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GROUNDWATER RESOURCES OF THE CITY OF CALGARY AND VICINITY

by
P. Meyboom

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ABSTRACT

Groundwater in the Calgary area is obtained from the Paleocene Paskapoo formation, consisting of interbedded sandstone and shale, and from thick gravel deposits along the Bow River. Water wells in the Paskapoo formation seldom yield more than 3 gpm because of the low transmissibility (100 - 200 gpd/ft), whereas wells in the extremely permeable gravel deposits may yield up to 1 million gallons per day.

In bedrock wells there exists a definite relationship between depth of the well and static water level. This phenomenon has been called "decrease in head with increasing depth". Wells that are located in topographically high areas are deeper and have a relatively lower water level than those that are located in lower areas. The cause of this phenomenon may be related to the vertical permeability of the confining beds.

Groundwater in the Calgary area is of the bicarbonate-type and the quality is suitable for industrial purposes as well as for human consumption. The seasonal fluctuations in the chemical composition of the river waters clearly reflect base flow conditions during the fall and winter months.

A stream-flow analysis of the Elbow River has been used to calculate the groundwater balance between 1949 and 1959. There appeared to be near-equilibrium between natural discharge and natural recharge, and the results indicate that on the average 2.06 inches, or 16 per cent of the total annual rainfall, were used as recharge. Bank storage accounted for 73 per cent of this amount, and discharge from contact springs for 19 per cent, whereas only 8 per cent of the total recharge contributed to bedrock aquifers. The rate of natural recharge to bedrock aquifers amounted to 0.16 inches, or 1 per cent of the mean annual rainfall.

As the rate of recharge to bedrock aquifers is about 4 gpm per square mile per day, groundwater depletion may be expected in areas where more than 150 people per square mile depend on groundwater supplies. Some of the suburban areas are already overpopulated in this respect.

The Bow River valley and associated stream channels offer excellent opportunities for an integrated development of groundwater and surface water which is economically a very favorable situation in semiarid western areas.

INTRODUCTION

Purpose and Scope of Investigation

This groundwater study was initiated within the framework of a much larger program of the Research Council of Alberta which is directed toward a complete assessment of the groundwater resources of the Province of Alberta. The City of Calgary showed great interest in an investigation of this nature, for groundwater plays an important role in many of the economic and engineering problems that the city is dealing with.

In the course of the investigation, which was carried out during 1959 and 1960, special attention was paid to the present and potential ultilization of groundwater, the groundwater resources available for industrial and suburban use, the role of groundwater in landslides and the fluctuations of the water table in so far as they affect roads and buildings. Automatic water level recorders were installed at various points in the city in order to obtain a better understanding of groundwater fluctuations in the area. A detailed geohydrological analysis of the regime of the Elbow River was made in order to determine the local groundwater balance.

Location of the Area and Physiography

Calgary (51° north latitude and 114° west longitude) is situated at the confluence of the Bow and Elbow Rivers, 45 miles east of the Rocky Mountains at the physiographic boundary between the Foothills and the Plains (Fig. 1). The area discussed in this report comprises about 216 square miles in

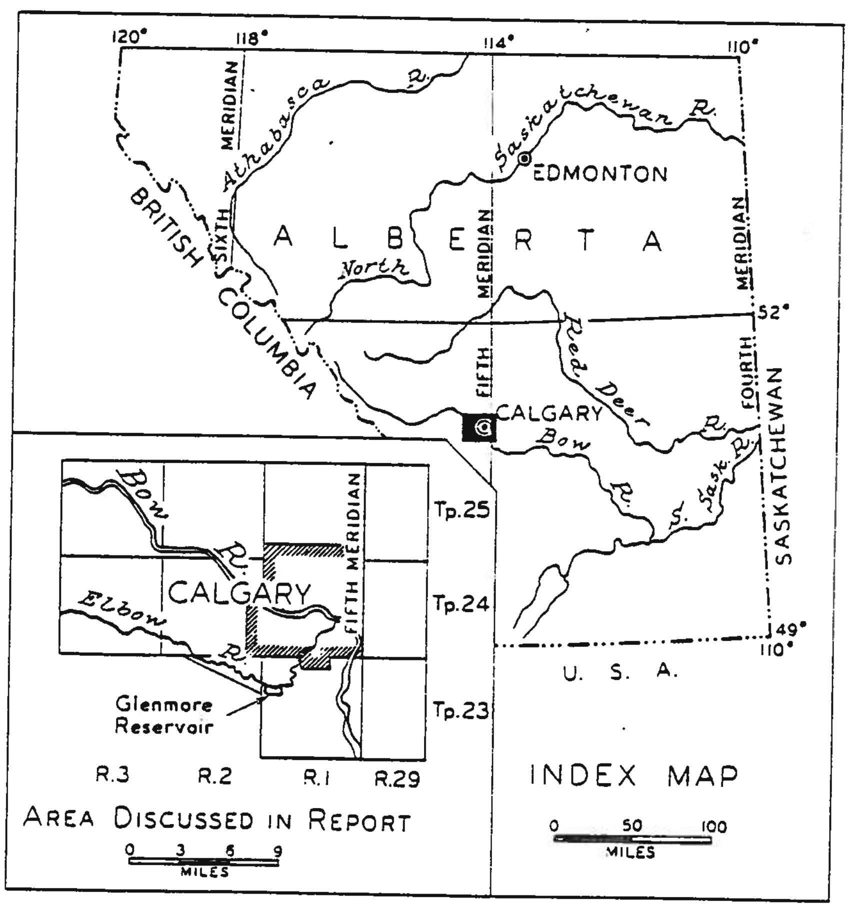


FIGURE 1.

and around the City of Calgary, consisting of townships 23, 24 and 25, ranges 1 and 2, west of the Fifth Meridian and parts of range 29, west of the Fourth Meridian (Fig. 1).

Topographic coverage of the area is provided by the following topographic maps, scale 1:50,000: Calgary 82 O/1, Priddis 82 J/16 East Half, issued in 1951 by the Department of National Defense, and the sheets: Dalemead 82 I/13 West Half and Dalroy 82 P/4 West Half, issued in 1951 by the Department of Mines and Technical Surveys. An excellent map of the metropolitan area of the City of Calgary, scale 1 inch to 2,000 feet, has been issued by the City Planning Department, but it should be noted that the datum level of the city map is 25 feet below that of the standard topographic maps. Aerial photographs of the entire district are available from the Alberta Department of Lands and Forests, and an unpublished geological map of the surficial deposits of the area prepared by J. C. Tharin (1960) was also available to the author during the preparation of this report.

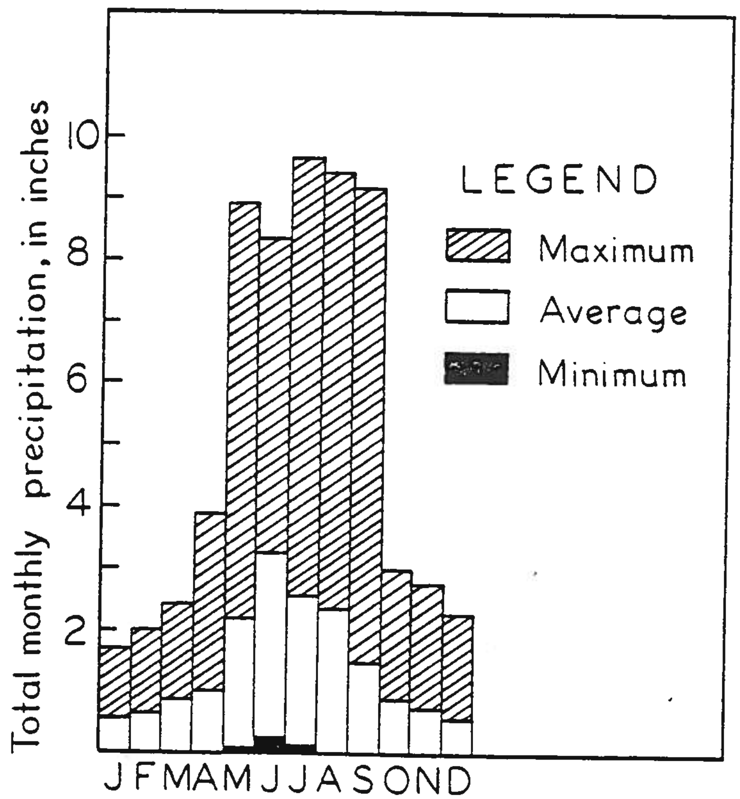
The Calgary area consists of rolling country, becoming hilly toward the west and gently undulating toward the east. The general elevation of the area slopes gradually from 4,000 feet in the Foothills to 3,300 feet toward the Plains. The average elevation of the City of Calgary is 3,500 feet above mean sea level.

The largest stream in the area is the Bow River which rises in the Rocky Mountains north of Banff, (Fig. 1), and which drains 3,136 square miles above Calgary. The Bow enters the area northwest of Calgary in Tp. 25, R. 2, W. 5th Mer. at an elevation of approximately 3,600 feet, and leaves the area in the southeast corner at an elevation of about 3,250 feet. The steep-walled valley is about 200 feet deep and is in places entrenched in bedrock. The average flow of the river in Calgary is 3,247 second-feet.

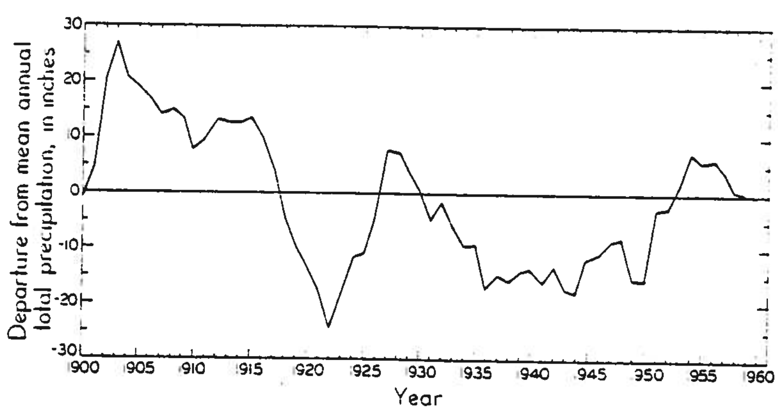
The Elbow River drains 640 square miles west of Calgary, which makes it the second largest stream in the area. It rises in the Rocky Mountains, west of Calgary, and enters the area in Tp. 24, R. 2, W. 5th Mer., where it flows virtually parallel with the Bow River at an elevation of nearly 3,600 feet. Approximately 5 miles southwest of Calgary the river turns abruptly north (hence its name) and joins the Bow River at an elevation of 3,400 feet in the middle of the City of Calgary. Calgary derives most of its power from Glenmore Reservoir, which is impounded by a dam across the Elbow River. The average discharge of this river above Glenmore Dam is 336 second-feet.

Entering the Bow River in Tp. 22, R. 1, W. 5th Mer. is Fish Creek, which flows nearly west-east, draining a total of 103 square miles of the Foothills area, with an average discharge of 20 second-feet at Midnapore.

Only one small creek, Nose Creek, flows into the Bow River from the north (Fig. 4). Nose Creek rises near Crossfield (Tp. 28, R. 1, W. 5th Mer.)



A: Histogram showing the maximum, minimum, and average monthly precipitation observed in Calgary between 1900 and 1959



B: Graph showing the cumulative departure from the mean annual precipitation in the Calgary area between 1900 and 1959

FIGURE 2. Precipitation records of Calgary

and joins the Bow River in East Calgary. The summer discharge of this creek in Calgary is about 5 second-feet. Its fairly wide and shallow channel, which reflects its origin as a glacial melt-water stream, offers a striking contrast to the much deeper valleys of the Bow and Elbow Rivers. The Bow River and its tributaries are part of the Saskatchewan River drainage basin, which discharges into Hudson Bay.

Climate and Vegetation

The climate of the Calgary area is classified as "cold temperate" but owing to the warm Chinook winds, most winters are rather mild (Dept. of Transport, Meteorological Division, 1959). Calgary has a mean temperature of 38.6°F., with January being the coldest month (average 14.8°F.) and July the warmest (average 61.9°F.). The mean total annual precipitation in Calgary amounts to 16.87 inches, 5.03 inches of which fall in the form of snow. The maximum monthly rainfall is in June (3.20 inches) whereas January, with a mean of 0.53 inches, has the lowest monthly precipitation. Values of average, minimum, and maximum precipitation as well as cumulative departures from the mean are shown in figure 2.

The potential evapotranspiration in the Calgary area is 21.3 inches, but because there is a normal water deficiency of 3.7 inches, the actual evapotranspiration is nearly 4 inches less than the potential evapotranspiration (Laycock, 1957). There is insufficient winter precipitation to fill surface-storage capacities and consequently there is no residual of precipitation available for runoff during the winter.

The area is characterized by a gradual change from the typical prairie vegetation in the south, north and east, to parkland vegetation in the west and southwest, as has been aptly described by Wyatt and Newton (1942).

History and Previous Investigations

> Of all towns I have seen on my westward progress Calgary has an honored place in my recollection. It is the most attractive little city, for many reasons, that I have seen in Canada. There is an indescribable Western freshness and freedom about its people, and its situation is exquisite, lying in a spacious valley as it does, with the beautiful fast-running Bow River winding on one side of it. And there are cowboys, too, and ranchers, the former riding their wiry little ponies with the inevitable cowboy sixty-dollar saddle—lariat rope at their side—the latter (many of them) Englishmen and of good family, who have the delightful but indescribable air of well-bred men. And there are gentlewomen who look nice and talk with an English accent. There is an absence of boastfulness and utter and complete dearth of blow. The men talk horse, honestly day in and day out. The air of the place makes young again the elderly, and the child is as merry as the kidling of the hills.

So in 1901 the Toronto newspaperman Bernard McEvoy described Calgary in one of his descriptive letters to the readers of the Toronto "Mail and Empire".

In 1875 the North West Mounted Police (N.W.M.P.) established a post near the present site of Calgary. According to Armstrong (1930) the name Calgary was suggested by Colonel J. F. MacLeod of the N.W.M.P., after the ancestral estate of his cousins on the island of Mull (Scotland), which he had visited shortly before coming to Canada. The word "Calgary" is Gaelic and although its origin is uncertain, it is generally believed to mean "clear running water", in which sense it is applied now in tourist folders. However, in view of the special connotation this name had for Colonel MacLeod, it is unlikely that he had the original meaning of the word in mind, when he gave this name to the new establishment.

In 1877 the tribes of the Blackfoot Confederacy signed a treaty with the Dominion Government as a result of which they settled down on reservations. Shortly after, some of the larger ranches had their beginning and by 1900 practically all the land was divided into ranching leases (Wyatt and Newton, 1942).

The discovery of the Sheep Creek gas field in 1913 (which 25 years later became the Turner Valley oil field) gave considerable impetus to the growth of the Calgary area and the city has consequently become the headquarters of the oil industry of Western Canada. The original agricultural character of the city slowly changed to its present appearance, which is one of a growing metropolis dominated by large and modern buildings and of extensive suburban areas. Presently, Calgary is the centre for many national and international business concerns and it has been stated that Calgary will maintain a strong attraction to national labor and investment. The present population is approximately 240,000 which is expected to have increased to 645,000 by 1981 (Smith, 1959). However, despite the enormous growth, resulting from the rapidly expanding oil industry, Calgary still has the same pleasant atmosphere that struck McEvoy.

Dr. James Hector visited the area in 1858 as a member of the Palliser expedition. Although Palliser's party camped at the site of Fort Bow, Hector's main interest was directed toward the Rocky Mountains which he studied carefully during the field season of 1858.

Dawson and McConnell (1895) collected information concerning glacial deposits in the Bow Valley and all the further studies in the area were mainly related to Pleistocene geology (Coleman, 1910; Allan, 1943; Tharin, 1960). Tharin's report gives a clear analysis of the glacial history of the area and his suggestions for the Pleistocene stratigraphy have been tentatively adopted in this report. The area east of the 5th Meridian and adjoining the Calgary district has been mapped by Stalker (1957).

Acknowledgments

The author expresses his sincere thanks to Mr. F. Zukas and Mr. S. A. Humeny, both of the Engineering Department of the City of Calgary, who provided many well logs and general information; and to Mr. J. Pascoe and Mr. R. A. Welin, also of the Engineering Department, who co-operated in installing and maintaining the water level recorders.

The author is indeed grateful for the information supplied by Mr. M. Curcio (Michele Drilling and Exploration Co., Edmonton) and also for the pleasant co-operation with the many industries in Calgary; especially the support given by Mr. Jones, waterworks engineer of the Calgary brewery and Mr. Brodi, engineer of the Standard Brands yeast plant, proved to be of great help.

Information supplied by Anderberg and Sons Drilling Ltd., James and Sons Well Drilling, and Interprovincial Drilling Contractors, all of Calgary, and by International Water Supply Ltd. (London, Ontario), has been used successfully to compile the piezometric map of the Paskapoo formation and the water table map of the Bow Valley.

Mr. Noble, Provincial Analyst, kindly supplied many chemical analyses in addition to the samples taken and analyzed in the course of the present study.

The writer remembers with pleasure and gratitude the hospitality shown by Jan and Betty Jansonius.

GEOLOGY

Geologic Formations and their Water-bearing Properties

The entire Calgary area is underlain by sandstones and shales of early Tertiary age which—except for a few scattered outcrops along the river valleys—are covered by Pleistocene and Recent deposits. The stratigraphic positions of the various formations that can be distinguished in this area are presented in table 1, while their present distribution is shown in figure 3. The nature and origin of these sediments will be discussed below.

Tertiary Sediments

The grey and greenish sandstones and the dark shales that constitute the bedrock of the Calgary area all belong to the Paskapoo formation. This Paleocene formation is believed to have been deposited on an extensive floodplain east of the present Foothills and extending far to the east as a thinning cover of continental beds. Allan and Sanderson (1945) report a

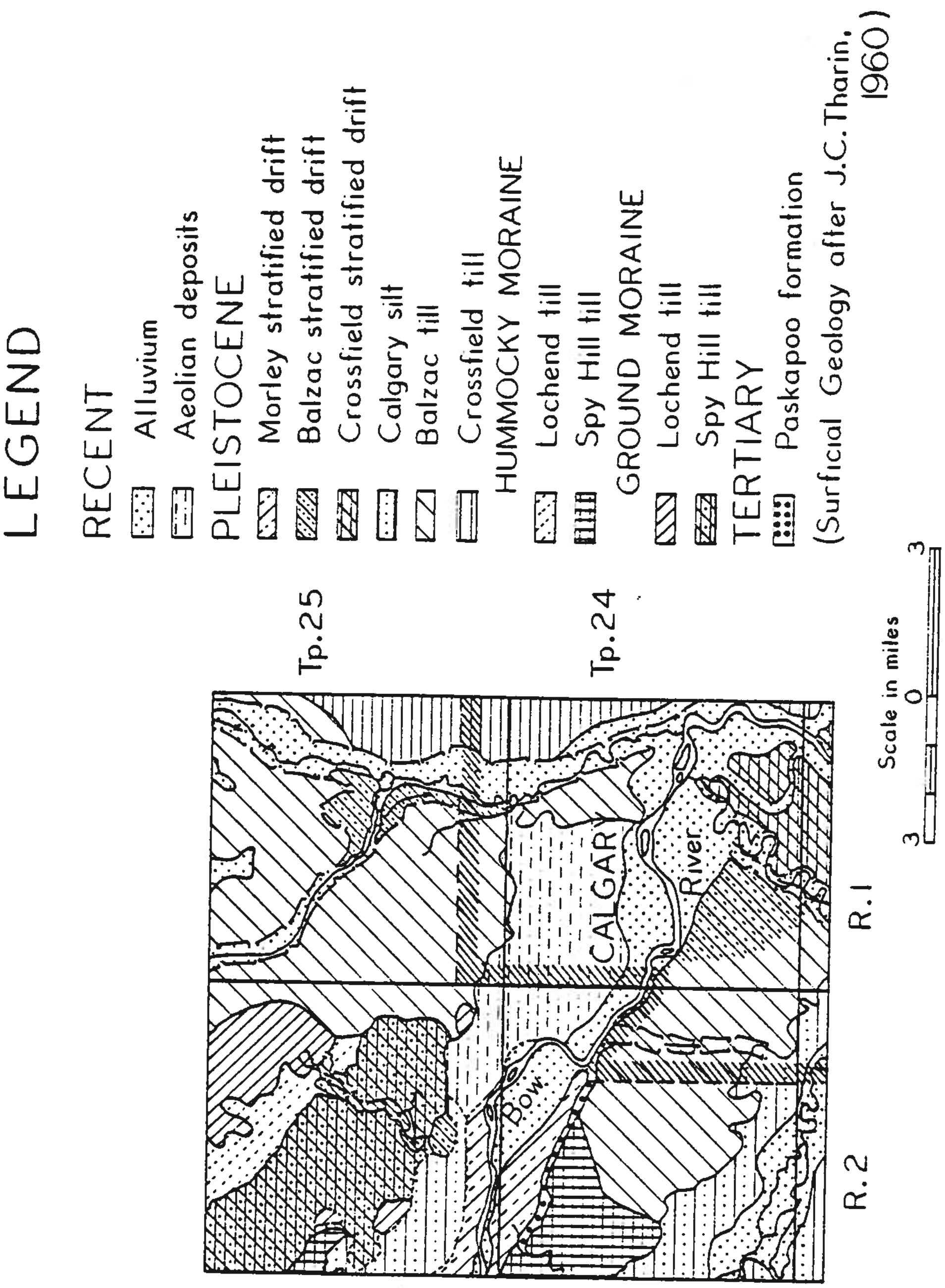


FIGURE 3. Map of the surficial deposits of the Calgary district

thickness of 800 feet in the Red Deer area, whereas the thickness in the Calgary area certainly exceeds 2,390 feet (Hume, 1937). The Paskapoo strata in the Calgary area lie almost horizontally or dip slightly westward toward the Alberta syncline.

Table 1. Stratigraphic column of Calgary area (after Tharin, 1960)

Area / Period	Mountains		Intermediate	Plains
	Stratigraphic units			
Recent	river gravels and sand dunes			
PLEISTOCENE	Morley gravels		Balzac stratified drift	Crossfield stratified drift
	Morley till	Calgary silt	Balzac till	Crossfield till
	Spy Hill till		Lochend stratified drift	
			Lochend till	
	Orange drift			
	Orange till			
	unconformity			
	Saskatchewan sands and gravels			
	unconformity			
PALEOCENE	Paskapoo			

The sandstone beds of the Paskapoo formation are of variable thickness and quite lenticular, which accounts for the fact that the beds cannot be followed laterally over large distances. The sandstone is generally fine-grained, with a maximum grain size of 1 mm., and 85 per cent of the weight of a typical sample is larger than 0.1 mm.; 10 percent being between 0.1 and 0.01 mm., and 5 per cent is smaller than 0.01 mm. (Parks, 1916). The sandstones are composed of 30 per cent quartz, 30 per cent weathered feldspar, and 40 percent chert and calcareous matrix. Parks (1916) observed that the fresh blue sandstone contains 27.32 pounds of calcium carbonate cement per cubic foot of unaltered stone. This cement is leached out upon weathering, producing a much softer and more porous rock, containing only 14.3 pounds of calcium carbonate per cubic foot. Besides the hard unaltered rock and its softer derivate, Parks noticed the presence of very hard bluish Paskapoo sandstone in various quarries. He ascribed this very hard variety to secondary concentration of calcium carbonate.

In the early years of Calgary's development, the Paskapoo sandstone was extensively used for building stone. McEvoy wrote: "Calgary is well built, there is capital building stone within a few stone's throw and this material is employed in many of the edifices with great advantage". The practice of quarrying Paskapoo sandstone has been abandoned, however, because of the hardness of the unaltered rock, which restricted the availability of suitable material to the exposed surface only.

The shales interbedded with the sandstone layers are generally dense and dark. Softer clay layers, containing freshwater gastropods, have been described by Allan and Sanderson (1945) who interpreted such strata as sediments of temporary lakes or flood pools. Lignite fragments and plant flakes are common in the Paskapoo shales and even thin coal seams have been reported at various locations.

Thin bentonite layers or bentonitic shales, products of former volcanic activity in the Rocky Mountains, are also present in the Paskapoo formation, but they are less abundant than in most Cretaceous formations of Alberta.

The following sections of the Paskapoo formation were exposed in old quarries and have been described by Parks (1916):

16 Street and 17 Avenue SW.

Description	Thickness, feet
Drift	10
Shale and thin sandstone	8
Sandstone in two variable beds	6
Sandstone, in beds up to 4 feet thick	28
Massive sandstone	10

Elbow River Valley

Description	Thickness, feet
Drift	10
Sandstone, thin, rough	8
Sandstone, interbedded with much shale	20
Sandstone to river level	20

Brickburn

Description	Thickness, feet
Drift	6
Shale, with broken layers of sandstone	12-15
Sandstone, heavy bedded	25

During the present study a Paskapoo section was observed north of Brickburn along the C.P.R. tracks (SE. ¼ Sec. 24, Tp. 24, R. 2, W. 5th Mer.) where as a result of a landslide the following section was exposed:

Description	Thickness, feet
Drift, well-bedded sand and gravel	5
Sandstone, yellow, lenticular bedding	8
Shale, dark-grey, dense, interbedded with 6 sandstone layers, all less than 1 foot thick	80

The elevations of the top of this section and the top of the Brickburn section referred to by Parks are the same, which demonstrates the great lateral variability of the sandstone beds, making it impossible to correlate the two sections. This great lateral variation of the sandstone lenses renders it equally impossible to correlate water-well logs.

It is clear that the only potential aquifers in the Paskapoo formation are the sandstone layers, which in some cases are sufficiently permeable to yield water. The average porosity of the unaltered sandstone is 7 per cent (Parks, 1916, p. 193) and transmissibility values range from 100 to 225 gpd/ft* (pp. 47-61). Most wells in the Calgary area which are completed in one or more sandstone layers in the bedrock are generally sufficient to satisfy most domestic needs. A more comprehensive description of these wells will be given in conjunction with the discussion of the hydrologic behavior of the bedrock.

Pleistocene (?) Deposits

Saskatchewan Sands and Gravels The exact age of these deposits is unknown, but they are preglacial in the sense that they underlie glacial de-

* Transmissibility is defined as the rate of flow of water in Imperial gallons per day through a vertical strip of the aquifer 1 foot wide and extending the full saturated thickness of the aquifer, under a hydraulic gradient of 100 per cent.

posits and they are post-Paleocene in that they overlie bedrock (Rutherford, 1937). These gravel beds are of various thicknesses and they contain pebbles of quartzitic and arkosic sandstone, dark limestone, chert pebbles and pieces of local bedrock.

According to Tharin (1960), Saskatchewan sands and gravels in the Calgary area occur at two levels, the first being at above 4,000 feet, the second at altitudes below 3,600 feet. The gravels that are reported in water-well logs to be resting upon bedrock in Cairn Heights (Tp. 24, R. 2, W. 5th Mer.) represent the higher level, whereas the gravel deposits resting upon bedrock along the Bow River belong to the lower level. During the course of the current study a good outcrop of the low-level gravels was observed in a sewer excavation along the new road that connects Inglewood and Burnsland (SW. ¼ Sec. 11, Tp. 24, R. 1, W. 5th Mer.). The lower part of this section, which is discussed in more detail in a later paragraph, is:

Description	Thickness, feet
Gravel, interbedded with grey cross-bedded sand is composed of 51 per cent white quartzite, 44 per cent dark limestone and dolomite, 5 per cent chert. All the pebbles are well rounded. The chert is present mainly in the sand fraction.	5
Shale, yellow-brown, somewhat sandy, bedding obscure	2

The elevation of the bedrock surface on which these gravels are lying is approximately 3,400 feet.

The presence of the low-level Saskatchewan sands and gravels has also been reported in various water wells, particularly along Highway 1A, in Sec. 31, Tp. 24, R. 1, W. 5th Mer. and Secs. 1 and 2, Tp. 25, R. 2, W. 5th Mer. Wells at these locations are finished in gravels underlying till and overlying bedrock at an elevation of approximately 3,600 feet. At these locations the gravel is about 10 feet thick (90 - 100 feet below surface) and serves as an excellent aquifer as will be shown in a later section (p. 53). Moreover, in the west half of Sec. 28, Tp. 24, R. 1, W. 5th Mer., Saskatchewan sands and gravels ranging in thickness from 0 to 20 feet are reported at a depth of 25 feet below surface, resting upon Paskapoo shale at an approximate elevation of 3,500 feet.

Saskatchewan sands and gravels belonging to the higher level have no importance as aquifers in this area.

Glacial deposits

Glacial deposits overlie the Saskatchewan sands and gravels. Tharin (1960) described five tills with associated fluvio-glacial deposits and the presence of a sixth till has been tentatively accepted. Before explaining the nature and distribution of the various Pleistocene deposits, it is necessary to review briefly the glacial history of the Calgary area, as described by Tharin (1960, p. 112 - 123).

Glaciers twice invaded the Calgary area from the Plains and from the Mountains. During the first advance, ice covered the entire area whereas the second advance left part of the area ice-free. During the second advance the eastern ice-sheet dammed the Bow Valley to form a large lake, called Lake Calgary.

The ice-sheets of the early glaciation invaded the Calgary area from the Mountains through the Bow Valley and over the Foothills. Outwash from this Spy Hill glacier was transported toward the east where it probably became incorporated in the advancing Keewatin ice-sheet, called Lochend glacier. Meltwater from both glaciers flowed southeast through the Bottrel channel (Tp. 28, R. 4 to Tp. 26, R. 2, W. 5th Mer.). The retreating Spy Hill and Lochend glaciers left an area that was covered by ground moraine and hummocky disintegration moraine. The Bow River resumed its drainage to the Plains.

The second ice advance was less extensive. Cordilleran (western) ice, the Morley glacier, advanced from the mountains down the Bow Valley to Jumpingpound River (Tp. 26, R. 4, W. 5th Mer.), but did not cross the Foothills north of the Bow River. The Athabasca glacier, moving eastward from Jasper, had been deflected to the south by the re-advance of eastern ice, and thus formed a buffer along the western margin of the approaching Crossfield glacier. The tongue of the Athabasca glacier that reached Calgary has been called Balzac glacier. Encroachment of the Balzac ice pushed by the advancing Crossfield glacier dammed the Bow Valley to form Lake Calgary.

After the final retreat of the ice, the surface of the area was modified to some extent, ultimately resulting in the present distribution of glacial and fluvio-glacial sediments as shown in figure 3 and as will be discussed below.

"Orange Till" and "Orange Drift" These deposits are probably not related to any of the above-mentioned ice advances. Their origin is rather uncertain and their full areal distribution is unknown. The materials have no importance as aquifers.

Spy Hill Till The Spy Hill till is a sandy till, containing varying amounts of limestone, dolomite and quartzite pebbles. A log of a water well in the NE. ¼ Sec. 10, Tp. 25, R. 2, W. 5th Mer. shows a total thickness of 120 feet of Spy Hill till, overlying the previously mentioned "orange till". The till is named after the Spy Hill area, where it is present as a hummocky disintegration moraine, with the characteristic "knob-and-kettle" topography.

Spy Hill till is also present south of the river, in the northwest corner of Tp. 24, R. 2, W. 5th Mer. In this area the till is deposited as a ground moraine ranging in thickness from 30 to 70 feet. Groundwater occurrences in this moraine are equally as poor as in the Spy Hill till north of the Bow River.

Lochend Till This till is sandy to clayey and contains Precambrian (igneous) pebbles indicative of Keewatin till. Lochend till is present both as ground moraine and as hummocky disintegration moraine; the groundwater prospects do not differ from those of the Spy Hill till.

Lochend Stratified Drift Stratified drift which is associated with the Lochend glacier consists of cross-bedded light-brown sand and silt, containing abundant Keewatin pebbles. Tharin (1960) observed sections ranging in thickness from 8 to 80 feet, underlying Balzac till. Although none of the surficial deposits in the area are composed of Lochend stratified drift, this unit has been encountered in a few outcrops which will be discussed in a later paragraph. Lochend drift has no value as an aquifer.

Morley Till This till is absent in the area covered by this report.

Calgary Silt The Calgary silt, deposited in Lake Calgary, comprises much of the surface material in the east part of the city and it is reported in nearly all well logs within the city limits. It consists of alternating beds of silt and clay, commonly resembling varves. Tharin (1960) reported that the thickness of this sequence varies from 25 feet to 125 feet. Owing to its relatively low permeability this lacustrine succession is a poor aquifer and hence none of the wells in the area obtain water from the Calgary silt.

Balzac Till The Balzac till which is present as a ground moraine in the northern and southern parts of the area is light brown in color and the material is calcareous and very sandy. The pebbles are largely of Cordilleran origin, but because of some mixing of the Balzac glacier in relation to the Keewatin (eastern) ice, some igneous pebbles may be present. The Balzac till cannot be regarded as an aquifer of any importance.

Crossfield Till This brown till is calcareous and sandy to silty. Pebbles of eastern as well as western origin are abundant in this formation. The Crossfield till occupies the eastern margin of the Calgary area, where it is developed as a typical ground moraine, characterized by a fairly flat surface and limited drainage. It is difficult to obtain even domestic water supplies from this formation and it will be shown in a later paragraph (p. 35) that both the composition and the quality of the groundwater in the bedrock of this area are strongly affected by the materials of this particular formation.

A complete section from Crossfield till to Paskapoo formation has been observed in the previously mentioned roadcut between the districts of Inglewood and Burnsland (p. 12).

Description	Thickness, feet
Till, yellow, argillaceous, only a few pebbles of both eastern and western origin	2
Loess, grey	2
Gravel, laterally grading into fine, grey, cross-bedded sand. The gravel is composed of 55 per cent white quartzite, 9 per cent dark limestone and dolomite, 18 per cent arkose, 14 per cent granite, 2 per cent gneiss and 2 per cent chert. The granite pebbles are extremely weathered and nearly decomposed.	3
Till, yellow, argillaceous, pebbles scarce. A large quartzite erratic (approximate size 3 feet by 4 feet) is embedded in the till at approximately 25 feet from the top of the till. The lowest 5 feet of the till contain a much greater proportion of gravel than the remaining portion of the section.	50
Gravel, blue and white in color, consisting of 51 per cent white quartzite pebbles, 44 per cent dark limestone and dolomite and 5 per cent chert fragments. Most of the chert is of sand size.	5
Shale, yellow-brown, sandy, bedding obscure	2

Morley Gravels The Morley gravels are prominent as valley-train, deposited by meltwater from the last Bow Valley glaciation. The gravels contain well rounded dark limestone and dolomite pebbles, quartzite pebbles and minor amounts of shale. Tharin (1960) assigns the gravels along the Bow Valley and on the adjacent highlands to the Morley gravels. A conspicuous terrace, consisting of Morley gravels, approximately 250 feet above the present river valley, is developed on both sides of the Bow River in the vicinity of Bowness. Gravel pits have been opened on this terrace north of Bowness. Similar terraces have been observed along the Bow River upstream from Bowness (Rutherford, 1927). The reworked Morley gravels, which are now partially covered by Recent alluvium, are the most important aquifers along the Bow River.

Balzac Stratified Drift Balzac stratified drift which covers a minor portion of the Calgary area (Fig. 3) consists of calcareous silt with local carbonate and quartzite pebbles, although igneous pebbles do occur. In the west half of Sec. 13, Tp. 24, R. 2, W. 5th Mer., the Balzac stratified drift forms a thin veneer of 3 to 5 feet over the bedrock. A much thicker section of Balzac outwash is located at the confluence of Nose Creek and Beddington Creek (Sec. 14, Tp. 25, R. 1, W. 5th Mer.). A pebble count in one of the gravel pits in this delta revealed the following composition: 54 per cent quartzite, 22 per cent limestone, 20 per cent arkose, 3 per cent granite. The total thickness of these gravels at this location is 25 feet. Although outwash plains commonly have sufficient porosity and permeability to permit the storage and withdrawal of substantial amounts of groundwater, this particular deposit is of little value to the groundwater resources of the area, as the base of the gravel is above the water table.

A similar outwash plain of Balzac drift has been observed east of Glenmore Reservoir in Sec. 31, Tp. 24, R. 1, W. 5th Mer., where the gravels are overlain by Recent aeolian material, thus forming a small-scale artesian reservoir which has been drained during the development of the Lake View subdivision.

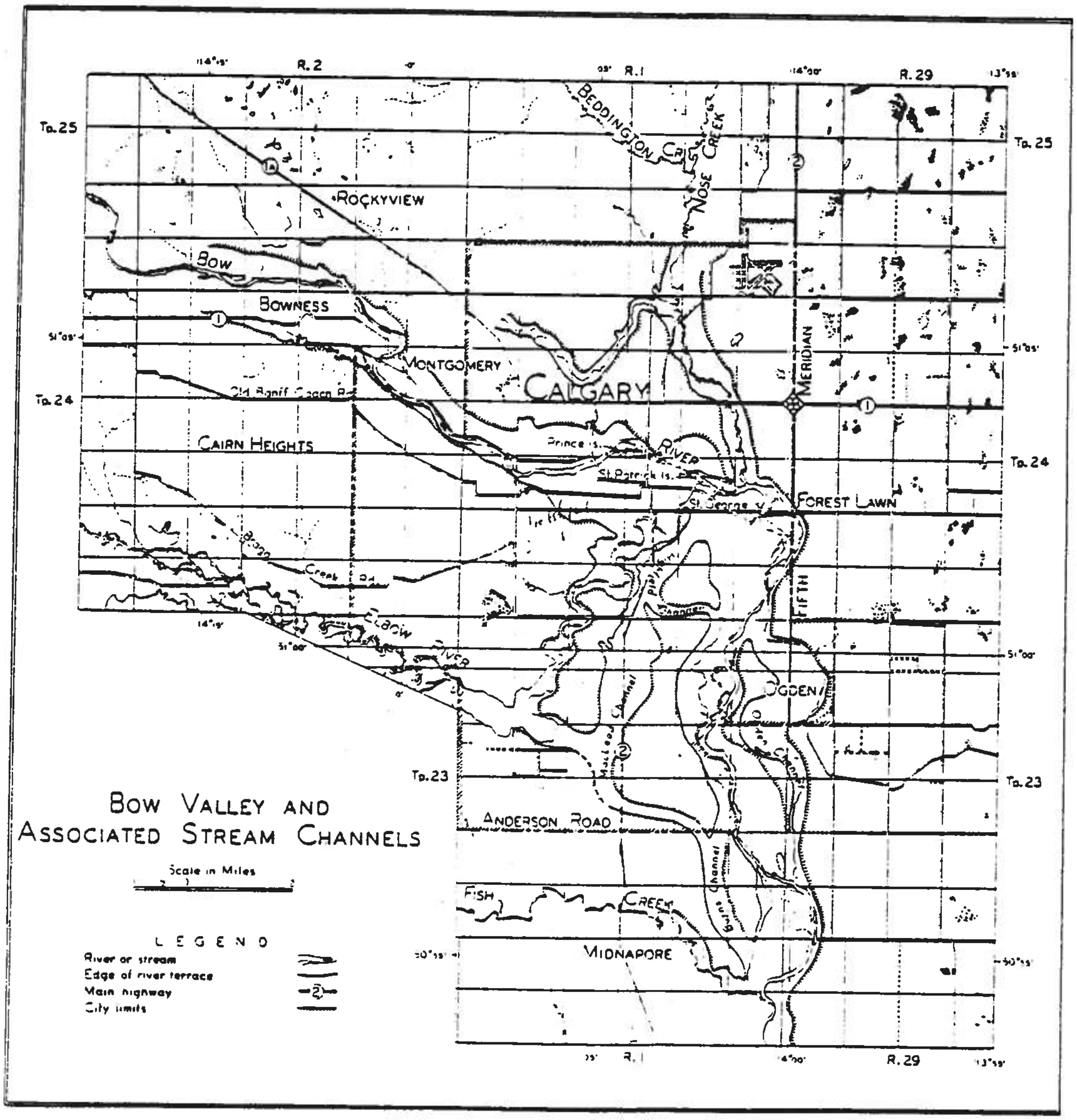
Crossfield Stratified Drift This unit, which constitutes the surface of the southeastern part of the area, consists of gravel that is composed of eastern as well as western pebbles. This material has been deposited by meltwaters from the Crossfield glacier. Although the thin veneer of Crossfield stratified drift that covers the erosion remnants along the Bow River is of no importance as an aquifer, some of the materials constituting the gravel aquifers associated with the Bow River have doubtless been derived from this formation.

A complete section of the successive Keewatin till and drift deposits has been obtained from the various outcrops in the ridge that separates Ogden from the Bow Valley (Fig. 4).

Lsd. 5, Sec. 16, Tp. 23, R. 29, W. 4th Mer.

Description	Thickness, feet
Gravel and sand, cross-bedded, containing pebbles of both eastern and western origin	1-3
Till, yellow, sandy, numerous Keewatin and Cordilleran pebbles, boundary with overlying gravel irregular	2-5
Sand, grey, cross-bedded, laterally grading into gravel	1-5

The same sand and gravel deposit is exposed at the top of the outcrop in Lsd. 5, Sec. 25, Tp. 23, R. 1, W. 5th Mer., where a gully has been created by water that is discharged from a nearby gravel pit. The southern wall of this gully shows the following succession:



BOW VALLEY AND
ASSOCIATED STREAM CHANNELS
Scale in Miles
LEGEND
River or stream
Edge of river terrace
Main highway
City limits
R. 2
R. 1
R. 29
Tp. 25
Tp. 24
Tp. 23
ROCKYVIEW
BOW
BOWNESS
MONTGOMERY
CALGARY
CAIRN HEIGHTS
Old Banff Coach R.
BEDDINGTON CR.
NOSE CREEK
MERIDIAN
FIFTH
RIVER
Prince Is.
St. Patrick Is.
FOREST LAWN
ELBOW RIVER
OGDEN
ANDERSON ROAD
FISH CREEK
MIDNAPORE

FIGURE 4.

Description	Thickness, feet
Soil	2
Sand, brown, interbedded with gravel lenses, resting unconformably upon the underlying beds	4
Loess, grey, somewhat silty	2
Gravel, medium to coarse sized, interbedded with fine, grey, cross-bedded sand. Pebble count in the gravel showed the following components: 44 per cent white quartzite, 29 per cent dark limestone and dolomite, 8 per cent arkose and 19 per cent granite. All pebbles are well rounded and the granite is nearly decomposed.	6
Till, yellow, argillaceous, only a few pebbles are visible at the exposed surface.	22

A stratigraphical interpretation of the combined sections gives the following results:

Description	Thickness, feet
Crossfield stratified drift	3
Crossfield till; the thickness of the till in this section agrees with the thickness reported by Tharin (1960, p. 62) who gave 6-15 feet	5
Lochend stratified drift In this sequence Lochend stratified drift also underlies Crossfield till rather than Balzac till.	at least 12
Lochend till. The contact between the till and the overlying drift is sharp, and not gradational, as has been observed elsewhere (Tharin, 1960, p. 72)	at least 22

A remarkable similarity between the section in the roadcut between Burnsland and Inglewood (p. 12) and the outcrop in Lsd. 5, Sec. 25, Tp. 23, R. 1, W. 5th Mer., is the presence of 2 feet of loess, capping the Lochend stratified drift. This deposit may be an indication of periglacial conditions after the first glaciers had retreated.

Recent Deposits

Where Calgary silt is exposed (NW. ¼ Tp. 24, R. 1, W. 5th Mer.) wind action has modified the surface to the extent that dunes have been formed. Tharin (1960) observed a buried soil, separating the dunes from the Calgary silt.

Recent alluvial deposits are exposed along the creeks and rivers of the Calgary area. A summary of the various gravel deposits that may be important as aquifers is presented in table 2.

Table 2. Gravel deposits in the Calgary area

Stratigraphic unit	Thickness, feet	Description
Postglacial gravel	5-58	These gravels have been deposited in various stream channels associated with the development of the present drainage pattern. The gravels are clean and well sorted and contain 50% white quartzite, 35% dark limestone, 9% grey arkose, 4% granite and gneiss, and 2% chert.
Crossfield stratified drift	1-3	Gravels of this formation are medium to coarse sized, well sorted and contain about equal amounts of western and eastern components.
Balzac stratified drift	3-25	These gravels are composed of well rounded pebbles of the following composition: 54% white quartzite, 22% dark limestone, 20% arkose, 3% granite. This formation forms a thin veneer over Balzac till.
Morley gravels	10-?	These gravels contain well rounded, coarse pebbles of western origin only, white quartzite, dark limestone and minor amounts of chert and shale and are present in the Bow Valley and associated terraces.
Lochend stratified drift	1-5	Gravel deposits of the Lochend drift contain well rounded pebbles of the following composition: 55% white quartzite, 9% dark limestone, 18% arkose, 16% granite and gneiss, 2% chert.
Saskatchewan sands and gravels	1-10	Saskatchewan sands and gravel are coarse, well rounded gravels, consisting of 50% white quartzite, 44% dark limestone and 5% chert. The gravels are interbedded with grey cross-bedded sand. This unit overlies the Paskapoo formation. Outcrops are scarce and the distribution appears to be limited.

Infiltration Capacity of Surficial Deposits

Part of the rainfall that infiltrates into the surficial deposits eventually serves as recharge to the various underlying aquifers. In order to understand this process it is of importance to have some conception of the physical properties that govern the infiltration. The infiltration capacity is defined as the maximum rate at which a soil in a given condition at a given time can absorb water, or the rate at which a soil will absorb water impounded on the surface. It is defined as the maximum volume of water which will pass into the soil per unit of area per unit of time. It therefore has the dimensions of velocity, LT^{-1} (Thorne and Peterson, 1954).

The rate at which rain water penetrates into the drift cover is determined by the degree of aggregation (amount of organic matter), texture and rate of swelling (clay content) of the soil that has been developed in the upper part of the drift. The amount of organic matter in the soils that are developed in Pleistocene deposits of this area is fairly constant (Wyatt and Newton, 1942). The two factors that show considerable areal variation are texture and clay content, both of which depend on the parent material and the mode of deposition of the drift.

On the basis of the mode of deposition it is possible to distinguish two textural groups of surficial deposits in the Calgary area: one with a relatively coarse texture, to which belong those sediments that are of fluvio-glacial or aeolian origin; the other, of finer texture, that includes the glacial and lacustrine deposits.

The rate of swelling, which is the third factor affecting the infiltration capacity of the drift, depends on its clay content, and especially on the amount of montmorillonite, which is characterized by its swelling property. The amount of montmorillonite in the drift is determined by its source area. Montmorillonite and illite are the most common clay minerals of the glacial deposits of the Alberta Plains, whereas chlorite and kaolinite are of subordinate importance. Tharin (1960) found that drift which is of eastern origin contains illite and montmorillonite in about equal amounts, whereas the percentage of illite of western tills exceeds the amount of montmorillonite at least as much as three times (table 3).

Table 3. Percentages of clay minerals of Calgary tills (after J. C. Tharin, 1960)

	Chlorite	Kaolinite	Illite	Montmorillonite
Western Tills:				
Spy Hill till	11.7	6.0	61.7	20.6
Morley till	14.7	5.3	74.4	5.2
Eastern Tills:				
Balzac till	10.8	7.0	49.0	34.3
Crossfield till	8.7	4.6	42.0	44.5
Lochend till	8.5	5.7	37.2	48.7

It follows from the distribution of montmorillonite that the infiltration capacity of western tills is higher than that of eastern tills and this fact, combined with the difference in texture, makes it possible to transpose the map of surficial deposits into a pattern of infiltration capacities.

The U.S. Department of Agriculture has tentatively classified soil-cover complexes according to minimum infiltration rates (Musgrave, 1955, p. 157). The minimum infiltration rates and the accompanying infiltration capacities that are believed to match the characters of the surficial deposits in the Calgary area are shown in table 4, and also on the groundwater map that accompanies this report (in pocket). Most of the minimum infiltration rates in the Calgary area fall within the "Below Average" group of the American classification, in which group minimum infiltration rate ranges from 0.05 to 0.15 inches per hour; these are characteristic infiltration rates for clay-loam soils and shallow sandy-loam soils.

Description of Bow River and Associated Features

Development of Drainage Pattern

It is evident both from the aerial photographs and from the topographic maps that there are various abandoned stream channels associated with the Bow River. From the elevations of these channels it is possible to recognize at least four different stages in the development of the present drainage system. A description of each of these channels will be given below, followed by a tentative interpretation of the development of the present drainage pattern.

The highest channel—which is marked MacLeod channel on figure 4—extends from Sec. 3, Tp. 24, R. 1, W. 5th Mer., to Sec. 11, Tp. 23, R. 1, W. 5th Mer. and is connected with another abandoned channel near Turner station in Sec. 21, Tp. 23, R. 1, W. 5th Mer., east of Glenmore Reservoir. It appears from well logs in Secs. 34 and 33, Tp. 23, R. 1, W. 5th Mer. and from outcrops in a sandpit in Sec. 15, Tp. 23, R. 1, W. 5th Mer. that there are at least 20 feet of sand and gravel in the MacLeod channel. The outcrop in the sandpit shows a total of 20 feet of medium- to fine-grained, grey, cross-bedded sand, interbedded with a few gravel layers 1 to 2 feet thick. A pebble count in one of the gravel lenses revealed the following composition: 54 per cent white and yellow quartzite, 30 per cent dark limestone, 11 per cent arkose, 5 per cent granite. The granite pebbles are extremely weathered and much of the finer fraction probably consists of decomposed granite.

In Sec. 11, Tp. 23, R. 1, W. 5th Mer. this channel joins a second channel marked Burns channel on figure 4. The channels do not meet entirely according to Playfair's law, for the bottom of Burns channel is approximately 50 feet below the bottom of the MacLeod channel. A deep and narrow gully connects the two channels, but its erosion has been insufficient to make the full width of the channels meet with accordant junction.

The Burns channel, which is the second highest channel in the area, is one-quarter mile wide and its bottom contains many small gravel outcrops. A large gravel pit in Sec. 2, Tp. 23, R. 1, W. 5th Mer. reveals the presence of 25 feet of cross-bedded sand and gravel, bearing all characteristics of fluviatile sediments. Thick gravel beds predominate in this section and a pebble count revealed the following percentages: 47 per cent light-colored quartzite, 37 per cent dark limestone, 11 per cent arkose, and 5 per cent granite.

Table 4. Estimated minimum infiltration rates and infiltration capacities for surficial deposits of the Calgary area

Surficial deposit	Minimum infiltration rate	Infiltration capacity
Outwash deposits, consisting of sand and gravel	more than 0.15 inches/hr.	very good to good
Moraine, consisting of sandy and gravelly till, containing less than 20% montmorillonite	0.10-0.15 inches/hr.	good to fair
Moraine, consisting of sandy and silty till, containing 20-40% montmorillonite Lacustrine and aeolian deposits, consisting of sand, silt and clay Outwash deposits, consisting of sand and silt	0.05-0.10 inches/hr.	fair to poor
Moraine, consisting of silty and clayey till, containing more than 40% montmorillonite	0-0.05 inches/hr.	poor to very poor

The Burns channel is connected with the Bow River in Sec. 14, Tp. 23, R. 1, W. 5th Mer. and Sec. 36, Tp. 22, R. 1, W. 5th Mer. At both places the floor of the Burns channel is above the floor of the Bow River Valley, and thus the two do not meet accordantly. A little creek, fed by a spring in section 14 has eroded a narrow gully toward the Bow River and this "reversed flow" has created a surface water divide in the Burns channel.

A third channel shown on figure 4 is the Highfield channel, the floor of which rises approximately 30 feet above the floor of the present Bow Valley. The sediments in the Highfield channel are predominantly gravel which can be seen in the various abandoned or operating sand and gravel pits. The best outcrops on the channel sediments are present in Burns gravel pit (Sec. 2, Tp. 24, R. 1, W. 5th Mer.). The northern wall of this pit shows 20 feet of grey, cross-bedded sand (Fig. 5) while toward the centre of the channel clean, well sorted gravel predominates. A pebble count in one of the gravel layers gives the following percentages of rock types: 48 per cent well rounded white quartzite, 34 per cent dark-colored limestone, 9 per cent arkose and conglomerate, 6 per cent chert and 3 per cent highly weathered granite.

FIGURE 5. Cross-bedded sand in the Highfield channel

Eastward toward the Bow River, the channel is entirely occupied by fairly dirty gravel, at least 6 feet in thickness. The lower junction of the Highfield channel and the Bow River is an extensive gravel flat, separated from the Inglewood area (Secs. 11 and 12, Tp. 24, R. 1, W. 5th Mer.) by a 20-foot high terrace, presently bisected by the Bow River.

The fourth channel, which is the lowest in elevation of all abandoned stream channels in this area, is the Ogden channel (Fig. 4). Its course is from Sec. 36, Tp. 23, R. 1, W. 5th Mer. to Sec. 9, Tp. 23, R. 29, W. 4th Mer., approximately parallel to the present Bow River. Two large gravel pits present a good vertical section of the channel deposits, which are thicker than the deposits in the other channels, although similar in composition.

The True Mix gravel pit in Sec. 25, Tp. 23, R. 1, W. 5th Mer. contains up to 30 feet of clean, coarse gravel, the pebbles consisting of 52 per cent quartzite, 35 per cent limestone, 7 per cent arkose, 1 per cent chert and 3 per cent granite and gneiss, 2 per cent Paskapoo sandstone. The Empire sand and gravel pit (NE. ¼ Sec. 9, Tp. 23, R. 29, W. 4th Mer.) also contains 20 feet of gravel, composed of "white and blue" mountain gravels and a minor percentage of eastern constituents. A number of springs that issue along the east side of the Ogden channel feed a little creek which meanders southward and enters the Bow River in Sec. 4, Tp. 23, R. 29, W. 4th Mer. (Fig. 4).

Assuming that all channels are related to a continuous erosion process, the highest channel must be the oldest and the lowermost the youngest. It should be kept in mind that the preserved channels represent a fragmentary record of the history of the present drainage pattern, for many intermediate stages in this history have been lost. Consequently, the following historical interpretation of these channels is a very tentative one.

Allan (1943) concluded that the preglacial Bow River deviated from its present course in the vicinity of Cochrane (Tp. 26, R. 4, W. 5th Mer.) and extended east to Glenbow Flats (Tp. 25, R. 3, W. 5th Mer.) along the valley of the present Elbow River west of Turner station (Sec. 21, Tp. 23, R. 1, W. 5th Mer.) (Fig. 6A), and south to Midnapore. The section of this channel between Glenmore Reservoir and Turner station has been described above in conjunction with the MacLeod channel. Its southern continuation to Midnapore is not evident from aerial photographs, although Tharin (1960) mentions that drilling in this area revealed the presence of fluviatile deposits. The present Elbow Valley and the channel segment between Glenmore Reservoir and Turner station can therefore be considered to represent the preglacial drainage. There are no remnants left of great changes in the drainage pattern after the first glaciation and it has to be assumed that the picture that we observe today has been produced by processes which were active after the last glaciation.

After the second glaciation, the scene in Calgary was dominated by Lake Calgary, situated between the retreating Balzac glacier and Crossfield glacier to the east and the retreating Morley glacier in the west. Material from the disintegrating eastern glaciers was transported southward through Nose Creek into Lake Calgary (Fig. 6B). After the ice had retreated sufficiently far east to expose the original Bow Valley south of Calgary, Lake Calgary became connected with this system by means of MacLeod Channel; Turner station thus represents the oldest junction of the Bow River and Nose Creek.

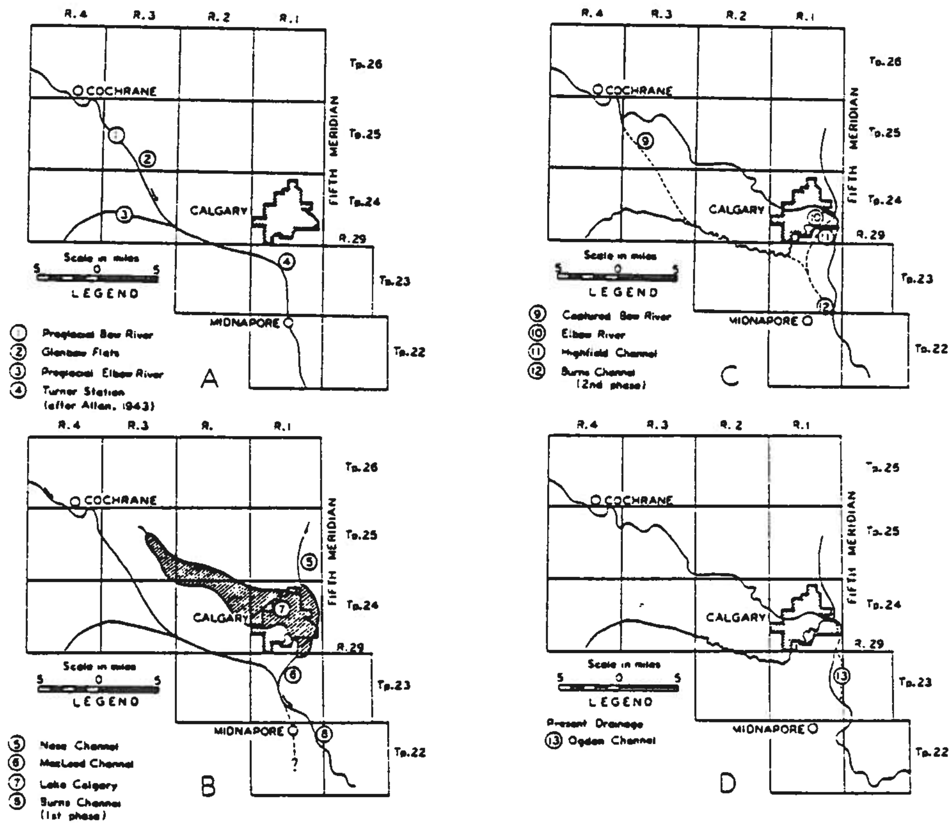


FIGURE 6. Sketch maps showing the four main stages of development of Bow River drainage system in the Calgary area

As a result of improving drainage conditions to the south, the water level in Lake Calgary began to drop, causing increased erosion in its contributing streams. Rapid headwater erosion of some of these creeks produced two features that are the essential components of the present-day drainage pattern, namely:

1. The capture of the outlet of Bow River into MacLeod channel, thus creating the characteristic "elbow" in the new course (Fig. 6C);
2. Creeks draining into Lake Calgary from the west, penecontemporaneously captured the Bow River near Cochrane, causing a strong decrease both in load and discharge in the remaining channel, which is the present Elbow River (Fig. 6C). The slope of the captured channel was probably considerably greater than was required for the transportation of the newly diminished load, and hence the stream obtained an adjusted lower slope by lengthening its entire profile. This has produced a feature that is characteristic for this type of readjustment, namely a stream meandering in a valley that is wider than its meander belt (Macklin, 1948).

At the same time the eastern glaciers had retreated sufficiently far that Nose Creek had lost much of its importance as a meltwater channel. Concurrently, the Bow River, being the only means of discharge for western meltwaters, experienced a strong increase in discharge and the entire drainage balance had thus shifted from Nose Creek to the Bow River, which consequently became the main stream in the area (Fig. 6C).

The Bow River now began to cut terraces in the Morley gravel train and large amounts of gravel were brought into the Calgary area. A conspicuous place of deposition was near the point where the new river bent sharply southward (Secs. 11 and 12, Tp. 24, R. 1, W. 5th Mer.); without having an outlet to the south that was entirely adequate for the new situation, deposition had to take place here in order to achieve the gradient required to transport the increased load. MacLeod channel was abandoned in favor of Highfield channel and Burns channel. The present reach of the river between Secs. 35 and 12, Tp. 23, R. 1, W. 5th Mer. was also occupied during this stage, as is evident from the higher terraces along this part of the valley. The absence of coarse material and the high percentage of arkose in the MacLeod channel indicate that it was abandoned prior to the new influx of coarse western material, probably at the time of the "Elbow capture". It is believed that neither Highfield channel nor Burns channel was competent to handle the new load and they were probably abandoned soon in favor of the Ogden channel, which, in its turn, was abandoned subsequently for the present course.

HYDROLOGY

Introduction

In terms of groundwater, Calgary is a city of extremes. The glacial and postglacial sediments in some of the stream channels yield an abundance of groundwater to a large number of consumers, whereas many bedrock wells in the suburban areas are barely sufficient to satisfy the domestic requirements. This situation poses an interesting problem in the evaluation of the groundwater resources, for it is self-evident that in order to obtain the maximum benefit from all groundwater occurrences in this semiarid area, the very good aquifers have to be developed just as carefully as the very poor ones.

The individual groundwater occurrences and some suggestions for their development are discussed below.

Groundwater in the Paskapoo Formation

General Statement

As has been explained in the foregoing paragraphs, the Paskapoo formation consists of dark-brown shale, interbedded with irregular sandstone lenses. Water in these sandstone layers is under considerable pressure and all wells penetrating such lenses have an appreciable pressure head. A water well that is developed in one or more of these sandstone aquifers may be expected to produce 1 to 4 gallons per minute (gpm) which is sufficient to satisfy most domestic requirements. Many houses in those suburban areas that have not yet been connected with the municipal water supply of Calgary or Forest Lawn obtain water from bedrock wells.

Permeability

Permeability values have been obtained from pump tests that were carried out by the driller at the time of well completion. The drillers' logs commonly report the results of such tests in terms of static level at the beginning of the test, water level at the end of the test, duration of pumping, and the pumping rate in gallons per minute. From these data it is possible to obtain an approximation of the aquifer permeability, but as most well casings have been slotted over more than 50 per cent of their length, water is withdrawn from both the sandstone and the shale; hence the transmissibility that can be calculated from these tests has been called "apparent transmissibility" and refers to that part of the formation from which water is withdrawn, and not necessarily to a specific aquifer in that interval.

Decrease in Head with Increasing Depth

Experience has shown that two adjacent wells at the same topographic elevation, both producing from a single aquifer although from different depths, have different static water levels. In such cases it is common that the deepest of the two wells has the lowest piezometric head and this phenomenon will therefore be referred to as "decrease in head with increasing depth."

The piezometric head at any given point in a confined or semiconfined aquifer is essentially determined by:

(a) The difference in elevation between the point of measurement and the recharge area of the aquifer,

(b) The frictional head loss encountered between the recharge area and the point of measurement.

Consequently, the piezometric head decreases continuously in the direction of flow (Hubbert, 1940).

It has been found (Jones, 1960; Farvolden, 1961) that bedrock aquifers in Alberta are recharged by local precipitation. This feature becomes apparent from the correspondence of "highs" on the piezometric maps with those on topographic maps. The piezometric surface of the Paskapoo formation in the vicinity of Calgary (plate I) is no exception to this rule and it is obvious from plate I that the piezometric highs are areas of groundwater recharge, whereas the streams are areas of natural groundwater discharge. This situation compares favorably to the flow system depicted by Hubbert (1940, Fig. 45).

Vertical and nearly vertical movement of water penetrating from the land surface to the bedrock aquifers must play a role in this hydrologic system, and the resistance that this flow encounters in the overlying beds accounts for a certain amount of head loss. The phenomenon of decrease in head with increasing depth is thus—at least partly—related to the vertical permeability of the beds overlying the aquifer.

Another factor contributing to head loss is related to lateral water movement within the aquifer. Water that has penetrated into the bedrock will move downward through a succession of flat-lying sandstones and shale layers. The effect of this anisotropy is a distortion of the stream-flow pattern (Hubbert, 1940, p. 902) with the result that a large portion of the initially nearly vertical flow will be diverted into a direction that may be even parallel to the bedding planes. This lateral flow within the aquifer also causes a certain head loss, which means that the total head loss observed is related to a vertical as well as a horizontal flow-component.

A third factor that has to be considered in the groundwater hydrology of this particular geological environment is the mutual interference of the sandstone aquifers that are tapped by the same well. In many cases one single sandstone layer is incapable of yielding the desired quantity of water and a number of wells therefore obtain water from more than one sandstone layer. This practice has indicated that in nearly all cases where two or more aquifers are developed within the same well, the piezometric head of the lower aquifer is below that of the higher one, owing to the factors discussed above. According to Bennett and Patten (1960), who first reported this phenomenon, the static water level in a so-called "multiaquifer well" is not static in the sense that no water movement takes place. A well connecting two aquifers of different piezometric heads will have an internal flow into the aquifer with the lower head; Bennett and Patten (1960) measured internal flows of up to 50 gpm. The water level in the multiaquifer well will thus be the result of two interfering pressure surfaces, a cone of depression of the discharging aquifer and a cone of impression of the aquifer being recharged (Bennett and Patten, 1960, Fig. 5). Internal flow will cease only if the pumping rate is such that the combined pressure surface is below the piezometric surface of the lowest aquifer. For most Alberta aquifers this rate of internal flow is probably much less than 50 gpm, but even a rate of 1 or 2 gpm may have a considerable effect on the water level in the well. Thus, in some cases the phenomenon of decrease in head with increasing depth may also be caused by water movement between two aquifers tapped by one well. Of the 93 available logs of bedrock wells in the Calgary area, 23 showed evidence of multiaquifer development.

In summary, it can be stated that decrease in head with increasing depth is essentially related to two processes:

(a) Head loss due to effects of vertical permeability.
(b) Head loss due to effects of lateral permeability.

The mutual effects of the components (a) and (b) depend on the place of the well within the flow system.

Plots of static water level versus well depth indicate the existence of a relationship between the two (Fig. 7), which appeared to be best expressed by a regression equation of the general form

$$y = bx + a \qquad (1)$$

in which y = static level

x = well depth

b, a = constants.

Diagrams similar to the one in figure 7 have been constructed for the following areas: Old Banff Coach Road, Bragg Creek Road and Springbanks, Bowness and Anderson Road.* Next, the regression equation for each area was calculated and these equations, together with mean areal elevations, average well depth, and average depth to first aquifer are presented in table 5.

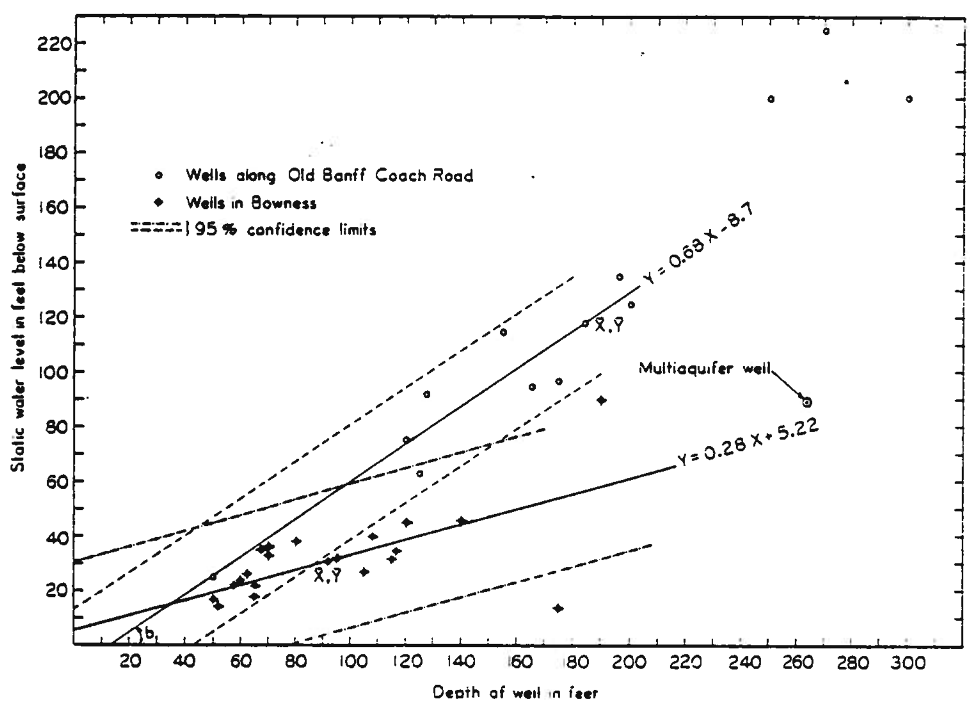


FIGURE 7. Scatter diagram showing the relation between static water level and depth for water wells producing from the Paskapoo formation

* These subdivisions were chosen with the idea in mind that extreme difference in well-head elevations within an area is approximately one-tenth of the difference between mean areal elevations. The areas discussed have been chosen in such a manner that those of similar mean areal elevation can be considered as belonging to different flow systems.

The t-test (Moroney, 1951, p. 311) was applied to the correlation coefficients "*r*" which were calculated for each regression equation (Table 5). All values of *r* were found to be significant at the 1% level, indicating a dependence of static level on well depth in all areas. Although a linear regression was used, it does not necessarily follow, however, that the relation between the two is linear. The assumption of some other mathematical expression for the relation could well result in a significantly higher value of *r* and, indeed, there is good reason to believe that a more complicated relation holds. Nevertheless, the statistical treatment of a linear regression is simple and the results derived therefrom are adequate for demonstrating the points to be made below.

As can be seen from table 5, the wells in the highest area are nearly twice as deep as the wells in the lowest, whereas water in the lowest areas has to be pumped from only one-quarter of the depth from which it has to be pumped at the Old Banff Coach Road. It is also interesting to note from figure 7 that one well along the Old Banff Coach Road deviates considerably from the areal trend. This well has a water level that is higher than should be expected for its depth. This well illustrates the effect of multiaquifer development (as is evident from the log), for the actual piezometric surface that corresponds with the aquifer at 250 feet is probably much lower. Thus regression equations will be seriously biased in areas where multiaquifer development is a common practice.

The constant b in equation (1), which is the sample regression coefficient, is an estimate of β, the population regression coefficient. This constant indicates the number of feet of decline in static water level per foot increase in well depth. Table 5 shows that b decreases toward areas of lower elevation. It is also worthwhile to know the actual margin of error associated with the calculated values of b; that is, within what range do the true values of β for the four equations lie? It may be said that in 95% of the cases β lies within the following limits (Snedecor, 1957, p. 135):

$$b - t_{.05}\, s_b \leqq \beta \leqq b + t_{.05}\, s_b \quad \text{------------------------} \quad (2)$$

in which s_b is the sample standard deviation of the regression coefficient b and $t_{.05}$ is Student's t value at the 5 per cent level for N—2 degrees of freedom (Snedecor, 1958, p. 135). The limits for β thus calculated are shown in table 5.

Thus, from the data in table 5 it can be seen that there is a significant decrease in slope of the regression lines, when going from a recharge area (Old Banff Coach Road) to a discharge area (Bowness). Thus, the phenomenon of decrease in head with increasing depth is most noticeable in the highest areas of the flow system which—according to the piezometric map—are also areas of recharge, and as the movement of water is more nearly vertical in these areas, it seems reasonable to associate the constant b in these areas principally with head loss due to the effects of vertical permeability.

The constant a can be seen to increase toward areas of lower elevation. This constant defines the point where the regression line intersects the ordin-

Table 5. Data pertaining to the relationship between well depth (x) and static water level (y) in the vicinity of Calgary

Area	Old Banff Coach Road	Bragg Creek Rd. Springbanks	Bowness	Anderson Road
Regression equation	$y = 0.68\,x - 8.7$	$y = 0.51\,x - 0.20$	$y = 0.28\,x + 5.22$	$y = 0.28\,x + 15.93$
Correlation coefficient (r)	0.84	0.77	0.56	0.73
95% Confidence limits: α	$-30.26 \leqq \alpha \leqq 12.86$	$-38.22 \leqq \alpha \leqq 37.82$	$-21.56 \leqq \alpha \leqq 32$	$-11.39 \leqq \alpha \leqq 43.25$
95% Confidence limits: β	$0.58 \leqq \beta \leqq 0.78$	$0.36 \leqq \beta \leqq 0.66$	$0.21 \leqq \beta \leqq 0.34$	$0.19 \leqq \beta \leqq 0.37$
Average elevation (feet)	3974	3731	3482	3492
Average well depth (feet)	184	115	93	116
Average static level (feet)	118	58	32	48
Average depth to first aquifer (feet)	121	66	58	63

ate. The hydrological interpretation of this parameter is uncertain, but it appears to be affected by the position of the area within the flow-system. In analogy with b being an estimate of the true β, it may be said that a is an estimate of the true population quantity α, and that α will lie within the following limits:

$$a - 2S_y \leqq \alpha \leqq a + 2S_y \quad (3)$$

in which S_y is known as the standard error of estimate of y (Moroney, 1951, p. 295). In about 95 per cent of the cases the actual value will lie within plus or minus two standard errors of the estimate values given by the regression equation. This calculation has been carried out for all areas (table 5) and the apparent differences of a in the regression equations appear not to be significant, for in all cases the confidence limits overlap within the region around the origin (Fig. 7).

Piezometric Surface of the Paskapoo Formation

It will be obvious from the foregoing observations that the construction of a piezometric surface has only a relative value in areas of this nature, for the piezometric head in a well is a function of its depth and its construction, as well as of the place of the well within the flow system. However, for most practical purposes it is sufficient to construct the piezometric surface for the most common well-depth in a particular area, as has been done on the accompanying groundwater map (plate I).

It follows from the nature of the flow system that the piezometric surface at greater depths will reflect the topographic relief to an ever-decreasing extent. At a certain horizontal level the irregularities introduced into the three-dimensional potential field as a result of the influence of surface topographic features will become negligible. The potential surfaces at this depth will be nearly vertical and parallel to one another, and the lower boundary of the local flow system will occur here. It is believed that groundwater below this depth is in the "medium zone of delayed flow" referred to in recent Russian publications (Norvatov and Popov, 1961). It follows from the restrictions to the present calculations that the true relation between well depth and static level cannot as yet be derived and consequently the lower boundary of the flow system cannot be calculated by means of the linear regressions.

Chemical Composition of Groundwater in the Bedrock

Groundwater from the Paskapoo formation in the Calgary area is similar to groundwater from the Paskapoo formation at other localities in Alberta, and the pattern obtained by plotting the limits of the chemical composition of many samples on semi-logarithmic paper (Fig. 8) is very similar to the one shown by Foster and Farvolden (1958, p. 20i, Fig. 3b). The quality of groundwater from the Paskapoo formation can be considered to be good in comparison to groundwater from other geologic formations within the Province.

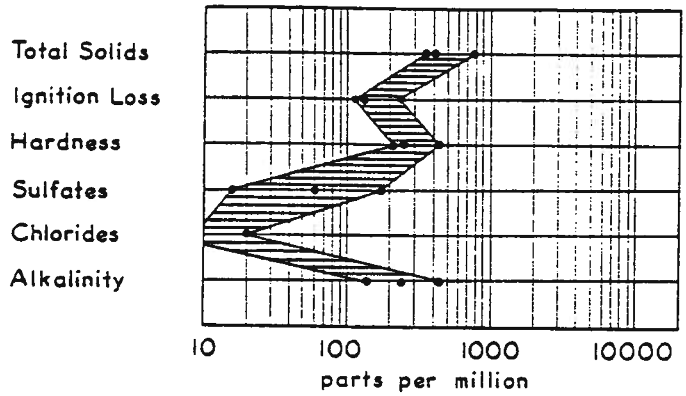


FIGURE 8. Limits of chemical composition of water from the Paskapoo formation in the Calgary area

For practical purposes it is often important to consider differences in water composition and to analyze the processes responsible for these differences. However, elementary changes in the composition of natural bedrock waters are generally noticeable only over considerable distances and cannot be detected within a relatively small area such as the one covered by this report. Nevertheless, the slight variations noted in composition are worth reporting, for they illustrate the principles of the flow system which has been described in the previous paragraphs, as well as the influence of the surficial deposits on the quality of deeper groundwater.

In order to facilitate graphical presentation of the available data, water analyses of each of the six suburban areas (Cairn Heights, Rocky View, Anderson Road, Bowness, Montgomery and the rural districts east of Calgary) were grouped together and each is represented by an average analysis. These analyses have been set out in table 6 and are shown graphically in figure 8.

As cations were not reported separately on the available analyses it was impossible to classify the Paskapoo formation waters according to Palmer's (1911) or Piper's (1944) classification; nevertheless an attempt has been made to assess the groundwater quality. To this end the anion field of Piper's trilinear quality-diagram has been subdivided into four fields, each of which has been given a name, depending on the anion that constitutes more than 50 per cent of that field (Fig. 9B). Figure 9 shows that all waters from the Paskapoo formation fall within the category of bicarbonate water, although groundwaters from the Rocky View district and the rural districts east of Calgary approach the composition of sulfate water.

In a second trilinear diagram (Fig. 9A) both the alkalinity and the hardness have been expressed in equivalent parts per million calcium carbonate and three types of water can be distinguished, depending on the mutual relations between hardness and alkalinity. Paskapoo water from Cairn Heights just falls within the limits of hard water, whereas waters from Bowness, Mont-

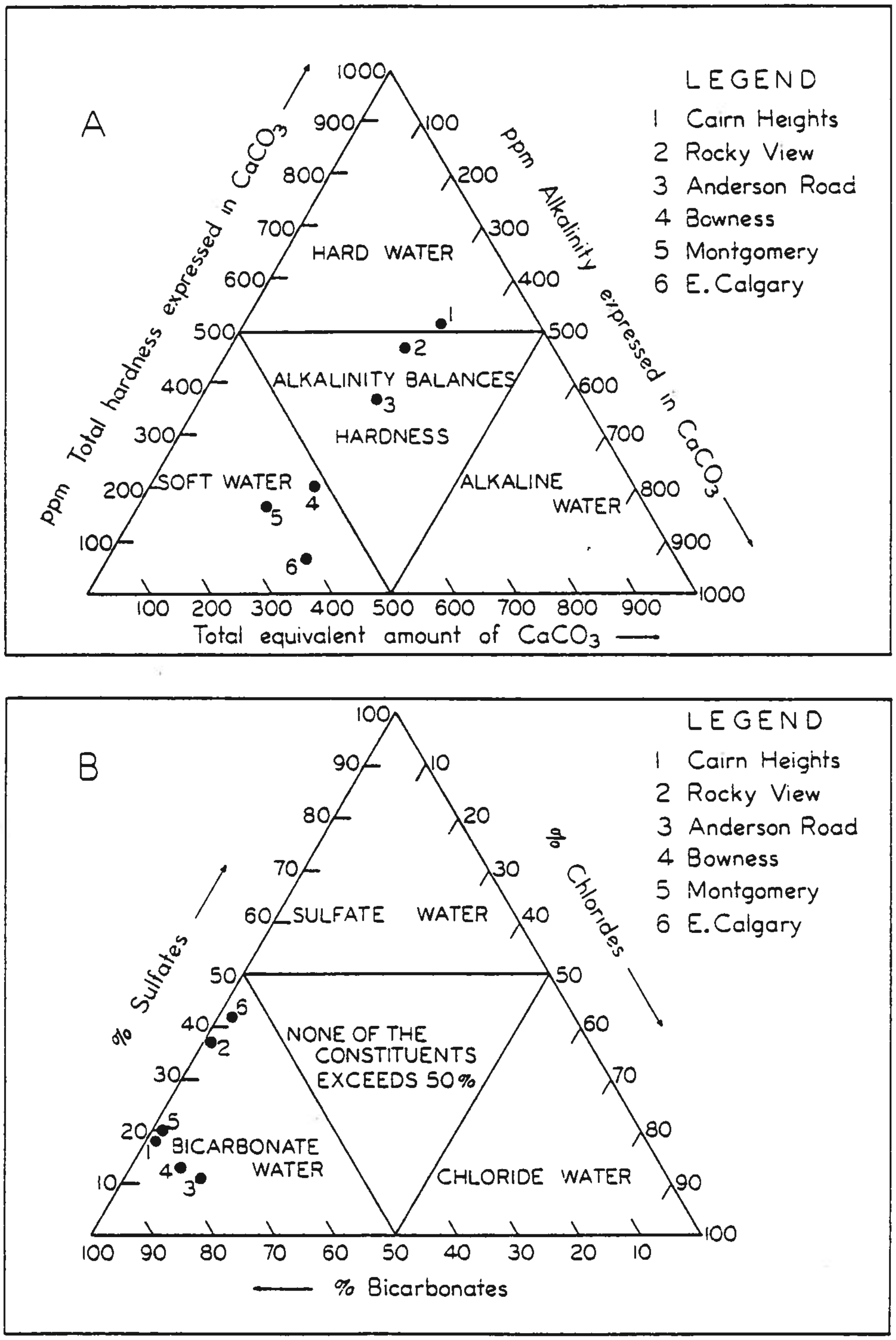


FIGURE 9. Trilinear diagrams showing the quality of water from the Paskapoo formation in the Calgary area

gomery and certainly East Calgary can be classified as soft water. Bedrock waters from the other localities are intermediate.

Let it be assumed that the rivers in the area separate the various flow systems in a similar way to that depicted by Hubbert (1940, Fig. 45), then—according to the piezometric map (plate I)—Bowness and Cairn Heights belong to the same system, as do Rocky View and Montgomery, whereas Anderson Road and East Calgary belong to flow systems of which the extents are unknown. Figure 9 shows that within one flow system the hardness decreases from areas of high elevation to areas of low elevation. This decrease in hardness does not appear to be associated with an increase in alkalinity in any of the areas, as is the case in other aquifers in Alberta (Meyboom, 1960). In the Cairn Heights - Bowness flow system (Fig. 9) the decrease in hardness is associated with a slight decrease in sulfates and a moderate increase in chlorides. The diminishing hardness in the Rocky View - Montgomery flow system is accompanied by a strong decrease in sulfates and no noticeable change in chlorides.

It is likely, therefore, that the decreasing hardness (hardness being the sum of carbonate hardness and noncarbonate hardness) is related to the decrease in sulfates, which make up the noncarbonate hardness. The diminishing sulfates could be brought about by a reduction process during the migration of the groundwater away from the recharge area. This process would be of the nature of:

$$SO_4^{--} + CH_4 \rightarrow HS^- + HCO_3^- + H_2O$$

in which the source of the carbonaceous material is thought to be located in the thin coal seams and finely dispersed lignite flakes that are present in the Paskapoo formation.

Table 6. Chemical composition of typical Paskapoo formation waters from six suburban areas near Calgary

(constituents expressed in parts per million)
(analyses by Provincial Analyst, Edmonton)

Constituents	Location					
	Cairn Heights	Rocky View	Anderson Road	Bowness	Mont-gomery	Rural areas east of Calgary
Total solids	622	769	512	540	409	1145
Ignition loss	212	191	120	120	78	82
Hardness	507	470	371	205	170	62
Sulfates	98	211	49	56	66	304
Chlorides	1.8	4	58	36	4	13
Alkalinity[1]	414	351	355	340	259	401
Iron	0.4	1	1.5	0.5	0.3	0.8

[1]The alkalinity is caused by bicarbonates of calcium and magnesium.

Table 6 shows that the hardness of groundwater in the rural areas east of Calgary is considerably less than the hardness of Paskapoo formation waters west of the Fifth Meridian. This fact is related neither to mineralogical differences in the bedrock, nor to different positions in a flow system, but rather to differences in the mineralogical composition of the overlying drift. The differences between eastern and western till are expressed not only by different percentages of montmorillonite, but also by significantly different percentages of calcium carbonate. Tharin (1960) found that western tills contain more carbonate than tills of eastern origin. For instance, the carbonate content of the Cordilleran Spy Hill till varies from 21 to 38 per cent, whereas the eastern Lochend till contains only 8 to 17 per cent calcium carbonate. Water percolating through western till will be able to dissolve more calcium carbonate than water seeping through one of the eastern tills and consequently, groundwater west of the Fifth Meridian will have a greater hardness than groundwater east of Calgary, although the bedrock composition at both localities is the same.

In nearly all analyses of water from areas west of the Fifth Meridian, the alkalinity was reported to be associated with bicarbonate of calcium and magnesium and not so much with sodium bicarbonate, as is the case elsewhere in the Province. This indicates that the base exchange rate of Paskapoo sediments is low. The reason for this is that bentonite, which is the chief source of sodium in Cretaceous sediments in Alberta, is almost absent in the Paskapoo formation. According to Parks (1916) the Paskapoo sandstone contains less than 1 per cent sodium and potassium. The fact that more soda does occur in analyses of water from the rural districts east of Calgary than in other parts of the area is explained by the mineralogical composition of the eastern drift. The eastern tills which have incorporated Cretaceous materials are rich in bentonite, and rain water reaching the bedrock after percolating through the drift will contain considerably more sodium than in the western parts of the area.

Decreases similar to the decrease in chlorides in the areas of higher elevation (Cairn Heights, Rocky View) have been reported from the Edmonton area also (G. Le Breton, 1961, personal communication) where they were interpreted to be the result of flushing of the bedrock formations. The same explanation is also probably true for the Calgary area, which would substantiate the assumptions regarding the nature of the flow systems.

Groundwater in the Unconsolidated Deposits

General Statement

The unconsolidated deposits that mantle the bedrock of the Calgary area were deposited as a consequence of widespread glaciation. In much of the area the glacial deposits are ground moraine or disintegration moraine (Fig. 3) as has been described in the second chapter. The glacial deposits generally do not yield water freely to wells and neither the till nor the fine-grained deposits of Lake Calgary can be considered as a useable source of groundwater in the area. The only unconsolidated sediments that are potential groundwater reservoirs are the gravel deposits in the stratified drift and the alluvial gravels along the Bow River and the associated stream channels as has been summarized in table 2 (p. 18). However, owing to the climate in the area only those gravels that are in permanent and immediate contact with bodies of surface water are saturated with groundwater, whereas the other gravel deposits are commonly dry. This means that economically important quantities of readily available groundwater are limited to the vicinity of the rivers. One exception to this rule will be described separately (p. 53).

Thickness and Permeability of Gravel Deposits

The thicknesses of the gravel deposits in the Bow Valley range from 0 to 58 feet (Fig. 10), with an average thickness of 22 feet. The maximum recorded thickness is at Pearce Estate (SW. ¼ Sec. 13, Tp. 24, R. 1, W. 5th Mer.) and vicinity. Experience has shown that at locations which are not immediately adjacent to the river and where the gravel is less than 15 feet thick, the saturated thickness of the gravel will be insufficient to allow establishment of a satisfactory groundwater supply. The 20-foot isopach in figure 10 therefore more or less coincides with the limit of potential groundwater development in the Bow Valley and Ogden channel.

The transmissibility values of the deposits range from 18,000 to 450,000 gpd/ft, and the specific capacity of gravel wells in this area varies accordingly from 33 to 390 gpm per foot of stabilized drawdown. The specific capacity is dependent not only upon the permeability but also upon well efficiency and upon the distance of the well from the source of recharge. It is obvious that large amounts of water can be withdrawn from these deposits and many industries in Calgary indeed obtain water from this valuable source.

Groundwater Movement in the Vicinity of Streams

A knowledge of the hydrologic relationship between gravel deposits and associated rivers is a prerequisite to determine the groundwater movement in these deposits. It has been shown by Todd (1955, 1959) and Meyboom (1961b) that during flood periods many rivers become influent, thus forcing water to enter the gravel beds along the streams. When the river level drops below the adjoining water table, the stream becomes effluent again and water held in bank storage is gradually released. As has been pointed out by Meyboom (1961b), discharge from bank storage is an important contribution to the river baseflow of the Bow and Elbow Rivers in the period between July or August of any given year and April of the next year. Hence, large changes in magnitude and direction of groundwater movement are brought about by fluctuations in river level.

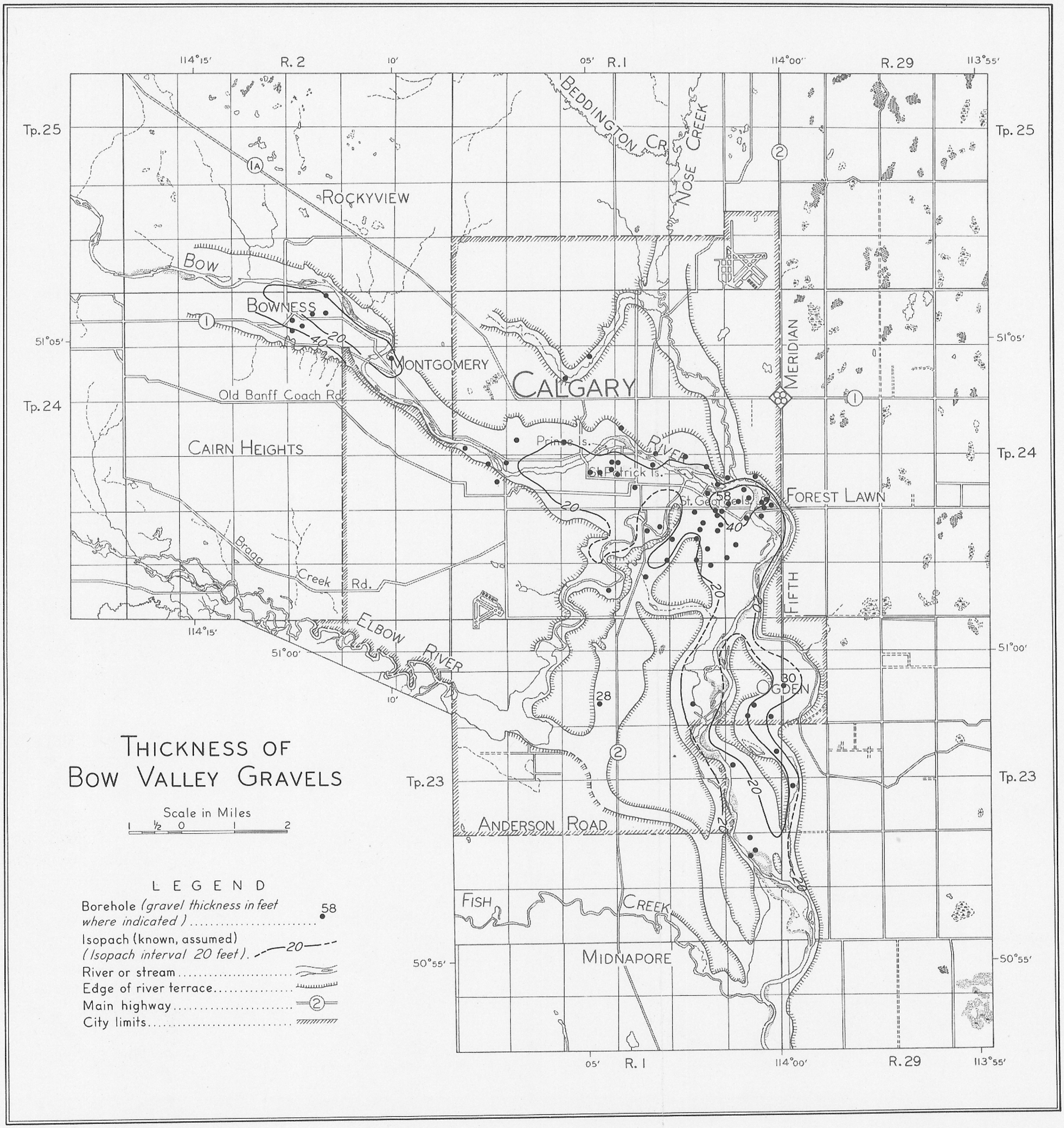


FIGURE 10.

Bulletin 8

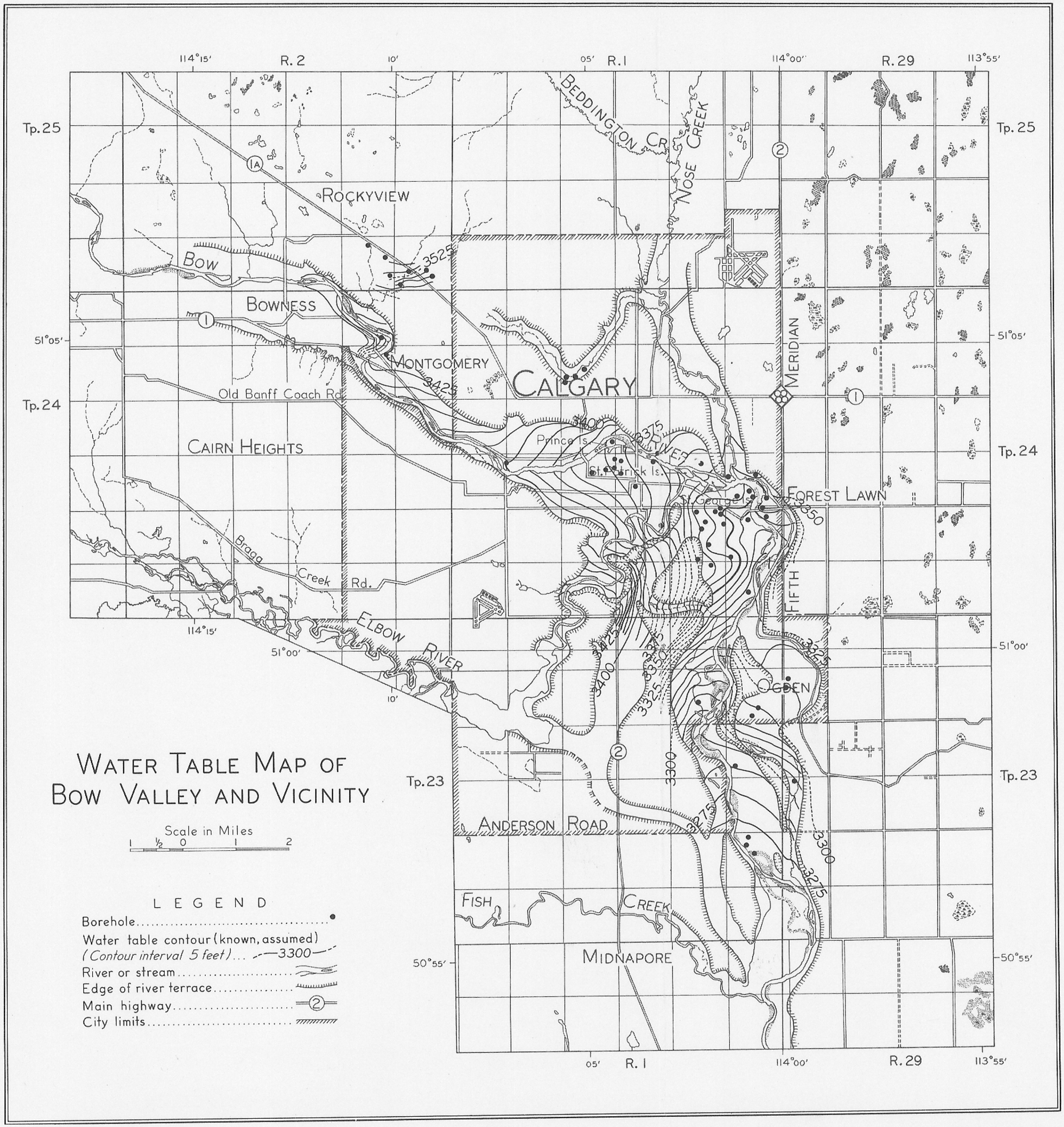


FIGURE 11.

Bulletin 8.

Water entering the banks at high water does not necessarily have to be discharged along the same path it came in, and discharge generally takes place at some point downstream from the point of entry. In the vicinity of river bends, the river water takes a "retarded shortcut" through the gravel banks which means that in a nonpumping condition groundwater moves obliquely toward the river during most of the year, which is inferred in figure 11*.

This characteristic behavior of bank storage discharge and bank storage recharge can be illustrated by the results of a few detailed investigations. The first experiment was carried out by introducing a dye into a test well located between the proposed production well of Calgary Packers Limited (SE. ¼ Sec. 11, Tp. 24, R. 1, W. 5th Mer.) and the Bow River. The investigation showed that the water did not move southward from the Bow River, but rather eastward toward the Bow River (Fig. 11). (This situation proved to be extremely fortunate, for during a fire a few years ago water was poured on the premises of the nearby stockyards, dissolving manure and doubtless introducing traces of nitrate into the groundwater. However, as the stockyards are located east of the packing plant, no contamination occurred in the production well.)

Another dye experiment was conducted in Sec. 12, Tp. 23, R. 1, W. 5th Mer. by Çanadian Industries Limited. In this case dye was introduced in the little creek that occupies Ogden channel, and samples taken from one of the C.I.L. wells showed that groundwater movement was toward the river. A detailed water table map constructed during an exploration survey of the same area in May, 1958, showed river water moving into the aquifer, thus illustrating the effect of an influent river stage.

Comparison of groundwater temperatures with temperatures of surface water affords another interesting illustration of the effect of changing bank storage (Fig. 12). According to the stream flow analysis of the Elbow River (Meyboom, 1961b) recharge of bank storage begins sometime in April. During the same month there is a rise in surface water temperature (Thomas, 1956). According to the daily temperature readings taken at the Calgary Brewery (NE. ¼ Sec. 11, Tp. 24, R. 1, W. 5th Mer.) the first signs of rising groundwater temperature appear in the last week of July or first week of August which indicates a time-lag of approximately three months between first rise of surface water temperature and first rise of groundwater temperature. The latest stages of river influency occur during August, when the surface water reaches a maximum temperature of 60°F. The maximum groundwater temperature is generally recorded in the last week of October or early November, which again indicates a lag period of approximately three months between the dates of maximum temperature recordings.

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* The water table map in figure 11 was constructed from static water levels that were reported when the various wells were newly drilled. However, the effect of interference drawdown from other wells that were in production already has not been taken into account.

It can be seen from figure 11 that groundwater that reaches the Calgary brewery from the Bow or Elbow River has to enter the gravel banks approximately 2,100 feet up-gradient from the brewery and the water travels this distance in approximately 90 days, at a rate of nearly 23 feet per day. The groundwater gradient toward the producing brewery wells is about 30 feet per mile and, assuming the porosity of the gravel deposits at 35 per cent, it can be calculated that under the prevailing conditions the permeability of the gravels allows the passage of about 8,800 gallons of water per day per square foot of cross-sectional area. This value equals a transmissibility of 350,000 gpd/ft, whereas the pump test at the Calgary brewery indicated a value of 450,000 gpd/ft.

Chemical Composition of Groundwater in the Unconsolidated Deposits

When the limits of the chemical composition of groundwaters from the unconsolidated deposits are plotted on semilogarithmic paper (Fig. 13) it appears that there is but little difference between this water and water from the Paskapoo formation (Fig. 8). The trilinear diagrams (Fig. 14) indicate that waters from the unconsolidated deposits can also be classified as *bicarbonate water* (Fig. 14B) and most samples fall within the limits of *soft water* (Fig. 14A). Moreover, figure 14 shows an interesting feature of the chemical composition of river water during baseflow conditions. In this diagram sample 1 represents water from the Elbow River during the initial stages of spring runoff, which is characterized by an absence of sulfates and chlorides.

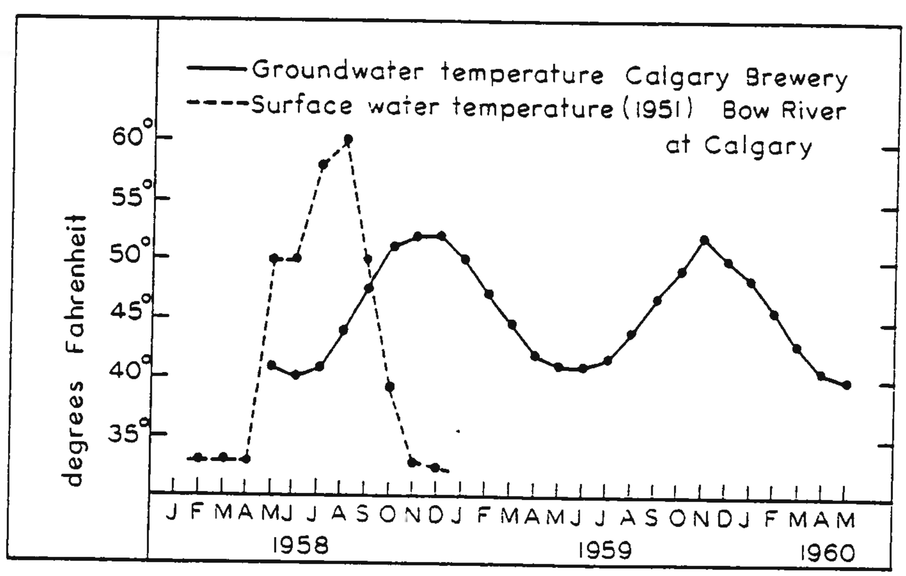


FIGURE 12. Graph showing the temperatures of groundwater from surficial deposits and surface water of the Bow River in the Calgary area

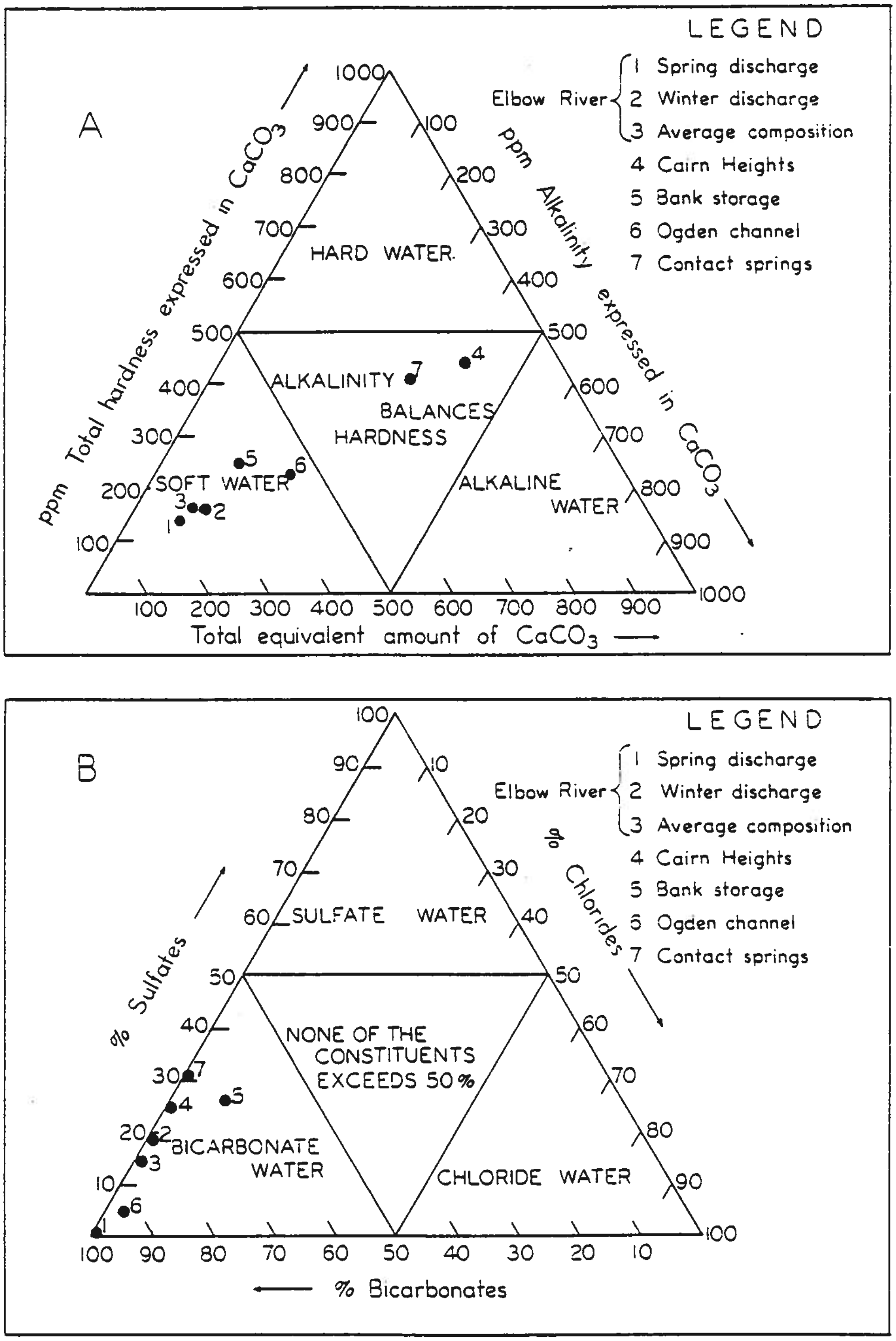


FIGURE 14. Trilinear diagrams showing the quality of water from the unconsolidated deposits and surface water in the Calgary area

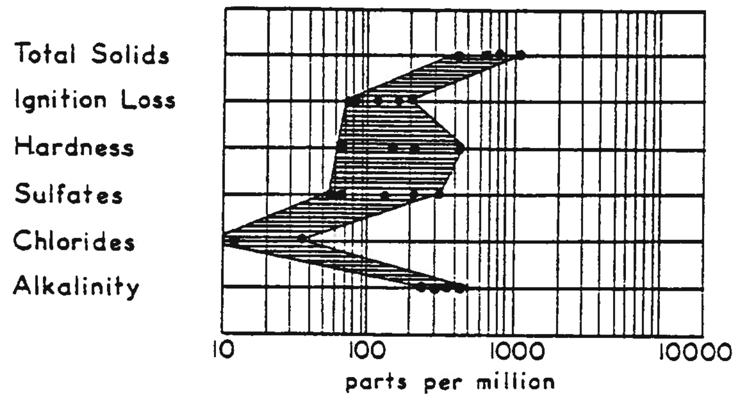


FIGURE 13. Limits of chemical composition of water from the unconsolidated deposits in the Calgary area

It can be seen that contact springs in general (sample 7) and particularly those along Cairn Heights (sample 4), as well as the bedrock waters (table 6) contain a considerable amount of sulfates. Thus it may be expected that during times when baseflow conditions prevail, the influence of groundwater discharge will be most noticeable in the amount of sulfates, and the composition of winter discharge from the Elbow River (sample 2) indeed shows a firm increase in sulfates.

Another chemical indication of groundwater contribution to baseflow is the changing amount of hardness in the streams. Between April and August, when most river water is derived from rain and melting snow, the hardness of river water is far below average (Fig. 15), but before April, as after August, coinciding with baseflow conditions in the rivers, a much higher hardness is recorded. This is to be expected, for groundwater discharge from bank storage, contact springs, and artesian leakage contributes to baseflow and the hardness of each of these components exceeds the average hardness of the streams in the area.

In connection herewith it is interesting to note that the average hardness of water in bank storage is 249 ppm (table 7), whereas according to Thomas (1956) the average hardness of the Elbow River is 186 ppm and of the Bow River 161 ppm. This indicates that river water that enters the gravel banks during influent river stages undergoes certain chemical changes which produce a higher hardness. This phenomenon has also been recognized by Noring (1954) in connection with Rhine water infiltrating its banks. Noring ascribes the rise in hardness to the formation of carbon dioxide during the infiltration of water containing free oxygen and oxidizable organic substances.

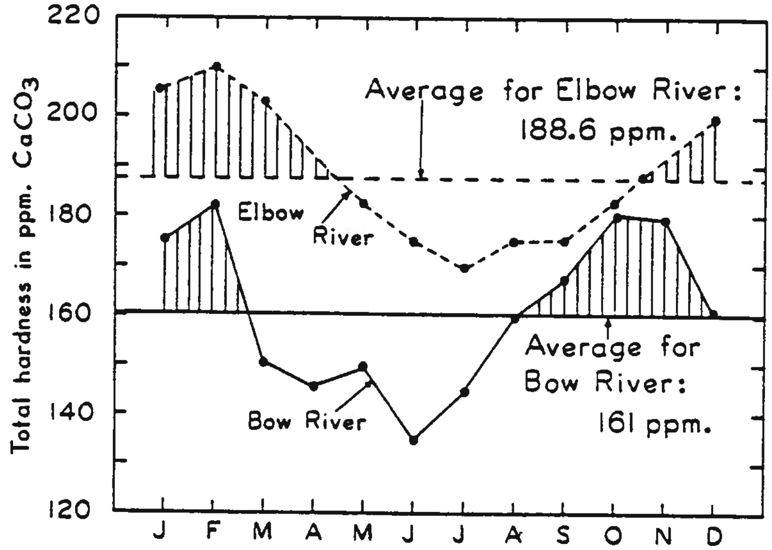


FIGURE 15. Graphs showing seasonal variations in the hardness of water from the Elbow and Bow Rivers

Table 7. Comparison of chemical composition of surface water and groundwater from the unconsolidated deposits in the Calgary area

(constituents expressed in parts per million)
(analyses by Provincial Analyst, Edmonton)

Constituents	Location				
	Bank storage, Bow Valley	Ogden channel	Contact springs	River water	
				Elbow	Bow
Total solids	348	374	778	210	176
Ignition loss	124	111	223	71	26
Hardness	249	223	416	186	161
Sulfates	60	16	180	43	32
Chlorides	20	8	1.5	0.8	0.9
Alkalinity[1]	152	270	402	175	153
Iron	0.4	0.3	0.3	0.4	—

[1]The alkalinity is caused by bicarbonates of calcium and magnesium.

Table 8. Elbow River hydrograph analysis, 1950 - 1958

Duration of groundwater recession	Total potential groundwater discharge		Actual groundwater discharge		Percentage of total flow	Remaining potential groundwater discharge		Total recharge (inches)	Change in storage (inches)
	(acre-feet)	(inches)	(acre-feet)	(inches)		(acre-feet)	(inches)		
August 20, 1950	31339	1.27							
March 30, 1951			31114	1.26	53	225	0.01		
August 5, 1951	93848	3.82						1951: 3.81	+2.55
April 5, 1952			89511	3.64	30	4337	0.17		
August 5, 1952	81261	3.31						1952: 3.13	−0.51
March 10, 1953			75403	3.07	58	5858	0.23		
August 7, 1953	60358	2.46						1953: 2.23	−0.85
April 15, 1954			56709	2.31	52	3649	0.15		
July 30, 1954	67978	2.77						1954: 2.62	+0.31
April 10, 1955			62514	2.54	37	5464	0.22		
August 20, 1955	37246	1.51						1955: 1.28	−1.26
March 25, 1956			33522	1.36	42	3724	0.15		
August 24, 1956	33127	1.35						1956: 1.20	−0.16
April 20, 1957			31100	1.26	33	2027	0.09		
July 30, 1957	25937	1.05						1957: 0.96	−0.30
April 8, 1958			23970	0.97	29	1967	0.08		
August 24, 1958	33435	1.36						1958: 1.28	+0.31
			Mean:	2:05	42			2.06	+0.01
			Total:	16:41				16.50	+0.09

$$C + O_2 \rightarrow CO_2$$

Because of the newly formed CO_2 an additional amount of calcium and magnesium carbonate will be dissolved from the gravels, thus raising the carbonate hardness of the water. Eventually, the carbonic acid will also dissolve iron and manganese, but table 7 shows that this process is of no importance in the Calgary area. The hardness of water in bank storage will also be increased by the mixing of river water and harder drift water flowing toward the river.

Groundwater Balance of the Elbow River Drainage Basin

The following paragraphs give a summary of a detailed streamflow analysis that was carried out in conjunction with the groundwater survey of the Calgary area. The full results of this study together with the theoretical implications of this technique have been published separately (Meyboom, 1961b), and only those conclusions that are considered of importance for this report have been included.

Baseflow, also called groundwater recession or groundwater discharge, represents withdrawal of groundwater from aquifer storage after groundwater recharge has ceased. During extended periods of dry weather, stream flow is maintained solely by groundwater discharge. It is possible to separate graphically the baseflow on a stream hydrograph by plotting the logarithm of the discharge against time. The total potential groundwater discharge (Q_{tp}) at the beginning of the baseflow recession is

$Q_{tp} = K_1 K_2 / 2.3$ (Butler, 1957; Meyboom, 1961b) ---- (4)

where:

K_1 = groundwater discharge at the beginning of the baseflow recession (t_0) in acre-feet per day

K_2 = time increment corresponding with one log-cycle change in discharge Q, in days.

Figures 16 and 17 show hydrographs of the Elbow River for nine successive years, in which baseflow has been separated according to the principle that the straight line connecting successive points of minimum discharge approaches true baseflow conditions. The total potential groundwater discharge has been calculated for the beginning of each baseflow recession and the results of these calculations are presented in table 8, expressed both in acre-feet and in inches over the drainage basin. The amount of actual groundwater discharge during one baseflow recession has been calculated from Butler's equation (10-b, 1958), and these values are also presented in table 8. It has been calculated that actual groundwater discharge during an average baseflow recession of the Elbow River amounts to 2.05 inches, or in other words, 42 per cent of the normal total river flow during the period between August and April is generally contributed by groundwater.

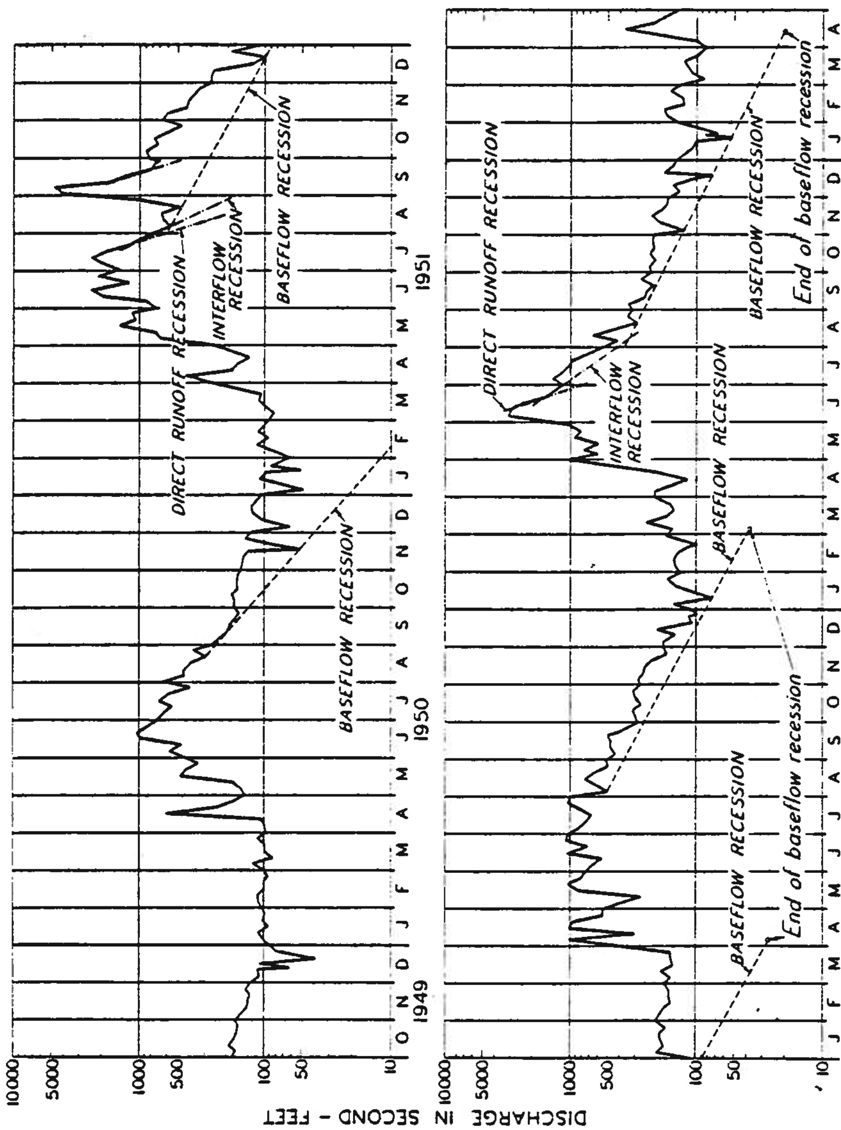


FIGURE 16. Hydrograph of Elbow River, 1949-1954

The difference between the total potential groundwater discharge and the actual groundwater discharge during the recession has been called remaining potential groundwater discharge, indicating the amount of groundwater that is still in aquifer storage. It can be seen from table 8 that there is a considerable difference between the remaining potential groundwater discharge at the end of any given baseflow recession and the total potential groundwater discharge at the beginning of the next baseflow recession; in other words, water

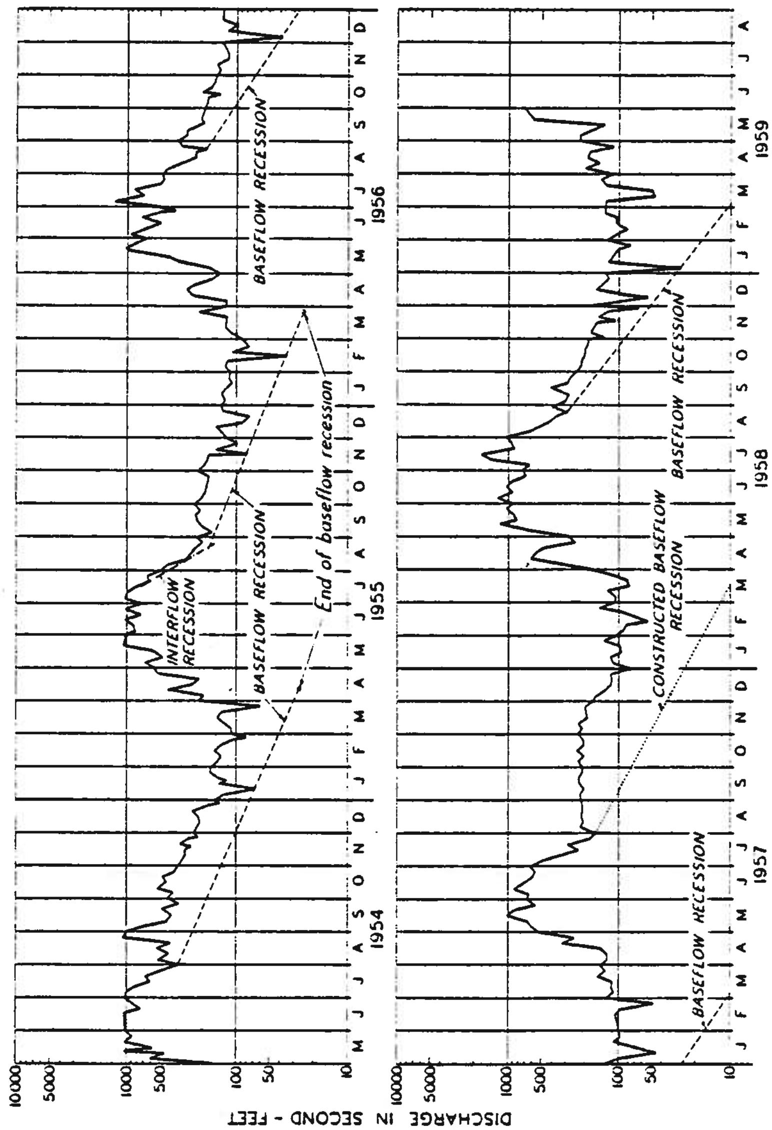


FIGURE 17. Hydrograph of Elbow River, 1954-1959

has been added to the groundwater resources and this difference has therefore been called total groundwater recharge, the values of which are also presented in table 8.

Rainfall rather than total precipitation is considered to be the chief recharging agent. Data over the entire Elbow River basin are not available, but the records for the City of Calgary are believed to be fairly representative for the general weather conditions in the area. If values for annual rainfall are plotted against the corresponding values of total groundwater recharge, a simple linear relationship is suggested (Fig. 18) that can be expressed by the equation

$y = 0.21\,x - 0.76$ ------------------------------ (5)

where:

y = total groundwater recharge, in inches

x = total annual rainfall, Calgary, in inches.

The mean annual rainfall in Calgary is 11.84 inches, and the mean annual rainfall over the entire Elbow River basin is estimated at 16 inches, and an approximation of the rainfall over the entire basin may be obtained by multiplying the value for the Calgary rainfall by 16/11.84 = 1.35. The upper scale in figure 18 shows the values thus obtained. Figure 18 shows that 3.6 inches of rain in Calgary (corresponding to 4.86 inches of rain over the entire basin) will produce no recharge at all, probably because insufficient quantities of stream runoff are available to make the rivers influent.

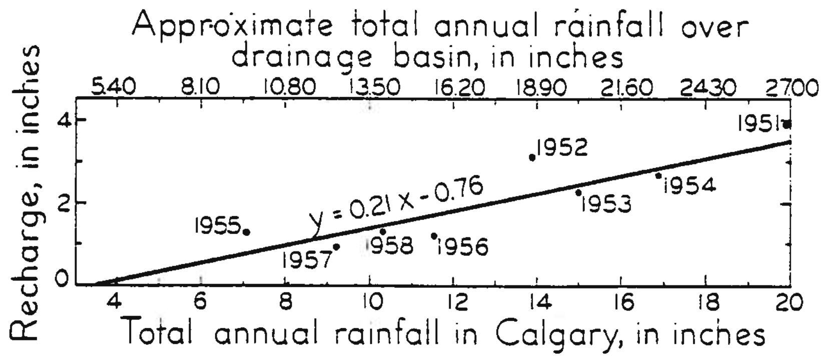


FIGURE 18. Scatter diagram showing the relationship between total annual rainfall in Calgary and total groundwater recharge

As has been mentioned in a previous paragraph, meteorological records of Calgary show an average total annual rainfall of 11.84 inches and by applying equation (5) it can be calculated that there is an average total groundwater recharge of 1.75 inches. During the period 1950 to 1958 the mean total annual rainfall was 12.94 inches with a mean total groundwater recharge of 2.06 inches.

The total potential groundwater discharge of any one year is not necessarily the same as the total potential groundwater discharge of the previous or of the following year (table 8). The difference between successive values of Q_{tp} has been considered to represent the change in groundwater storage during the intervening period. The values of changes in groundwater storage, being the third entity in the basic hydrologic equation, are also set out in table 8, expressed as depth in inches over the drainage basin.

Substituting the values of actual groundwater discharge, total groundwater recharge, and changes in groundwater storage from table 8 into the basic hydrologic equation: Groundwater recharge = Groundwater discharge ± Changes in groundwater storage; we obtain the groundwater balance for the Elbow River drainage basin between 1950 and 1958: 16.50″ = 16.41″ + 0.09″, or in terms of mean annual values of 2.06″ = 2.05″ + 0.01″.

This balance indicates that over the period of observation near-equilibrium existed between recharge and discharge, and it may, therefore, be assumed that the quantities of recharge to the various baseflow components (bank storage, contact springs, and artesian leakage) were nearly equal to the quantities of discharge. On this assumption the average recharge to the baseflow components has been calculated (Meyboom, 1961b), and a summary of the results is presented in table 9. These show that 19 per cent of the total recharge is consumed by drift aquifers, 8 per cent penetrates into the bedrock, while the remaining 73 per cent contributes to bank storage.

Table 9. Amount of recharge to baseflow components

Baseflow component	Amount of recharge (inches)	Percentage of total recharge	Percentage of mean total annual rainfall in Calgary 1950 - 1958
Contact springs	0.39	19	3
Artesian leakage	0.16	8	1
Bank storage	1.51	73	12
Total recharge	2.06		16

ECONOMIC GEOLOGY

Present and Potential Utilization of Groundwater in the Calgary area

Following the discussion of the general hydrologic features of the Calgary area, an attempt will be made to give a more detailed description of the groundwater conditions of specific areas in and around the city. The various urban, suburban, and rural areas are discussed individually, for the economic conditions of these areas differ to such an extent that it is impossible to apply the same standards to each area. The following discussion is intended to be complementary to the groundwater map which accompanies this report (plate I), and should therefore be read in conjunction with this map.

The groundwater map shows the nature and distribution of the most important aquifers in the Calgary area. The map also contains information concerning the infiltration capacity of the surficial deposits and the probability of obtaining certain quantities of groundwater at a given location. Special symbols indicate the chemical composition of groundwater in various subdivisions of the area, and the static water level to be expected in bedrock wells is shown by piezometric contours, the theoretical implications of which have been discussed in a previous section (p. 31). The name groundwater map has been used here to designate a map "that presents one or more groundwater characteristics" (Margat, 1960; Meyboom, 1961a).

Forest Lawn

Forest Lawn, which is a rapidly expanding town on the east side of Calgary, is located in the west half of Tp. 24, R. 29, W. 4th Mer. According to the 1956 census the population of Forest Lawn and vicinity amounted to 4,260 inhabitants, but is now probably close to 7,500. Until recently the population obtained its water from Calgary and from domestic wells, but since 1959 a municipal water supply system has been in operation. This system obtains its water from three wells which are located in the SE. ¼ Sec. 13, Tp. 24, R. 1, W. 5th Mer., north of the Cushing Bridge, on the gravel island formed by the Bow River and the C.P.R. irrigation canal. The water that is withdrawn from these gravel deposits along the river is derived partly from bank storage and is partly water that has infiltrated directly from the Bow River. This process is called "induced infiltration", for the infiltration takes place along the gradient toward the pumping wells. The wells showed the following logs:

Well No. 1

Description	feet
Topsoil	0 - 1
Coarse, dirty gravel	1 - 16
Medium gravel and sand	16 - 29

Static water level: —14′ 8″

Well No. 2

Description	feet
Topsoil	0 - 1
Coarse, dirty gravel	1 - 14
Medium-sized gravel and silty sand	14 - 28

Static water level: —14′ 7″

Well No. 3

Description	feet
Topsoil	0 - 3
Coarse gravel	3 - 7
Coarse gravel, boulders, sand	7 - 20
Coarse gravel	20 - 31
Silty clay	31 - 32
Coarse, dirty gravel	32 - 35
Clean, medium-sized gravel	35 - 42
Static water level: —8′ 6″	

The permeability of the gravels at this location is approximately 5,700 gpd/ft^2. Wells No. 1 and No. 2 have an average production of 260 gpm each, yielding a total supply of 0.5 - 0.8 million gallons per day. Well No. 3 which is capable of producing 600 gpm is used in case of emergency only. The town has 2,600 water services and the average daily water consumption per service ranges from 192 to 307 gallons; assuming three consumers per service, there is then a per capita daily consumption of 64 to 102 gallons.

Forest Lawn covers nearly three square miles and the daily water consumption expressed in gallons per minute per square mile thus ranges from 115 to 184 gpm per square mile, which is a fairly high production considering the absence of industrial consumers. The entire amount can be obtained from the gravel wells, however.

The Firestone Tire and Rubber Company which is located east of Forest Lawn obtains its water from two wells at the same gravel island along the Bow River. The drillers' logs of these wells reported sand and gravel to a depth of 41 feet below surface and the wells have a specific capacity of 75 gpm per foot of stabilized drawdown, which is comparable to the specific capacity of the municipal wells of Forest Lawn. Provided that proper techniques are applied, this type of deposit is capable of yielding even larger quantities of water than are presently produced.

The bedrock in this area provides an alternative source of groundwater, but these supplies are meagre. A typical log of a bedrock well is the log of the Forest Lawn school well, which was drilled in 1954.

Sec. 15, Tp. 24, R. 29, W. 4th Mer.

Description	feet
Topsoil	0 - 6
Yellow clay	6 - 36
Blue clay	36 - 78
Hard, grey, sandy shale, some water	78 - 79
Blue shale	79 - 99
Hard, grey, sandy shale, some water	99 - 100
Blue shale	100 - 120

Static water level: —50′

The casing of this well was perforated from 76 to 120 feet and the well is a typical example of a multiaquifer well. The composite transmissibility of the exposed Paskapoo formation at this locality is 68 gpd/ft, which is barely sufficient for a domestic supply. Bedrock wells in this area should not be considered a potential source of groundwater that exceeds 1 gpm.

Ogden

This suburban area is located in the southeast part of Calgary and encompasses the Ogden channel and the adjacent highlands. The major part of the residential area of Ogden has been connected with Calgary's municipal water supply but there is still a considerable number of private water supplies south of 82nd Avenue SE. (S. ½ Sec. 25, Tp. 23, R. 1, W. 5th Mer.). Houses in this area obtain water from three sources:

1. *Contact Springs* These springs issue along the east wall of the Ogden channel at the contact between Crossfield stratified drift and Crossfield till. The springs (which do not yield over 5 gpm) feed a little creek that presently occupies Ogden channel.

2. *Bedrock wells* Bedrock wells in the Ogden area have an average depth of 75 feet and may produce up to 3 gpm. A typical log of one of the deeper wells reported the following succession:

NE. ¼ Sec. 36, Tp. 23, R. 1, W. 5th Mer.

Description	feet
Clay and boulders	0 - 26
Blue shale	26 - 90
Sandstone	90 - 94
Blue shale	94 - 120
Sandstone	120 - 124
Blue shale	124 - 132

The upper sandstone bed does not provide an adequate water supply so that the well has been completed as a multiaquifer well.

3. *Gravel wells* Gravel wells in the Ogden channel range in depth from 15 to 25 feet and are probably capable of producing large quantities of water. Although no pump test results are available, various observations substantiate this opinion. For instance, one of the gravel pits in the Ogden channel has to dispose of 700,000 gallons of water per day. Another indication of the high permeability and the high water table in the Ogden channel is the fact that 162,000 gallons of water per day have to be pumped out of the basement of the C.P.R. boiler house (SW. ¼ Sec. 33, Tp. 23, R. 29, W. 4th Mer.) to keep it accessible. Both instances show that quantities of the order of 1,000 gpm per square mile can indeed be obtained from the channel deposits. These quantities are comparable to the present production from the Bow River gravels.

A lateral hydrologic connection exists between the Bow River and the Ogden channel (Fig. 11). This connection probably consists of Lochend till which is sufficiently permeable to allow some water to pass, but compared to the channel deposits the till will act as a semipermeable medium the hydrologic behavior of which can be determined only by careful pump testing. The fact that a hydrologic connection between the Bow River and the Ogden channel exists is indicated by the fact that water level fluctuations in the gravel pits in the Ogden channel seem to follow the fluctuations of the Bow River.

The Ogden channel appears to be a promising source of adequate quantities of industrial water. It should be mentioned, however, that both the groundwater seeping into the C.P.R. basement, as well as the storm sewer discharge from the Ogden channel showed traces of oil. The origin of this oil is uncertain but the quantity diminished markedly during the summer of 1960.

Bowness and Montgomery

Both of these towns, which are located on gravel terraces along the Bow River west of Calgary, originally satisfied their water requirements by means of domestic wells. A preliminary survey of the groundwater resources of Bowness and Montgomery was carried out by the Research Council of Alberta in 1957, but the results indicated that no municipal groundwater supply could be developed here, and the towns now obtain water from the City of Calgary. The present water consumption of the combined area, which in 1956 had a population of 11,754, is estimated at 80 gpm per square mile, which could never have been obtained from private water systems.

The banks of the Bow River at this locality consist of rather dirty gravel, the thickness of which varies from 20 to 40 feet and most of which is above river level. The saturated thickness as well as the permeability of the sediments is insufficient to supply large-capacity wells.

There is still a considerable number of domestic wells in both towns, the majority of which yield between 1 and 5 gpm from the Paskapoo formation. The presence of a fairly continuous sandstone layer at 65 feet below the surface is indicated, rather definitely, by a large number of the well logs in the Bowness area. Most bedrock wells, however, obtain water from a greater depth and from more than one aquifer as is illustrated by the following log:

New Bowness Hotel

Description	feet
No record	0 - 10
Clay	10 - 20
Shale	20 - 60
Sandy shale	60 - 65
Shale	65 - 85
Sandstone	85 - 96
Shale	96 - 102
Sandy shale	102 - 107
Shale	107 - 112
Sandstone	112 - 118
Shale	118 - 137
Sandstone	137 - 142
Shale	142 - 157
Sandstone	151 - 160
Shale	160 - 175

Static water level: —14'

The apparent transmissibility of this section is 114 gpd/ft, which is not significantly different from the transmissibility of the Forest Lawn school well.

The average transmissibility of bedrock wells in these areas is 140 gpd/ft and it can be seen from table 5 (p. 30) that the average well depth is 93 feet and the average static level is 32 feet below surface.

In a few cases contact springs issuing along both valley walls of the Bow River serve as a domestic water supply. A large spring was observed near the Bowness Golf and Country Club and several ranches along Highway No. 1 have similar springs. The long-term fluctuations in the yield of these springs closely coincides with long-term climatologic fluctuations in this area (Fig. 2). The water that is discharged from these springs flows toward the Bow Valley and in many instances it disappears into the gravels before reaching the river. Consequently, the only places in Bowness where it is possible to withdraw large quantities of water from the gravels are those localities where the gravels are recharged in this fashion. This information was used during the construction of the Trans-Canada Highway which is situated on a higher river terrace south of Bowness. The flow of various contact springs which were impeding proper road construction was directed through culverts into dry wells on the lower gravel terrace. This indicates that the gravel deposits in Bowness may be suitable for artificial recharge but it should be remembered that surface pollution can easily enter this aquifer. However, bacteriological pollution will be removed in about 100 to 300 feet of travel through the aquifer.

Municipal District of Rocky View

Rocky View This name is used here to indicate the rapidly expanding suburban area west of Calgary situated along Highway No. 1A. The highway follows a fairly flat terrace about 125 feet above the Bow Valley until it reaches Sec. 2, Tp. 25, R. 2, W. 5th Mer. Here the highway crosses the 3,700-foot contour and reaches a second terrace which has a more irregular topography.

Nearly all the water wells on the lower terrace are finished in gravel. Logs of these wells report 80 to 90 feet of sand and clay, underlain by 10 to 20 feet of gravel, as is shown in the following log:

Lsd. 13, Sec. 25, Tp. 24, R. 2, W. 5th Mer.

Description	feet
Loam	0 - 5
Clay	5 - 35
Sand	35 - 55
Fine gravel	55 - 70
Yellow clay	70 - 100
Gravel	100 - 117

Static water level: —50′

The wells are reported to produce 15 gpm or more without signs of depletion.

This gravel deposit appears to occur in a channel-like depression in the bedrock, which probably finds its continuation in a shallow valley southeast of Sec. 30, Tp. 24, R. 1, W. 5th Mer. As can be seen from the groundwater map, this valley is occupied by a small creek which eventually joins Nose Creek (plate I). Test drilling in this valley within the city limits gives the following succession:

Sec. 28, Tp. 24, R. 1, W. 5th Mer.

Description	feet
Peat	0 - 6
Till	6 - 28
Gravel	28 - 50
Shale	50 - 55

The water in the gravel was under sufficient artesian pressure to produce a 25 gpm flow from this test hole. A 24-hour pressure-recovery test indicated a transmissibility of 13,000 gpd/ft which would infer a possible production of 75 to 120 gpm from a well in this channel.

Wells drilled on the terrace above 3,700 feet no longer encounter the gravel deposits and have to obtain water from bedrock. Initially most wells that were drilled in the new subdivision of NW. ¼ Sec. 2, Tp. 25, R. 2, W. 5th Mer. tapped a fairly continuous sandstone layer at a depth of 130 feet, having an apparent transmissibility of the order of 250 gpd/ft and a static water level of 100 feet below surface. However, the wells were spaced closely together and individual wells were overpumped, so that the resulting self-caused drawdown and mutual interference between wells have resulted in a rapid depletion of the aquifer, the areal extent of which is unknown. The wells were recently deepened to 180 feet, where a second sandstone layer was encountered. The transmissibility of the second aquifer appears to be 180 gpd/ft and the new static level was 152 feet below surface.

As neither the production nor the well spacing was changed, this second aquifer can be expected to be depleted also in the near future for the following reasons. If the amount of natural recharge to bedrock aquifers in the Elbow River basin (table 9) is converted from inches over the drainage basin to gallons per minute per square mile, the calculated recharge to bedrock aquifers is 4 gpm per square mile. For the sake of argument this amount will be taken as representative of natural recharge to bedrock aquifers in the entire area, for the Paskapoo formation is fairly uniform throughout the area. The population of Tp. 25, R. 2, W. 5th Mer. consisted in 1956 of 899 inhabitants and if this number of people were distributed evenly over the entire township their water consumption would amount to approximately 1 gpm per square mile. This amount is well below the amount of natural recharge so that such a population distribution would not create conditions of groundwater depletion. However, the population in this area is concentrated within less than two square miles, which implies a groundwater consumption of nearly 15 gpm per square mile, an amount that exceeds the rate of natural recharge by almost four times.

If the degree of development is defined as the ratio of the rate of groundwater consumption to the estimated rate of groundwater recharge, over-development is indicated by all values exceeding 1.00. The amount by which the degree of development exceeds 1.00 is defined as the degree of over-development. The degree of over-development of Rocky View is nearly 3, and in view of this fact it is not surprising that depletion of the aquifers is taking place. Thus, the Paskapoo formation in the Calgary area is not considered to be a dependable source of groundwater in areas where the population density exceeds 100 to 150 persons per square mile.

Above the highest terrace, at elevations higher than 3,900 feet, water is extremely difficult to obtain. A water well drilled at the site of the Spy Hill jail penetrated 128 feet of drift before reaching bedrock, but no water could be obtained either from the drift or from the bedrock, and the jail is now supplied with surface water from the Bow River.

Contact springs are common features in this area also. Some of the springs issue on inter-drift contacts rather than drift-bedrock contacts, but their hydrologic nature is the same and their yield is small.

Old Banff Coach Road The ridge separating the Elbow River from the Bow River (called Cairn Heights on plate I) is bounded to the north by the Old Banff Coach Road. Descending on the south side of Cairn Heights one reaches the Bragg Creek road area which will be discussed separately. Rural Route No. 2, which extends in a northerly direction along the west boundary of Secs. 2, 11, 23 and 26, Tp. 24, R. 2, W. 5th Mer., is the city limit at this side of Calgary. Recently this area has become quite popular for suburban development and many country houses have been built during the past few years.

The area has not as yet been connected with the municipal water supply of the City of Calgary and each house has its own bedrock well. The average depth of wells in this area is 184 feet, with an average static level of 118 feet below surface. Transmissibility values are the same as those of the Paskapoo formation elsewhere in the Calgary area and range from 150 to 250 gpd/ft. A typical log is presented below.

Lsd. 12, Sec. 29, Tp. 24, R. 2, W. 5th Mer.

Description	feet
Gravel	0 - 28
Soft shale	28 - 43
Blue shale	43 - 63
Grey shale	63 - 81
Blue shale	81 - 96
Grey shale	96 - 107
Hard sandstone	107 - 117
Black shale	117 - 141
Hard sandstone	141 - 156
Black shale	156 - 168
Hard sandstone	168 - 176
Hard, black shale	176 - 188
Sandstone (water bearing)	188 - 196
Black shale	196 - 200

Static water level: —125′

At places where the houses are built closely together, depletion of the aquifers may occur. For instance, the population density along the Old Banff Coach Road in Sec. 23, Tp. 24, R. 2, W. 5th Mer. is estimated at 160 persons per square mile, which would imply a groundwater consumption of 5.5 gpm per square mile, and consequently the degree of over-development of this district is estimated at 1.4. This area is in the initial stages of overproduction and those wells with the highest elevations are showing signs of depletion. The future development of this subdivision should be planned with regard to the scarcity of potential groundwater supplies.

Bragg Creek Road and Elbow River Valley The situation on the south side of Cairn Heights is similar to that on the north side in that all domestic wells withdraw water from bedrock, the upper 200 feet of which has an apparent transmissibility of 100 to 200 gpd/ft. Depletion has been reported at one location (SW. ¼ Sec. 11, Tp. 24, R. 2, W. 5th Mer.) and this well had to be deepened from 120 feet to 170 feet with an accompanying drop in static water level.

The lower population density of this area accounts for the fact that depletion of groundwater has not yet occurred, but the groundwater situation of the district does not differ from that of Rocky View or the Old Banff Coach Road.

The Elbow River Valley is occupied by a widely meandering stream which —similar to the Bow River—periodically recharges the gravel deposits along its banks. Little is known about the thickness of these deposits for most of the area is occupied by grazing land, and no test drilling has been carried out. A natural result of the hydrologic connection between the stream and the gravel banks is the fact that water in the oxbow lakes (abandoned meanders) still moves in the general direction of the stream, which makes them ideal rearing ponds for trout.

Anderson Road

The name Anderson Road has been applied to designate the area that belongs to the Foothills Municipal District and is located between Highway No. 2 and the Sarcee Indian Reserve. This area is another popular district for suburban development and many beautiful homes have been built here during the past few years. Water in this area is obtained from the Paskapoo formation by means of domestic wells, which have an average depth of 116 feet and a static level of 48 feet below surface. The nature of the Paskapoo formation does not differ from that of the bedrock elsewhere in the Calgary area and the following log shows the typical succession of sandstone and shale:

NW. ¼ Sec. 9, Tp. 23, R. 1, W. 5th Mer.

Description	feet
Clay	0 - 5
Sandy clay and rocks	5 - 16
Gravel	16 - 20
Sandy clay	20 - 30
Blue clay	30 - 65
Hard blue clay	65 - 80
Sandstone	80 - 81
Shale	81 - 84
Sandstone	84 - 85
Shale	85 - 87
Sandstone	87 - 88
Shale	88 - 96
Sandstone	96 - 97
Sandy shale	97 - 105
Sandstone	105 - 106
Sandy shale	106 - 112
Sandstone	112 - 113
Sandy shale	113 - 125
Hard shale	125 - 148
Sandstone	148 - 149
Shale	149 - 154
Sandy shale	154 - 159
Shale	159 - 167
Sandstone	167 - 168
Shale	168 - 175

Static water level: —47′

The casing in this well has been perforated from 86 to 175 feet, which again indicates that multiaquifer development is often the only possibility to obtain an adequate supply from the Paskapoo formation. The apparent transmissibility of the section is 140 gpd/ft.

In 1956, the Anderson Road district had a population density of 78 persons per square mile, indicating a groundwater consumption of about 2.7 gpm per square mile, which is safely below the rate of natural recharge. The only reason that over-development has not taken place here is because of the greater spreading of the population in this area, as compared to, for example, Rocky View.

Rural Districts

In the rural districts surrounding the City of Calgary groundwater from the Paskapoo formation is also the most common source for domestic water supplies. In 1956, the population density around Calgary amounted to nine inhabitants per square mile which offers a striking contrast with the population density of the urban or suburban areas of Calgary. Consequently, domestic groundwater consumption (excluding stock watering) of the rural areas probably amounts to approximately 0.5 gpm per square mile, which is far below the estimated rate of natural recharge, and the groundwater resources of the rural areas are therefore considered to be entirely adequate for the current demands and no over-development is expected.

Bow River Valley

Plate I shows that the largest amounts of groundwater can be withdrawn from the Bow Valley in Secs. 11, 12, 13 and 14, Tp. 24, R. 1, W. 5th Mer. The clean and exceptionally thick gravel deposits in this area are extremely suitable for large-scale groundwater production. A number of industries in the Inglewood and Bonnybrook areas (Sec. 12) have realized the importance of this resource and utilize the groundwater both for cooling and processing purposes. The average yield of wells in this area is 300 gpm and it is estimated that industries in this area use about 4.5 million gallons of groundwater per day. Two typical logs are given below.

Pearce Estate, SW. ¼ Sec. 13, Tp. 24, R. 1. W. 5th Mer.

Description	feet
Sandy soil	0 - 5
Sand with some gravel	5 - 15
Gravel with some sand	15 - 30
Coarse gravel	30 - 45
Coarse and fine gravel	45 - 50
Fine gravel, some sand, clay	50 - 54

Static water level: —10′

Inglewood, SW. ¼ Sec. 12, Tp. 24, R. 1, W. 5th Mer.

Description	feet
Topsoil	0 - 4
Fine gravel and sand	4 - 18
Yellow clay	18 - 21
Coarse gravel and some sand	21 - 32
Shale	32 -

Static water level: —15′

Groundwater from the gravel deposits in the downtown area between 10th Avenue South and the Bow River is extensively used for air-conditioning purposes, and is entirely satisfactory for this practice. Air conditioning requires approximately 1 gallon of water per minute at a preferred temperature of 45° to 48°F. for each 300 square feet of space to be cooled. Large buildings with between 50,000 and 150,000 square feet of office space require 0.25 to 0.75 million gallons of water per day and the maximum groundwater consumption in the downtown area is estimated at 3.5 million gallons per day during a warm summer day. A typical log of the gravel deposits in this area is:

3rd Street and 8th Avenue West

Description	feet
Fill	0 - 3
Gravel with some clay	3 - 31
Coarse sand	31 - 32
Blue clay	32 - 42

Static water level: —24′

Temperature in March: 51°F.

On some occasions the water is returned into the gravel aquifer after being circulated through the cooling system. The maximum rise of water temperature in an air-conditioning system is about 12°F. but the over-all groundwater temperature within the aquifer does not seem to be substantially affected.

If the water has been used for industrial cooling, the increase in temperature may be considerably more and one situation is known (Sec. 12, Tp. 23, R. 1, W. 5th Mer.) where the disposal of cooling water at 75°F. caused the groundwater temperature to rise to 72°F. at a distance of 200 feet from the disposal well. Data on heat relationships within aquifers of this nature are scarce. Noring (1954) developed an empirical method to determine the effective distance which the water has to travel before it has acquired the original groundwater temperature again. He reports that in gravel aquifers along the Rhine in West Germany water was returned into the aquifer at a temperature of 50°C. (112°F.) and recaptured at 1,600 feet from the disposal well at a temperature of 15°C. (59°F.), which at that location was close to the normal groundwater temperature.

If all water that is used for air conditioning, industrial cooling and industrial processing is grouped together as "industrial water consumption", Calgary is estimated to have a maximum total groundwater consumption of 8 million gallons per day, or approximately 1120 gpm per square mile of river terrace. The per capita industrial groundwater consumption would then amount to 25 to 34 gallons per day which is a very normal value for an area of this nature. The average total per capita consumption from the municipal water supply (Glenmore Reservoir) is 65 gallons per day. The maximum gross per capita consumption was 269 gallons per day during an extremely warm day in June, 1961.

Pearce Estate, which certainly fulfills the hydrologic requirements for yielding large quantities of water, is the only area along the Bow River where the tremendous groundwater potential has not as yet been exploited. According to a recent article in the Calgary Herald (August 30, 1960) some exploration has been carried out by Ranney Method Water Supplies (Canada) Limited, and in view of the fact that vertical wells near this area are capable of yielding up to 3 million gallons per day, the site seems to be extremely favorable for induced infiltration by means of horizontal wells or infiltration galleries. The use of horizontal wells or infiltration galleries is quite common throughout the United States and Europe, but Canadian cities seem to be reluctant to obtain their water supply from this source. A common conception is that the formation around a horizontal well will "become clogged", causing wells of this type ultimately to fail. It is generally forgotten, however, that surface reservoirs, which are an alternative source of water, also rapidly lose their capacity, for reservoirs reduce the carrying capacity of a river to practically nil causing nearly all the transported sediment to be deposited in the reservoir. The costs involved in consequent modification of the water supply plants, and damage to recreational facilities will greatly exceed the costs of installing horizontal wells.

In the case of an infiltration gallery or a horizontal well, pumping would induce river water to infiltrate into the gravels. If it is assumed that up to 10 million gallons per day would infiltrate from the Bow River, this amount would still be only 0.6 per cent of its average daily discharge, which would be an insignificant proportion of the river flow.

In conclusion, it appears that present and future industrial water requirements of the City of Calgary can be satisfied by groundwater supplies from the Bow River gravels at suitable locations.

The hydrology of the abandoned stream channels associated with the Bow River is but little known. A well drilled in the MacLeod channel showed the following log:

Lsd. 8, Sec. 28, Tp. 23, R. 1, W. 5th Mer.

Description	feet
Boulders	0 - 1
Clay and gravel	1 - 3
Boulders and gravel	3 - 10
Clay, boulders and gravel	10 - 25
Coarse gravel	25 - 28

Static water level: —10′

The transmissibility of this section is 565 gpd/ft.

Fish Creek Valley

West of Midnapore, Fish Creek has cut a valley of about 50 feet deep into bedrock. The alluvial deposits on the narrow valley bottom may be sufficient to yield domestic supplies but will not yield larger supplies. The average gradient of Fish Creek is 0.0052 (27.35 ft/per mile) which is twice the average gradient of the Elbow and Bow Rivers. Consequently the carrying capacity of Fish Creek is much higher than that of the other streams and the river is probably in a much more active stage of scouring than the other streams in the area. A thick accumulation of sediments should not be expected here.

Engineering Problems Related to Groundwater

Landslides

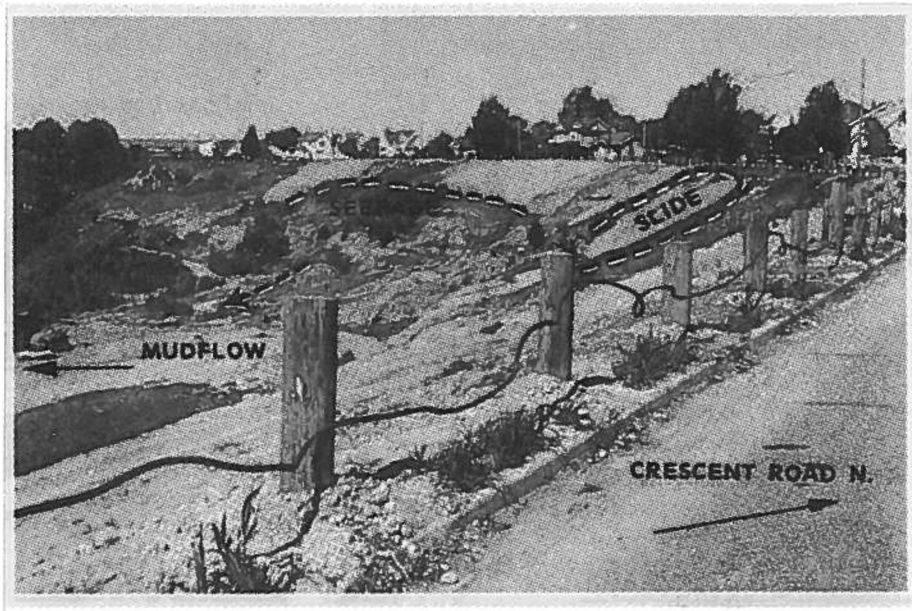
The steep walls of the Bow Valley bear marks of past, present, and potential landslides and the City of Calgary has spent a vast amount of money in remedial measures for slides that threaten to destroy parts of the most beautiful residential districts in the city.

In these paragraphs a possible explanation is offered for a few slides where groundwater played a conspicuous role. Although the slides are an economic menace, they are, geologically speaking, an essential part of the process of valley development by lateral slope retreat.

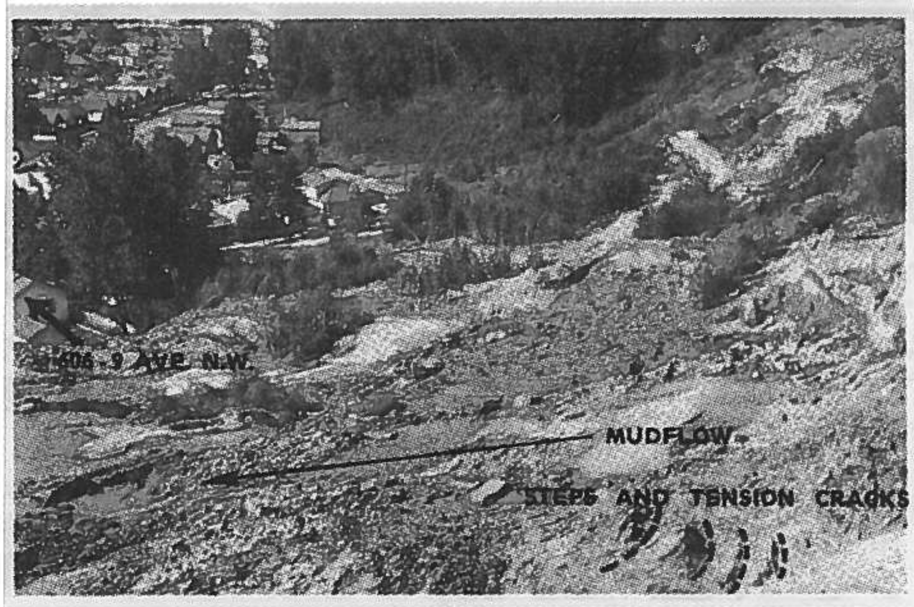
The most recent landslide (1960) in Calgary is along Sunnyside Hill (Fig. 19). Slides in this area have cost the City of Calgary close to $500,000.00 since 1945 (Calgary Herald) and it was anticipated that another $200,000.00 would be spent during the program initiated in 1960. The slide is located along the northern valley wall of the Bow River in the centre of the city.

Test drilling behind the slide showed the area to be underlain by a succession of clay, silt, sand, and till varying in thickness from 180 feet at the centre of the slide to 100 feet at the flanks. The map of the bedrock topography (Fig. 20) shows the presence of a small bedrock gully filled with (Lochend ?) till. This till is overlain by 50 to 60 feet of grey and brown silt which is capped by 5 to 20 feet of interbedded clay and silt, that laterally grade into a second (Balzac ?) till. The top of the section consists of 15 to 20 feet of silt, intercalated with sand and clay lenses. Cross-sections through these deposits are presented in figures 20 and 21. Except for the local sand lenses the materials which comprise this section have an extremely low permeability.

At regular periods—generally during spring—part of the slope suddenly moves downward, often preceded by the formation of tension cracks along the crest of the danger zone. During the sliding, the upper part of the moving mass subsides, whereas the lower part bulges and the slide-scar becomes a C-curve (Fig. 19). The flanks of the slide are marked by steps and tension cracks. This type of movement falls within Terzaghi's definition of a landslide (Terzaghi, 1950).



A: General view of slide area south of Crescent road



B: Detail of mud flow, showing steps and tension cracks

FIGURE 19. Sunnyside Hill slide, Calgary

The stability of a slope in moist cohesive material depends on its shearing resistance which is expressed by Coulomb's equation:

$$s = c + p \tan \phi \qquad (6)$$

where: s = shearing resistance
c = cohesion
ϕ = angle of internal friction
p = normal stress on the surface of sliding.

If the average shearing stress on a potential slide surface becomes equal to the shearing resistance, a slide occurs. Slope failures can, therefore, be caused either by a decrease of the shearing resistance (internal causes) or by an increase of the shearing stress (external causes). If the sediments contain water under pressure, then the piezometric head tends to decrease the shearing resistance. Terzaghi (1950, p. 92, eq. 4) has modified Coulomb's equation to take this into account:

$$s = c + (p - hw) \tan \phi \qquad (7)$$

where: h = pressure head at that point
w = unit weight of water.

Hence, an increase in hydrostatic pressure in such a sediment causes a decrease in shearing resistance in that layer.

It can be seen from figures 20 and 21 that Sunnyside Hill is underlain by two silty layers, separated by clay. Till underlies the lower silt bed and rests upon bedrock. While drilling into this section the holes appear to be moist but free water is not encountered immediately. After a few days or hours, however, water has drained out of the formation and it is possible to construct a piezometric surface of the area (Fig. 21). It is apparent that contours of the piezometric surface closely resemble those of the bedrock topography which suggests that the fairly gravelly till which covers the bedrock surface in the main aquifer, containing confined or semiconfined water which slowly rises above the silt-till contact when the till is penetrated.

Under normal conditions groundwater probably drains out of this formation into the adjacent river valley, the elevation of which is about 3,400 feet (indicated by "preferred surface" in Fig. 21). During periods of rain (spring and early summer) recharge suddenly increases, causing a rapid rise in piezometric surface. This sudden rise is probably one of the causes of the slides, for the suddenly increasing water pressure is transmitted rapidly (although the water itself may not be transmitted) decreasing the shearing resistance of the slope, and the overburden tends to "float" (Terzaghi, 1950). The piezometric surface (Fig. 21) shows how the hydrostatic pressure is highest around the deepest parts of the bedrock channel and that future slope failures are to be expected there.

Groundwater affects the stability of this slope in other ways as well. Some of the rain water that penetrates into the ground does not reach the lower

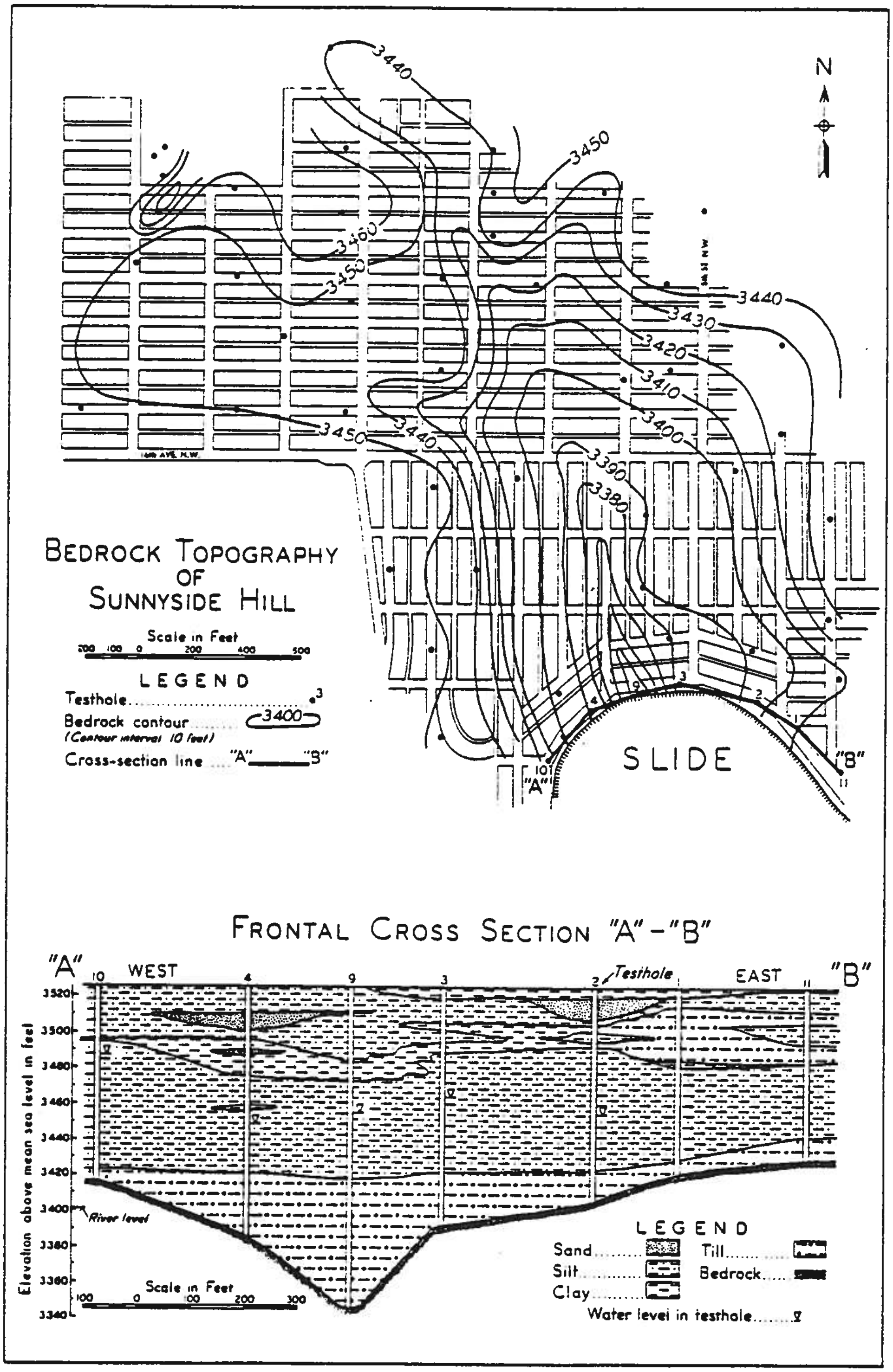


FIGURE 20. Bedrock topography and frontal cross section of Sunnyside Hill slide, Calgary

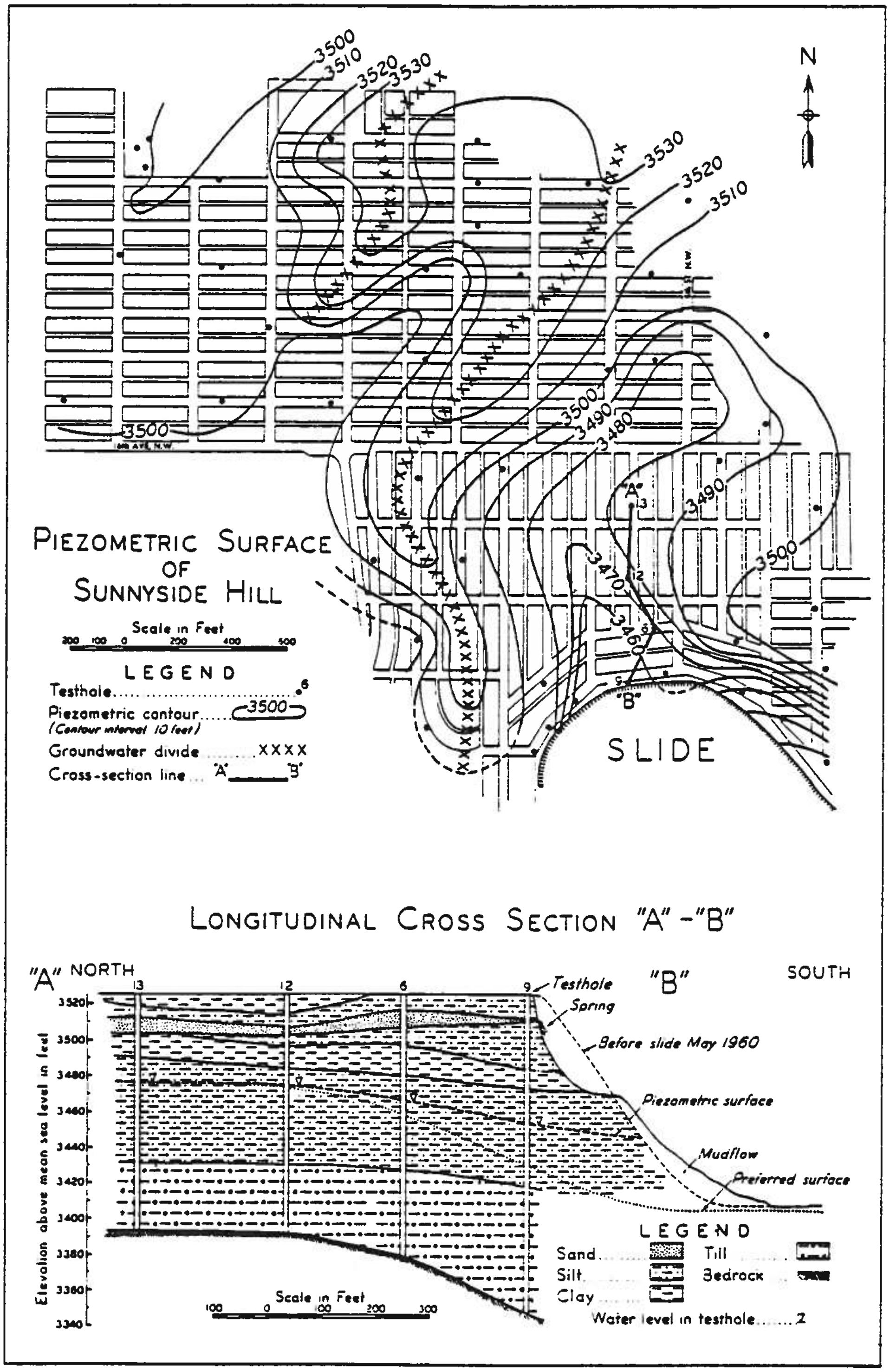


FIGURE 21. Piezometric surface and longitudinal cross section of Sunnyside Hill slide, Calgary

portion of the section as it is discharged laterally through sand lenses in the upper silt. Wet zones at one or more places at the face of the slide show where these sand lenses intersect the surface (Fig. 19). These springs issuing along the sand outcrops freeze during the winter, causing an excess hydrostatic pressure in the sand body behind the frozen surface. Furthermore, frost action tends to deteriorate the slope material, causing a decrease in cohesion which in turn leads to a decrease in shearing resistance (equation 7).

In summary, it can be said that groundwater contributes to the landslides at Sunnyside Hill in three ways:

1. Rapid increase in piezometric head due to increasing recharge during spring and early summer
2. Increase in pore pressure in isolated sand lenses during periods of frost (upper lenses)
3. Deterioration of slope material due to frost action.

It is interesting to note that the amount of freely moving water involved in the Sunnyside slides is relatively small. Pump-test data indicate that the average transmissibility upgradient from the 3,490-foot piezometric contour is about 30 gpd/ft. The average gradient toward this contour-line is 0.083 (1 foot per 12 feet), and the length of the intake area along the 3,490-foot contour is 4,100 feet. The total daily groundwater flow across this contour has been calculated from the Darcy equation and is approximately 9,200 gallons per day, or about 12 acre-feet per year.

The map of the piezometric surface (Fig. 21) shows that the slide area is separated from adjacent areas to the northwest by a pronounced groundwater divide. It is evident from the topographic map (contour interval 10 feet) that this groundwater divide coincides with a surface divide, and the entire groundwater basin that is feeding the slide area could thus be outlined on the topographic map. This basin comprises 307 acres, which indicates that the total annual groundwater discharge toward the slide area amounts to about 0.32 inches over this drainage basin. This value agrees very well with the amount of groundwater contributing to contact springs, as has been calculated from the baseflow analysis (p. 47). Although the quantity of water that contributes to the slides is small, it is dispersed over such a relatively large area that effective remedial drainage will present serious technical problems.*

The slides are also the source of further concern. After slope failure has taken place, the clay turns into a thick slurry, partly because of the destruction of the clay molecules which caused adsorbed water to be released and partly because of the presence of free water that is discharged from the outcropping sand lenses. By these processes the slide material is transformed into a mudflow which is equally dangerous to the houses at the foot of the hill as are the slides to the houses along the crest of the hill. On July 25, 1960,

*During the preparation of this report Sunnyside Hill slide was reported to be drained effectively by horizontal drains.

the Calgary Herald reported with respect to one of the houses at the foot of the slide: "Since April a 10-foot high mound has completely covered one section of their back yard with rocks, mud and fallen trees. Where a family once enjoyed evening get-togethers around their outdoor bar-b-que, now stands a huge pile of mud and rocks extending to and surrounding the garage", which is a vivid description of an active mudflow.

This combination of slide and mudflow has also been observed along the C.P.R. tracks west of Calgary in the vicinity of Brickburn. Here the slide consists of bedrock material, and springs issue along the contact of a 5-foot sandstone bed underlain by shale. Rises in the hydrostatic pressure in the Paskapoo sandstone lenses as well as frost deterioration at the face of the outcrop are possible causes of the slide. The tongue of the slide has been transformed into an active mudflow that is gradually approaching the railroad tracks. Water that is discharged from the springs forms a system of little brooks and ponds on the surface of the mudflow which, as a result, is barely accessible.

Virtually every place along the Bow River where the steep valley walls are composed of relatively impermeable material is a potential slide area. In places where the river is engaged in active undercutting of the slope the danger may be greater than elsewhere, but the nature of the bulk of the glacial deposits as well as that of the bedrock sediments is such that a sudden rise in the piezometric surface cannot be responded to by a quick drainage, and the shearing resistance of the valley walls decreases accordingly every year during spring and early summer.

Creep

The term "creep" refers to the displacement of a mass of rock or soil, but the rate of movement of creep is imperceptible as compared to that of a landslide. In Calgary, creep manifests itself at various places of which a few busy streets and intersections are the most conspicuous. A striking example of this slow down-hill movement of a sheet of earth is near the intersection of 50th Avenue Southwest and the MacLeod Trail (Fig. 22) where the pavement is in need of more or less continuous repair.

Test drilling at this location showed the presence of 2 to 10 feet of fill overlying silty sand and clay (Fig. 22). The piezometric surface of this area shows that the direction of groundwater movement is toward MacLeod Trail. The main reason for road-creep is the zone of low shearing resistance on the contact between the fill and the underlying silt in the lower portion of the creep. As long as the fill is saturated with moving water, the resistance of this contact to the stresses exerted by traffic and pavement is insufficient to maintain a stable condition, and the fill moves continuously downward, causing the observed effect.

Figure 22 illustrates why the situation at the lower part of the hill is worse than above test hole No. 8. The fill in the upper part of the hill is still

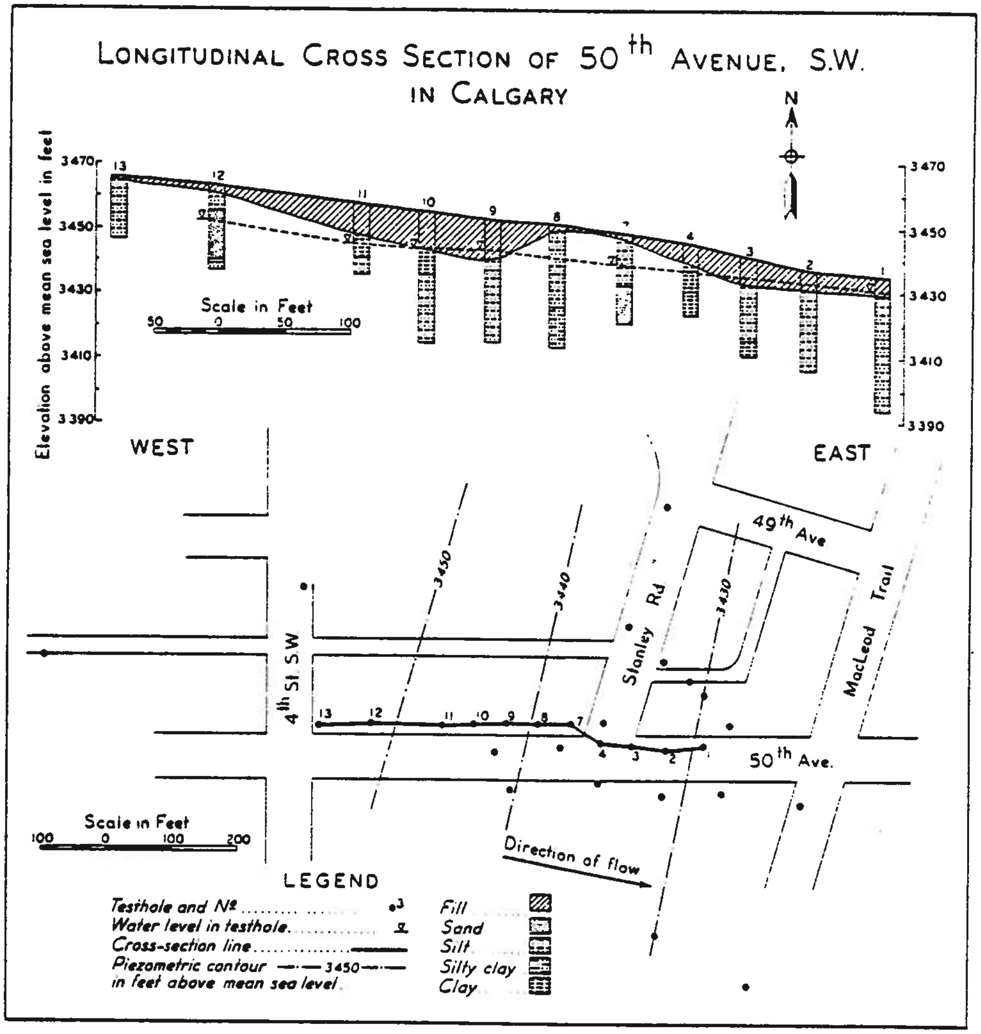


FIGURE 22. Piezometric surface and cross section of 50th Avenue Southwest and MacLeod Trail, Calgary

slightly supported by a knob in the drift surface. The effect of this knob is that slope failures in the upper portion of the hill are confined to shear planes within the fill, where slope failures in the lower portion of the hill take place at the fill-drift contact which has a much lower shearing resistance than the fill itself. This condition is probably the cause of road creeps at various other locations in the city as well, and remedial measures should be directed toward better drainage of the material underlying the creep as well as settling of the fill.

Inundated Basements

Some subdivisions of the City of Calgary are characterized by a high water table and during spring many basements in these districts become inundated. The annual fluctuations of the water table were obviously unknown during the time of construction of the houses, or the construction period coincided with a period of a minimum water table elevation. It is known from the literature that long-term climatologic fluctuations similar to those shown in figure 2 cause comparable fluctuations in the water table elevation and the inference may be drawn from figure 2 that the water table in the Calgary area reached a maximum height during 1956 or shortly thereafter.

Automatic water-stage recorders which were placed at strategic locations within the trouble areas during 1960 indicated that the annual water level fluctuation is nearly 6 feet, which is considered to be a normal fluctuation in a shallow drift-aquifer in Alberta. Water table elevations reach a maximum during April or May and drop steadily throughout the summer and autumn to a minimum level during January or February. Superimposed on these annual fluctuations are long-term fluctuations of unknown magnitude. If the downward trend in annual precipitation, suggested by the data in figure 2, were to continue for some years to come, the groundwater level would be lower in successive years and the maximum peak occurring in April might eventually be even as low as 10 feet below the surface in areas now characterized by basement inundation. On the other hand, a succession of years with above-average precipitation might cause the water table to rise and the maximum yearly elevation might even be above ground surface in some locations, creating sloughs and marshes.

CONCLUSIONS

C. S. Conover, in an address to the Western Resources Conference in Boulder, Colorado, in 1961, stressed the importance of integrated development of surface water and groundwater, based on the reasoning that this kind of development will be most suitable to supply large quantities of water on a perennial basis in the semiarid Western United States. Summarizing his speech, Conover stated: "Optimum development and integrated management of groundwater singly and in conjunction with surface waters promises to solve perplexing water problems of the West. But the solution will neither be easy nor inexpensive. The public as well as those responsible for water resources development and management must be informed and convinced of the need and value of such measures."

The same plea could be made for Western Canada and areas where such an integrated development of groundwater and surface water is possible can be considered to be in a favorable economic position. The results of the present study indicate that the Calgary district certainly belongs to this category, for the relation between the gravel aquifers and surface water in this area is ideally suited for a maximum integration of both resources. The gravel aquifers can yield large quantities of water and are considered to be suitable for industrial or municipal development. The bedrock aquifers, on the other hand, cannot be considered as dependable sources of domestic groundwater supplies in areas where the population density exceeds 150 inhabitants per square mile, and the Paskapoo formation does not lend itself to an integrated development with surface water.

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RESEARCH COUNCIL OF ALBERTA

LEGEND

EXPLANATION

This map is an interpretation of all hydrogeological information that was available in 1960. It does not wholly alleviate the need for detailed investigations concerning the amount and nature of locally available groundwater.

I LITHOLOGY OF STREAM-CHANNEL DEPOSITS

The majority of the shallow aquifers consists of stream-channel deposits which are not covered by glacial sediments. The infiltration capacity of these aquifers is good to very good and recharge takes place both vertically and laterally from nearby streams.

- Coarse gravel.
- Medium to fine gravel.
- Medium to fine gravel, commonly intercalated with sand and silt. (In some cases so-called "buried-channel" deposits).
- Sand, commonly with gravel, silt or clay.

II INFILTRATION CAPACITY OF SURFICIAL DEPOSITS

The surficial deposits of the map area are of glacial and fluvioglacial origin and do not serve as substantial aquifers. They overlie the interbedded sandstone and shale layers of the Paskapoo formation and recharge to the bedrock is governed by the infiltration capacity of the surficial deposits. Symbols of infiltration capacities have been superimposed on the pattern of groundwater probability.

- Outwash deposits, consisting of sand and gravel. Infiltration capacity good to very good.
- Moraine, consisting of sandy and gravelly till, containing less than 20% montmorillonite. Infiltration capacity good to fair.
- a. Moraine, consisting of sandy and silty till, containing 20-40% montmorillonite.
  b. Lacustrine and aeolian deposits, consisting of sand, silt, clay.
  c. Outwash deposits, consisting of sand and silt. Infiltration capacity fair to poor.
- Moraine, consisting of silty and clayey till, containing more than 40% montmorillonite. Infiltration capacity poor to very poor.
- Surficial deposits of unknown composition, infiltration capacity unknown.

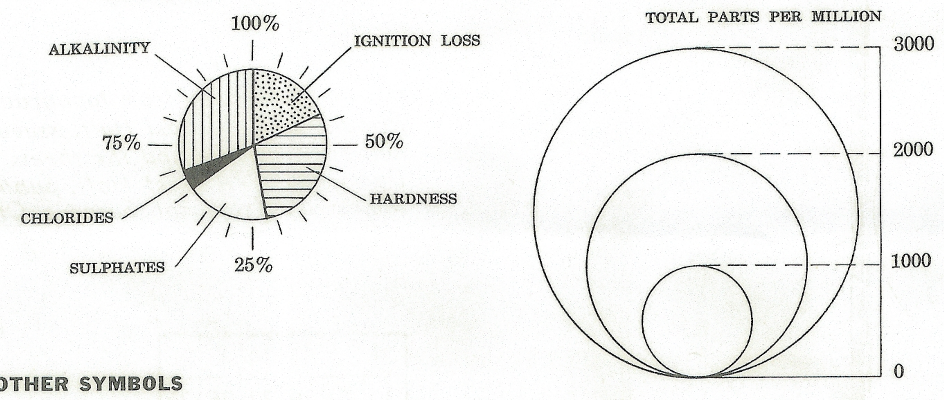
III GROUNDWATER PROBABILITY

The following quantities are expected to be obtainable from one vertical well which is constructed and developed according to the usual water-well standards.

- 250-750 imperial gallons per minute (gpm) and more, obtainable from a few suitable locations in alluvium along the Bow River. Present and potential source of industrial and municipal supplies.
- 100-250 gpm, obtainable from typical alluvium in the vicinity of the major streams. Present and potential source of industrial supplies.
- 50-100 gpm, obtainable from buried-channel deposits and the margins of alluvial deposits along the major streams.
- 5-50 gpm, obtainable from outwash deposits, sandy, stream-channel deposits and alluvium along the minor streams.
- 1-5 gpm, obtainable from sandstone layers in the Paskapoo formation. Main source of domestic supplies throughout the area.
- Less than 1 gpm, obtainable in topographically high areas, from sandstone layers in the Paskapoo formation. Source of limited domestic supplies where no other source available.
- Highly variable yield.
- Area where groundwater can be obtained at a rate of 1-5 gpm from sandstone layers in the bedrock, but where surficial deposits may yield 5-50 gpm with artificial recharge.
- Area where groundwater has not been utilized, but where surficial deposits may yield 100-250 gpm with artificial recharge.
- Area where groundwater has not been utilized, but where surficial deposits may yield 5-50 gpm with artificial recharge.

IV GROUNDWATER COMPOSITION

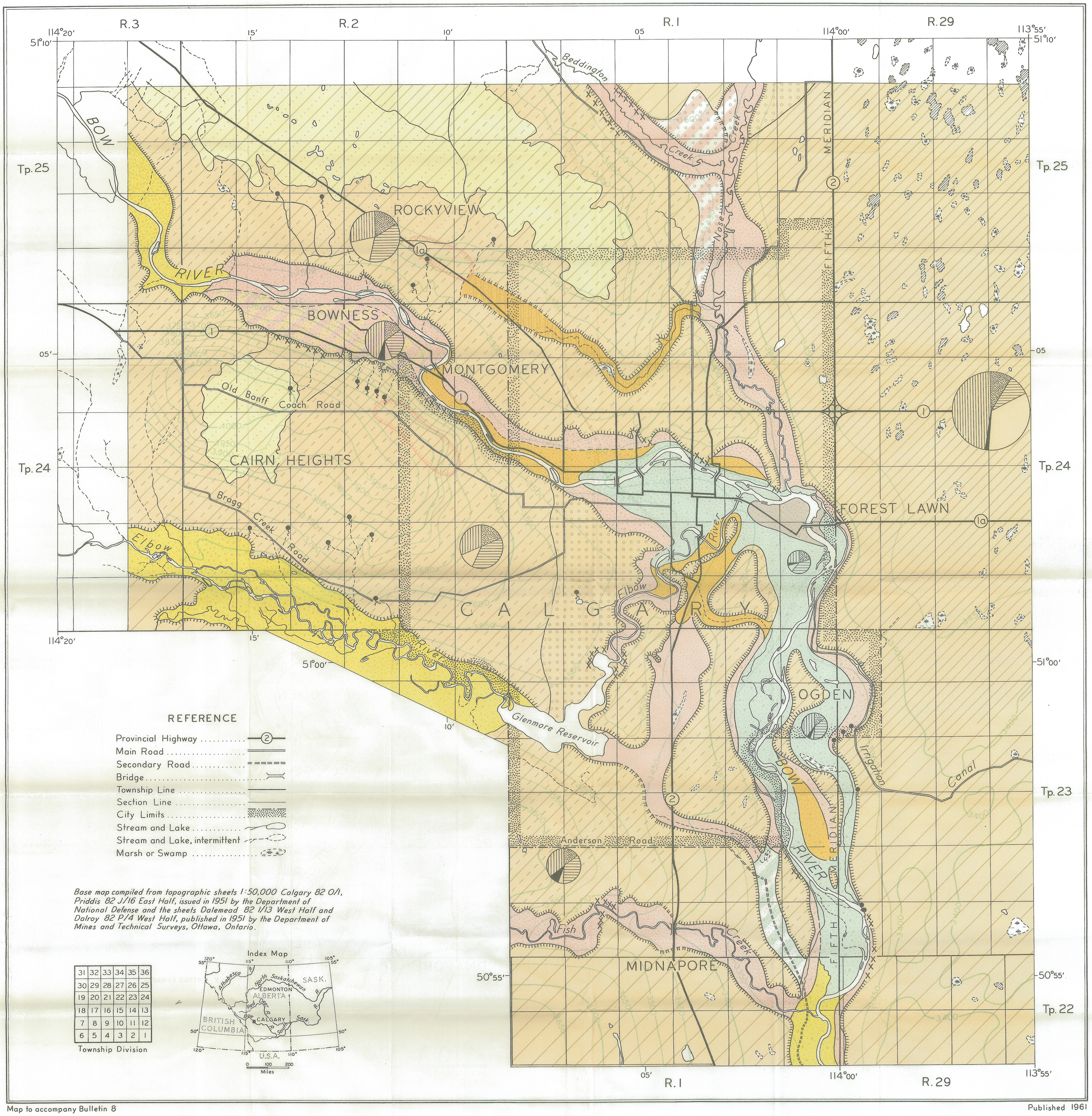
The groundwater composition is presented in the form of pie diagrams which indicate the amount of total dissolved solids. The segments of the circles show the percentage composition of individual constituents.



V OTHER SYMBOLS

- Area of active groundwater depletion
- Piezometric contour of Paskapoo formation, showing the expected static water-level in feet above mean sea level, in a well having a depth of approximately 125 feet. Contour interval 50 feet (3800)
- Lithologic boundary and probability boundary (known, uncertain)
- Edge of river valley (known, uncertain)
- Contact spring
- Bedrock outcrop

Groundwater geology by P. MEYBOOM, 1960-1961
Glacial geology after J. C. Tharin, (1960)



Map to accompany Bulletin 8

Published 1961

PLATE I

GROUNDWATER MAP OF THE CALGARY DISTRICT, ALBERTA

Scale 1 : 50,000

1 ½ 0 1 2 3 Miles

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