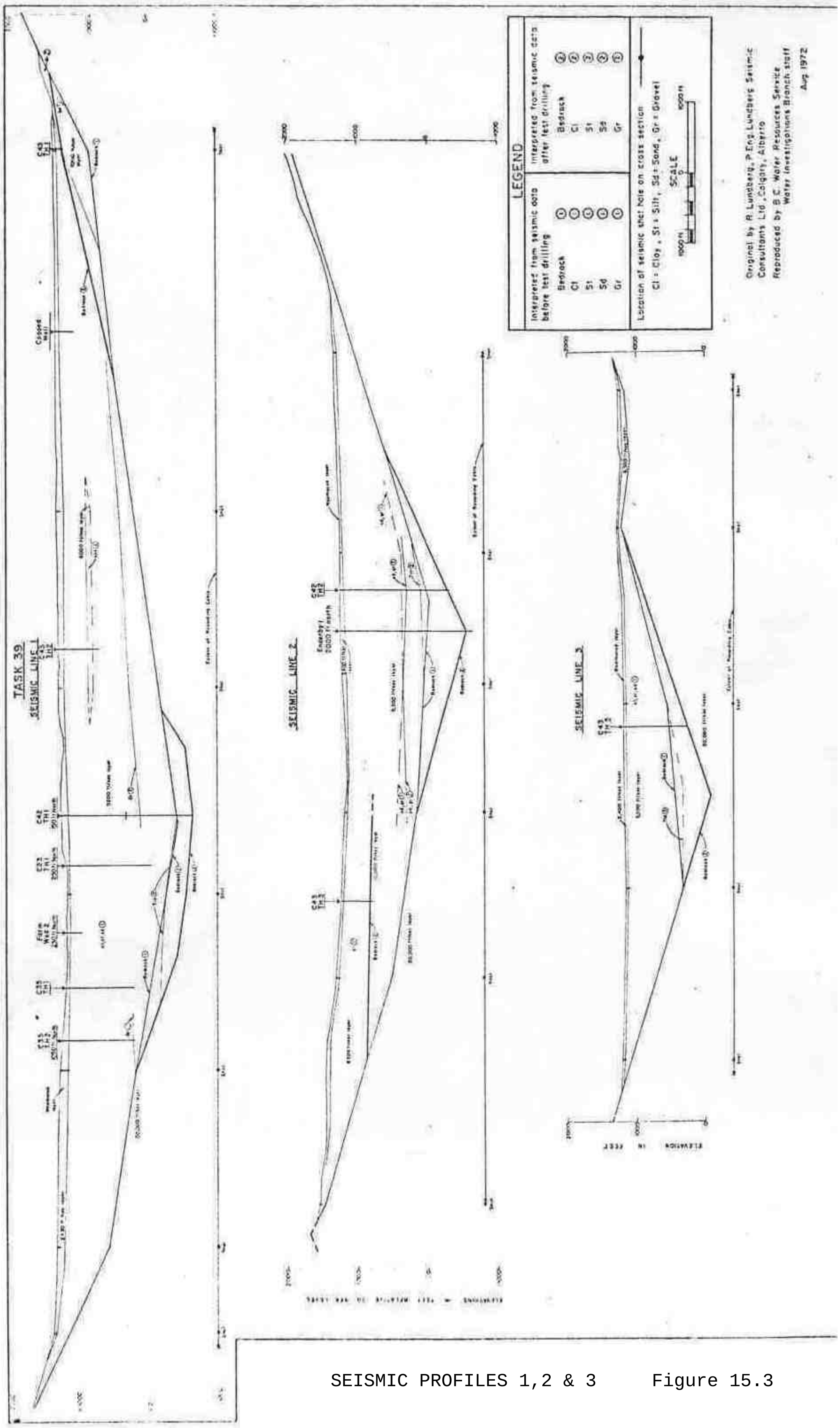
Significant observations to be made were that the valley was filled mainly with silt and sand. Bed thicknesses, except as in the special case of the thin silt layer for part of seismic line 1, are hard to determine due to lack of velocity contrasts between the silt and sand. Even during test drilling it is sometimes difficult to pick lithologic changes especially as sands or silts



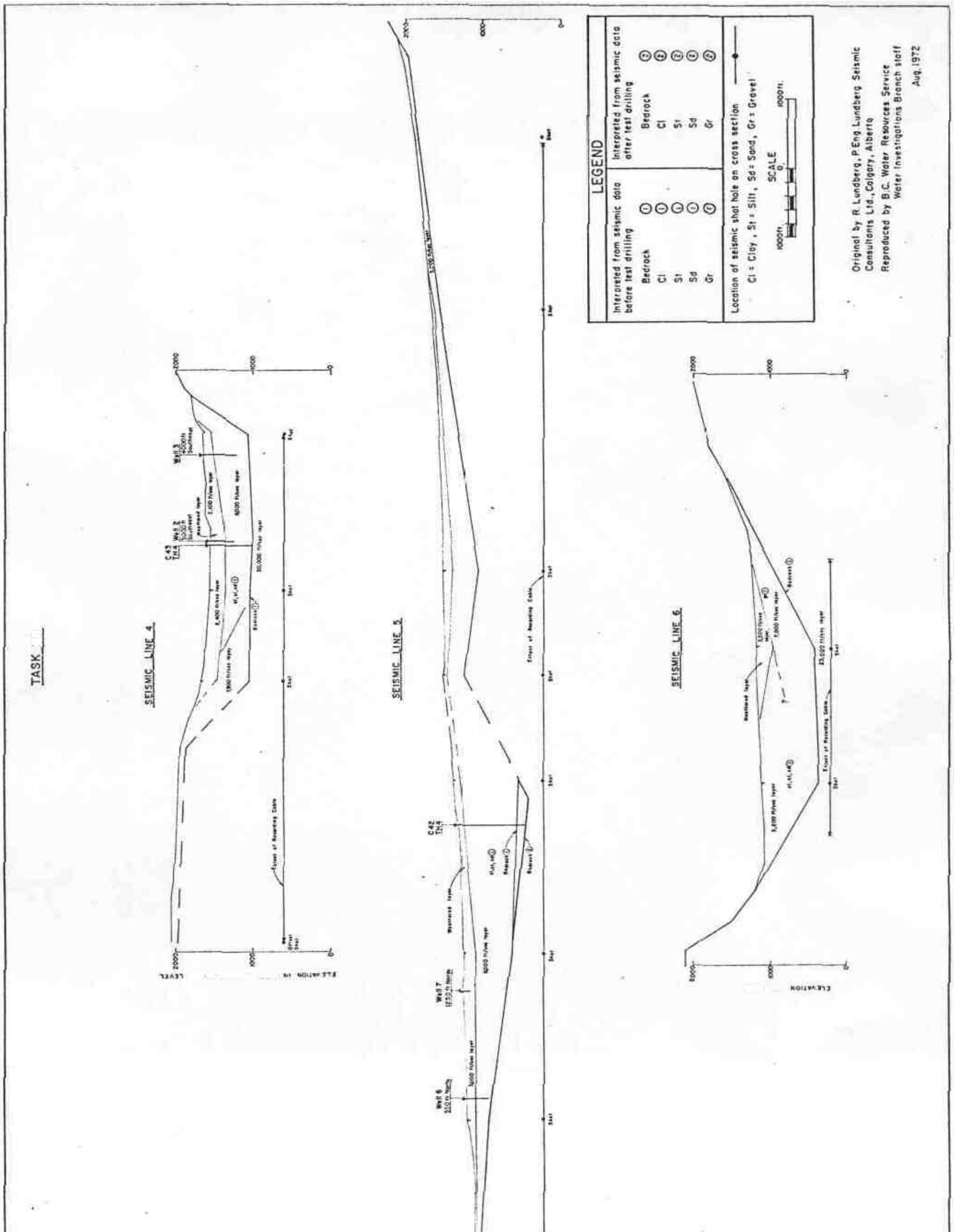
LEGEND

SEISMIC LINE 4

FIGURE 15-2
LOCATION OF SEISMIC LINES
NORTH ENDS
OKANAGAN RIVER BASIN

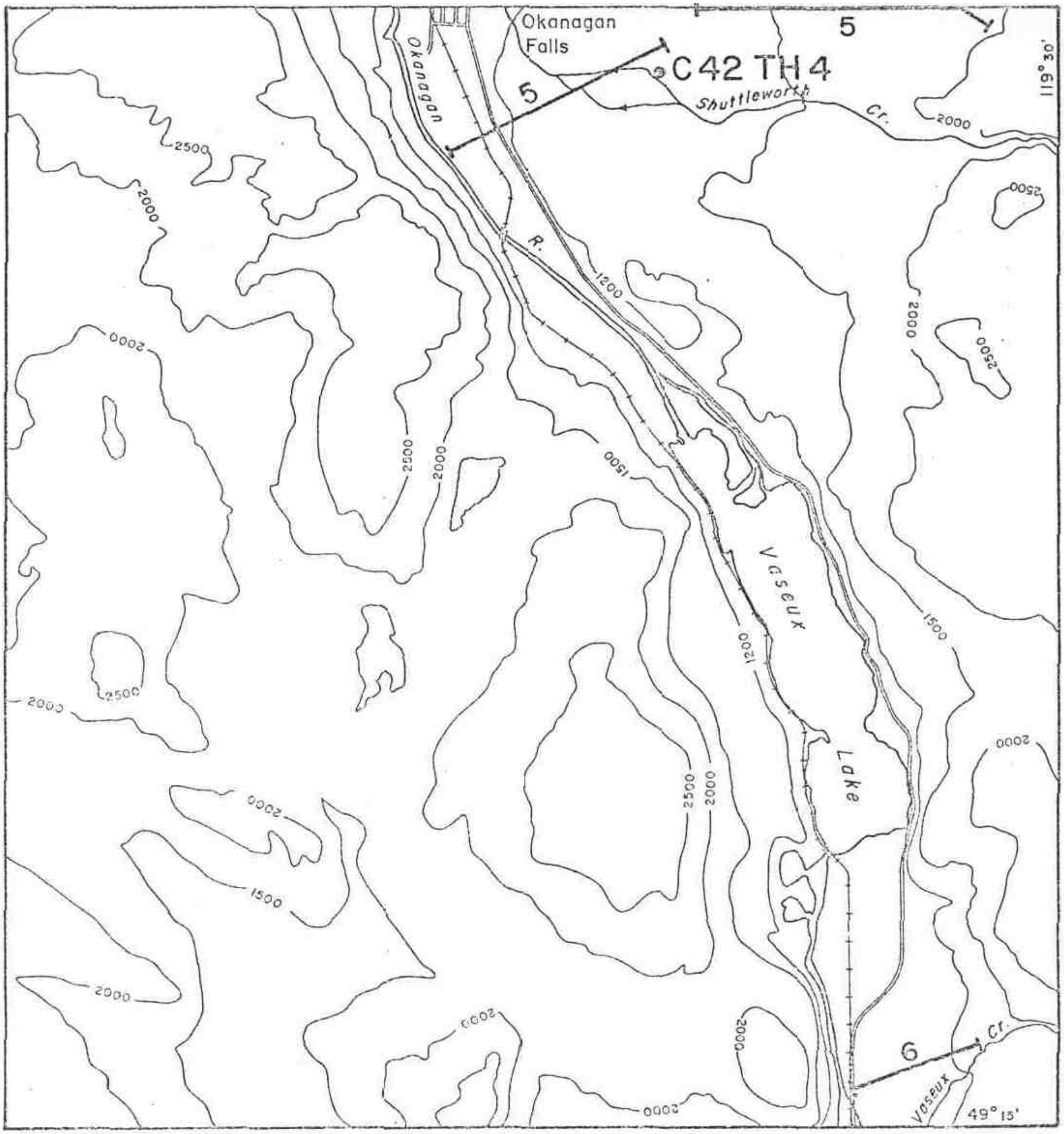


SEISMIC PROFILES 1,2 & 3 Figure 15.3



SEISMIC PROFILES 4,5 & 6

Figure 15.4



LEGEND

SEISMIC LINE	6	
WELL LOCATION		
CONTRACT NUMBER	C	
TEST HOLE NUMBER	TH	
SCALE 1:50,000		

FIGURE 15-5

LOCATION OF SEISMIC LINES, SOUTH END OF OKANAGAN RIVER BASIN are often thinly interbedded and much of the sand is of very fine grain size. The Consultant 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 the Consultants revised final report is given in Appendix F. 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. The Consultants 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."

Rotary Test Hole Drilling Programs (Task 40)

15.5.1 Objective

Beginning in late September 1970 and continuing on into early November, two rotary test hole programs were conducted. 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.

15.5.2 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 "ConCor' 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 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 boreholes logs were run in eight of the nine holes. Composite drilling logs are outlined in Table 15.1 with this report, one set being derived mainly from Mr. E. Livingston's work on the deep test holes. 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.

15.6 Hydrogeology

15.6.1 General Statement

Prior to a more detailed discussion of the north end of the valley, reference will be made to Figure l5.6 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 Vaseux 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).

15.6.2 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 15.l 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.

15.6.3 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 (Figure 15.1). 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.

TABLE 15.1

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 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 - 1040	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 - 1480	sand and silt, gray and white
1480 - 1540	till
1540 - 1570	bedrock

C42 TH4	
Elevation (map): 1,300 feet Location: 10,500 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

TABLE 15.1 (CONT'D)

COMPOSITE TEST HOLE LOGS - CONTRACTS 42 & 43

C43 TH1

Elevation (map): 1,325 feet

Location: 6,000 feet south of Lat 50^{0} 26' 15" N and 14,000 feet west of Long 119^{0} 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): 1570 feet

Location: 11,200 feet south of Lat 50^{0} 26' 15"N and 7,800 feet east of Long 119^{0} 07' 30" 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): 1,270 feet

Location: 6,300 feet south of Lat 50^{0} 30' 00" N and 3,800 feet west of Long 119^{0} 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; somegravel, oxidized 370-400 ft, pale yellowish brown
415 - 450	bedrock

C43 TH4

Elevation (map): 1570 feet

Location: 11,200 feet south of Lat 50^{0} 26'15"N and 13,300 feet east of Long 119^{0} 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 feet, 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^{0} 33'45" N and 1,500 feet east of Long 119^{0} 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 sand
860 - 875	sand, gravel, silty, light olive gray
875 - 912	bedrock

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 (Figure 15.1). 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 4 1/2 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 1/2 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.

15.6.4 Groundwater Movement, Recharge and Discharge Areas

Figure 15.6, intergrates 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 waterlevel contours and from

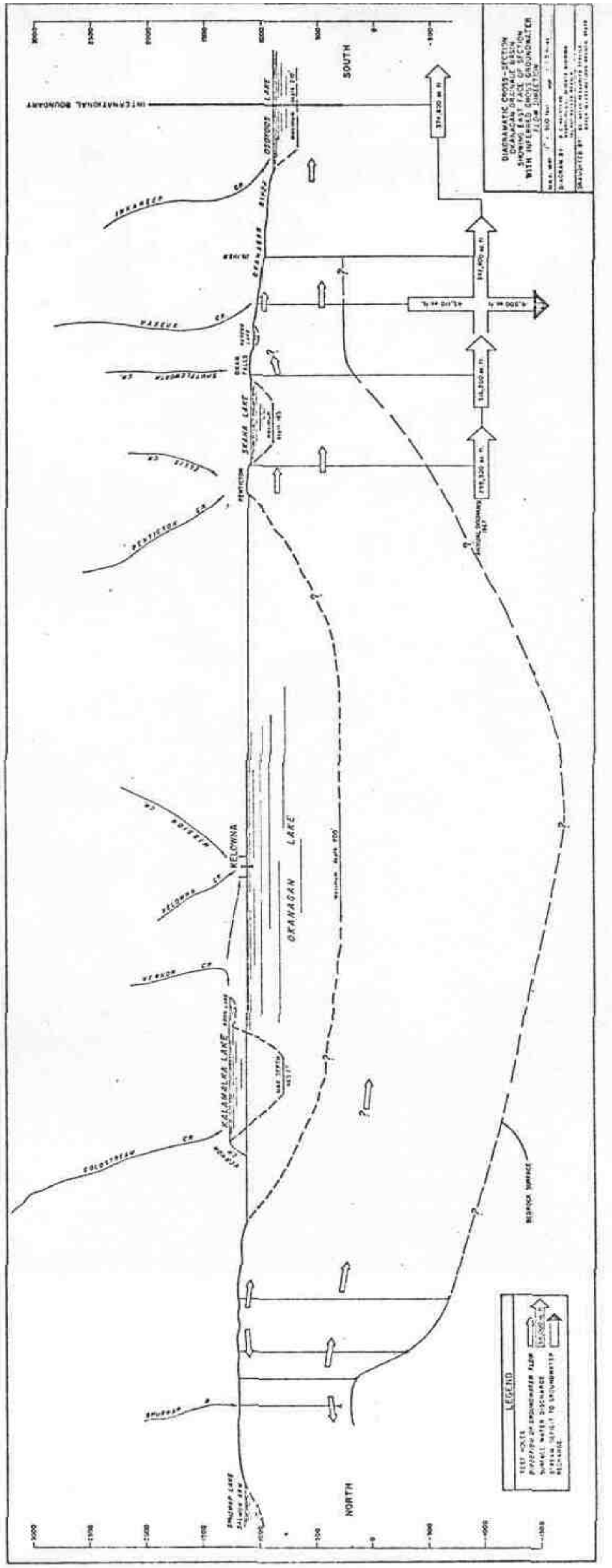

DIAGRAMMATIC CROSS-SECTION
OKANAGAN DRAINAGE BASIN
SHOWING EAST FACE OF SECTION
WITH INFERRED GROSS GROUNDWATER
FLOW DIRECTION
INTERNATIONAL BOUNDARY
SOUTH
NORTH
KELOWNA
OKANAGAN LAKE
KALAMALKA LAKE
SKAHA LAKE
LEGEND

FIGURE 15-6

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 formentioned 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 1 1/2 and 3 miles south of Armstrong (Figure 15.1). 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 nonflowing wells. In well C42 TH3 at an elevation of about 1,215 feet above sea level, the water level has risen as close as 1 1/2 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 11 1/2 °C, C42 TH2, compared to the other 3 wells with warm waters of about 17 to 20°C (Table 15.2). 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

TABLE 15.2

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 (pipesize: same ID as casing)							
	(a) diameter (inches)	6.5	4	4	4	4	4	4
	(b) slot size (No.)	40	40	40	15	40	40	615
	(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_{10} 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 pentration

*** equivalent to hydraulic conductivity, the field coefficient of permeability 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 (Figure 15.1).

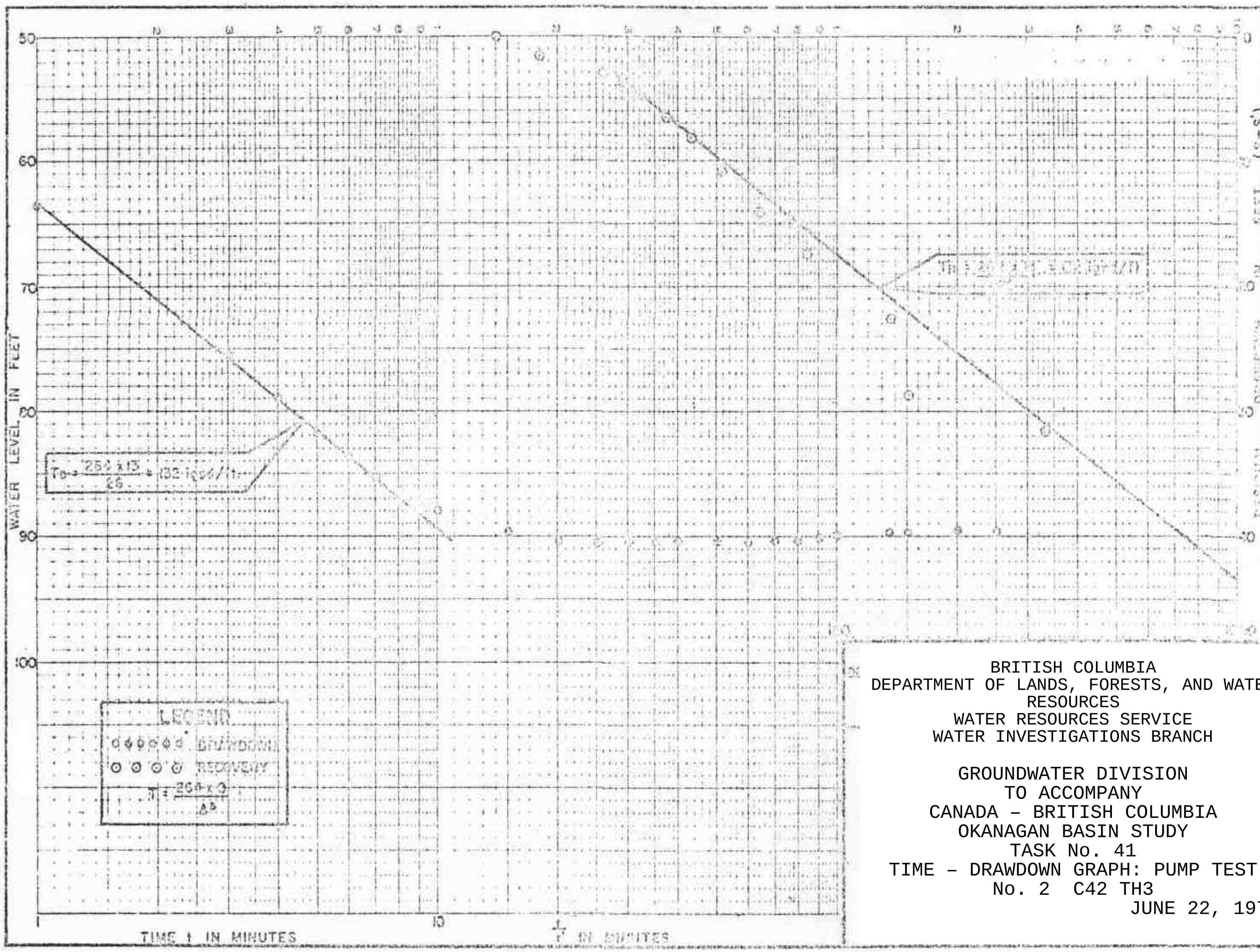
The nonpumping water level of 101 feet in well C43 TH2 was about 40 feet deeper than expected. The original purpose of the test hole was to determine the nature of an anomolous lens detected by seismic work along the Maid Creek cross section (Figure 15.1). The cause of the low water level may be a result 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 Toth (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.

15.6.5 Transmissivity Values

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

Transmissivity values (Table 15.2) for aquifers in the tower 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 (Figures 15.7 and 15.8) 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 15.2 are different from those on the graphs because corrections have been made for partial penetration in wells is comparable (Table 15.2) 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 15.9 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. 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 considerably lower well yield.



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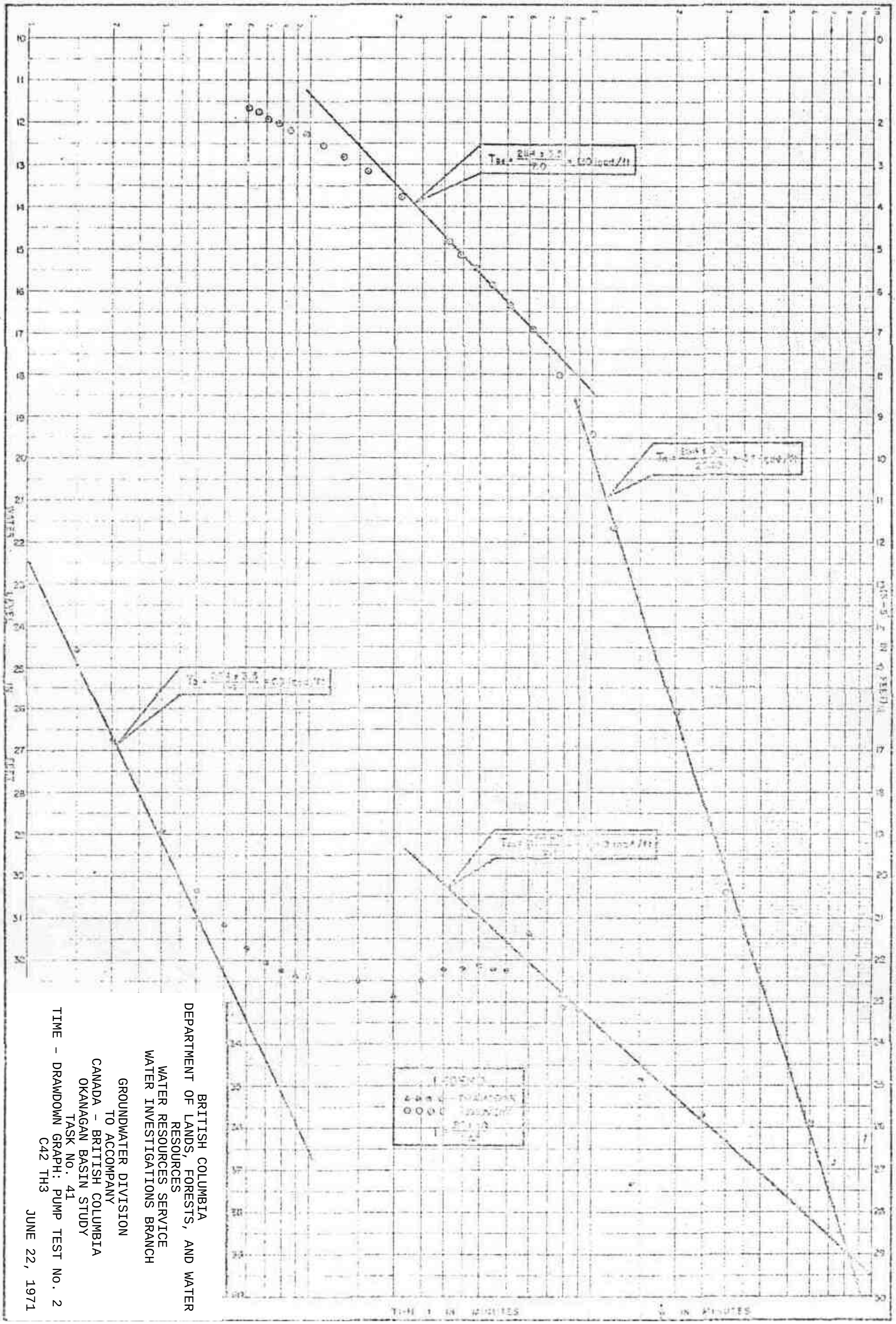
GROUNDWATER DIVISION
TO ACCOMPANY
CANADA – BRITISH COLUMBIA
OKANAGAN BASIN STUDY
TASK No. 41
TIME – DRAWDOWN GRAPH: PUMP TEST
No. 2 C42 TH3
JUNE 22, 1971

Figure 15-7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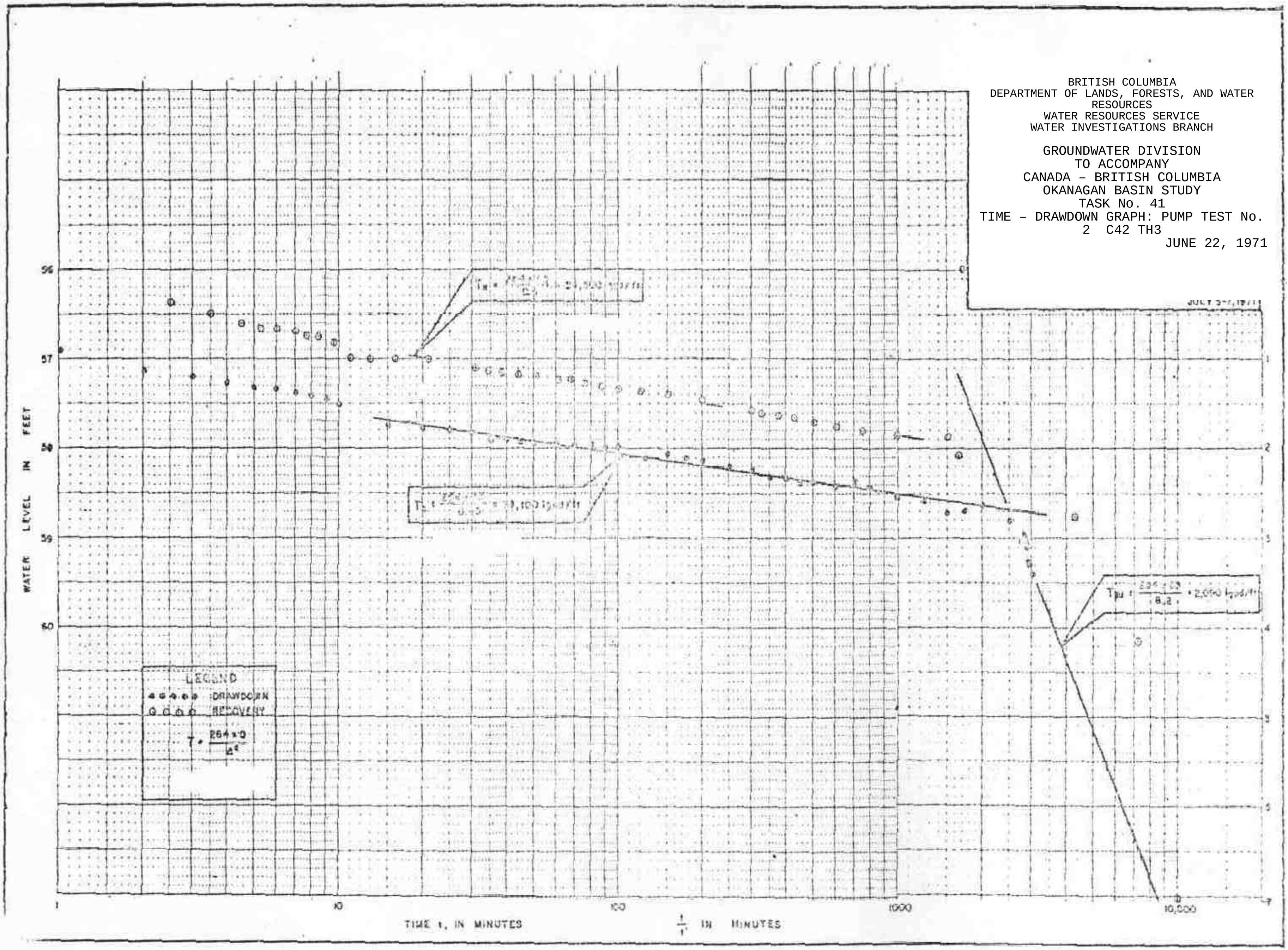
OKANAGAN BASIN STUDY
TASK NO. 41
TIME - DRAWDOWN GRAPH: PUMP TEST No. 2
C42 TH3
JUNE 22, 1971

FIGURE 15-8



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CANADA - BRITISH COLUMBIA
OKANAGAN BASIN STUDY
TASK No. 41
TIME - DRAWDOWN GRAPH: PUMP TEST No. 2 C42 TH3
JUNE 22, 1971

FIGURE 15-9

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 (Figure 15.10) 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.

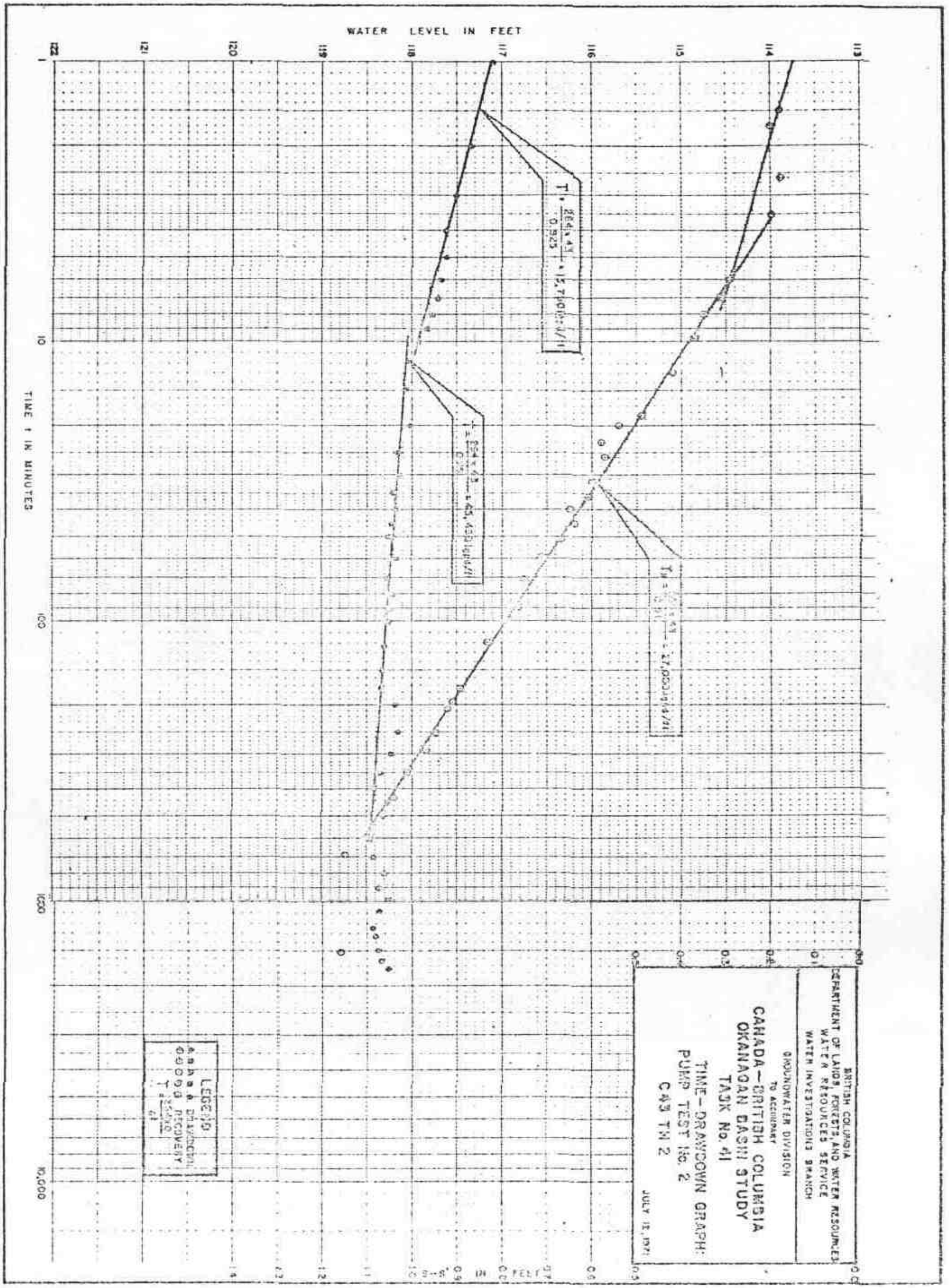
15.6.6 Water-Well Yields (Task 41)

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 15.2) 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 four 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 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 (Figure 15.1).

The significant differences in yield between the two wells is primarily due to design. The calculated yield from C43 TH2 is obtained from a test hole completed for observation-well use and to obtain preliminary groundwater information.


WATER LEVEL IN FEET
TIME t IN MINUTES
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WATER RESOURCES SERVICE
WATER INVESTIGATIONS BRANCH
GROUNDWATER DIVISION
TO ACCOMPANY
CANADA–BRITISH COLUMBIA
OKANAGAN BASIN STUDY
TASK No. 41
TIME-DRAWDOWN GRAPH:
PUMP TEST No. 2
C43 TW 2
JULY 12, 1971
LEGEND
DRAWDOWN
RECOVERY

FIGURE 15-10

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 (Figure 15.1) had a free flow of about 320 igpm from 220 feet. The specific capacity of this well is 9 igpm/ft of drawdown giving the 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 (Figure 15.1) little reference has been made to this valley so far. On the basis of specific capacity data (Table 15.2) it would appear that high well yields are obtainable from the O'Keefe Valley aquifer. As specific capacity declines with yield (Todd, 1959, p.III) 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, 4 1/2 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 4 1/2 miles north of Armstrong is supplied mainly by one spring flowing at an estimated rate of 150 igpm (Figure 15.1).

15.6.7 Groundwater Flow Calculations

The following calculations for groundwater flow are based on the data obtained from Task 41 and replace previous calculations (LeBreton, 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 (Figure 15.1). 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 G.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 (Figure 15.1) 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 (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 $K = 1.32 \times 101$ igpd/ft^2

$I = 1.40 \times 10^{-3}$ 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 portion 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 ground-water flow calculations. This figure for that portion of the aquifer over-lying the silt lens compares favourably with a figure of 140 igpd/ft from well C26 TH2 having an aquifer thickness of about 600 feet.

Using the formula:

$$Q = KIA$$

where $K = 1.3 \times 10^{1}$ 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 2 1/2 cfs (1,825 acft/yr) is likely to be a reasonable figure.

Total groundwater 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).

15.6.8 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 watertable 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 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 2 1/2 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 possiblity.

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 (LeBreton, 1971).

15.6.9 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 (Table 15.3). 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, 11 1/2°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 18 1/2° to 20°C. Similarly warm water 16 1/2°C and water quality data were obtained for the well completed in the middle unit Unit D, of the lower part of the surficial deposits. 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 10 1/2°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 (Figure 15.6), 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.

15.7 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 hydrogeological 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. Estimates have also been made for the determination of groundwater 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 seismic 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.

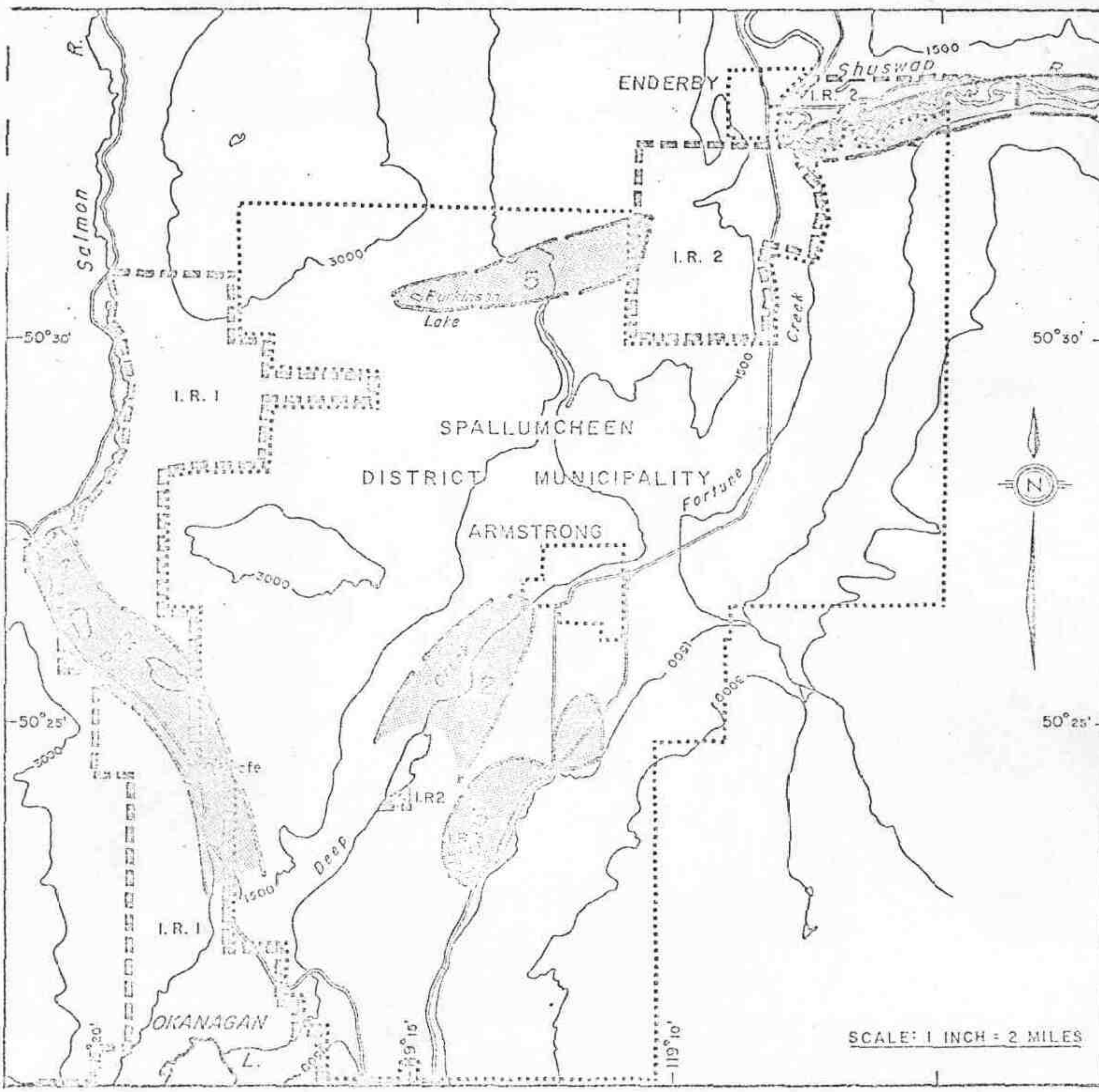
15.8 Potential Groundwater Development

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 is 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.

15.8.1 Lower Part of the Surficial Deposits

From the existing pump-test data, there appears to be little prospect for considerably 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 (Figure 15.11). 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 lake of information on the proximity of less permeable boundaries and their attendant effect on 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 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.



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

INDIAN RESERVE BDY.

DISTRICT MUNICIPAL BOUNDARY

AREAS INDICATED FOR GROUNDWATER EXPLORATION Figure 15.11

15.8.2 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 (Figure 15.11). Within this locality well yields of up to 850 igpm can definitely be obtained 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 Figure 15.1 near the east side of the valley are two flowing wells. The well designated as CW (apped 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 (Figure 15.11) 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 under flow 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 (Figure 15.1) 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 (Figure 15.1) are presumed to be of importance as only supplying small water supply requirements for domestic or livestock purposes.

15.8.3 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 not 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 than 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 (Figure 15.11).

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.

15.8.4 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 (Figure 15.11). 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 of slightly higher. Spring discharge, from a point 4 1/2 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 suggest 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 4 1/2 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.

15.8.5 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 know. 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 Vaseux Creek. 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:

TABLE 15.3
BASIC CRITERIA TO DETERMINE AVAILABILITY OF GROUNDWATER

Aquifer	Length feet	Width feet	Thickness feet	Effective Assumed 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

he above figures four 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 ground-water 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.

15.9 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.

15.9.1 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 (1970 Dollar Value).

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 does 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 acre feet per day for 90 days	$ 3,238	$3,613	$3,978
Total 25 years costs	$80,000	$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 acre feet per day for 90 days	$ 5,297	$5,832	$6,342
Total 25 years costs	$132,500	$145,800	$158,500

The total annual costs per acre feet 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) <u>$25,000 well</u>

	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 acre feet per day for 90 days	$ 3,902	$4,277	$4,642
Total 25 years costs	$97,500	$106,900	$116,000

(B) <u>$50,000 well</u>

	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 acre feet per day for 90 days	$ 6,922	$7,672	$8,402
Total 25 years costs	$173,100	$193,800	$210,000

The total annual costs per acre feet 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%
(C) Lower Limit	$10.69	$11.70	$12.71
(D) 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.

15.9.2 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.

15.10 Conclusions

The surficial deposits in the north end of the Okanagan River Basin are primarily fine grained, low permeable materials, mainly silt and finegrained sands. There are some coarser graned, high permeable deposits of sand and gravel. The fine-grained materials are expected to have permeability values of less than 10 igpd/ft 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 ground-water 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.
9. Long range studies to further evaluate groundwater resources, movement and recharge are a natural follow-up to the present preliminary studies conducted prior to an as part of the joint Canada-British Columbia Okanagan Basin Study Agreement.