Do Not Sale!

BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES

Volume 20, Part 1 — January 1973

CONTENTS

Brigham Young University Geology Studies

Volume 20, Part 1 — January, 1973

Contents

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Editor

Jess R. Bushman

Brigham Young University Geology Studies is published semiannually by the department. *Geology Studies* consists of graduate student and staff research in the department and occasional papers from other contributors.

Distributed January 31, 1973

Price $4.50

Groundwater Investigation, Peace-Athabasca Delta

GRANT NIELSEN

Geology Branch,
Earth Sciences & Licencing Division;
Alberta Department of the Environment, Edmonton, Canada

ABSTRACT.—The Peace-Athabasca Delta Project was set up to investigate the effects of the W.A.C. Bennett Dam upon the ecology of the highly complex inland delta formed at the junction of the Peace and Athabasca rivers. The author was asked to investigate the groundwater regime of the delta and to evaluate the changes in groundwater movement due to the dam.

Lower levels of surface waters and the absence of floods since 1968 have caused the water table to drop in certain areas. As a result, low willow/shrub is invading and replacing meadows, and high willow vegetation is invading low willow/shrub areas. The highest parts of modern levees are dominated by spruce and aspen which prefer a deep water table and are not affected by the changes brought about by the dam.

No subsurface water transfer occurs between Peace River and Lake Claire and limited transfer of water takes place between lakes through the levees to the adjoining channels. The recharge rate and water-table configuration are directly related to the relative geological age and degree of compaction of the deposits in the several subdeltas.

CONTENTS

INTRODUCTION

At the junction of the Peace and Athabasca rivers in northeastern Alberta, a highly complex inland delta has formed. This delta being on the four major flyways of migratory birds for all North America, has prolific production of aquatic fowl. It also contains the world's largest concentration of bison and has produced valuable crops of commercial fish and furs.

Starting in 1967, however, all of this was threatened when the W.A.C. Bennett Dam in British Columbia was completed on the Peace River. Subsequent filling of the reservoir prevented the annual floods that had both filled the innumerable lakes within the delta and provided nutrients to the vegetation around them. Many lakes dried up, and levels dropped in others, threatening wildfowl, fish, and beaver populations. And vegetation patterns began to change, destroying the food supply of bison and moose.

For these reasons, a joint intergovernmental organization, the Peace-Athabasca Delta Project, was set up to investigate the problem, and to recommend remedial action. This author was asked to investigate the groundwater regime of the delta to determine—

1. whether fluctuations in the surface-water stage are related to corresponding fluctuations of the water table
2. whether artificially raising levels in the major lakes (i.e., Lake Athabasca, Lake Claire, Mamawi Lake) and rivers would also raise the levels of smaller adjacent lakes through groundwater transfer
3. the relationship between plant communities and water-table depth in the Delta, and the changes in plant distribution caused by changes in groundwater depth.

The study area (Text-fig. 1) is at 59 degrees north latitude, in the northeastern corner of Alberta. Relief is less than 20 feet, except on gneissic outcrops of the Canadian Shield in the eastern and northeastern parts of the delta. Except in the gneissic areas, relief is produced by levee and channel formation and by the subsequent meandering of the main distributaries. Much of the area is wooded, but there are large open meadows, adjacent to the main lakes, that support bison herds. The area of the delta is about 1,600 square miles.

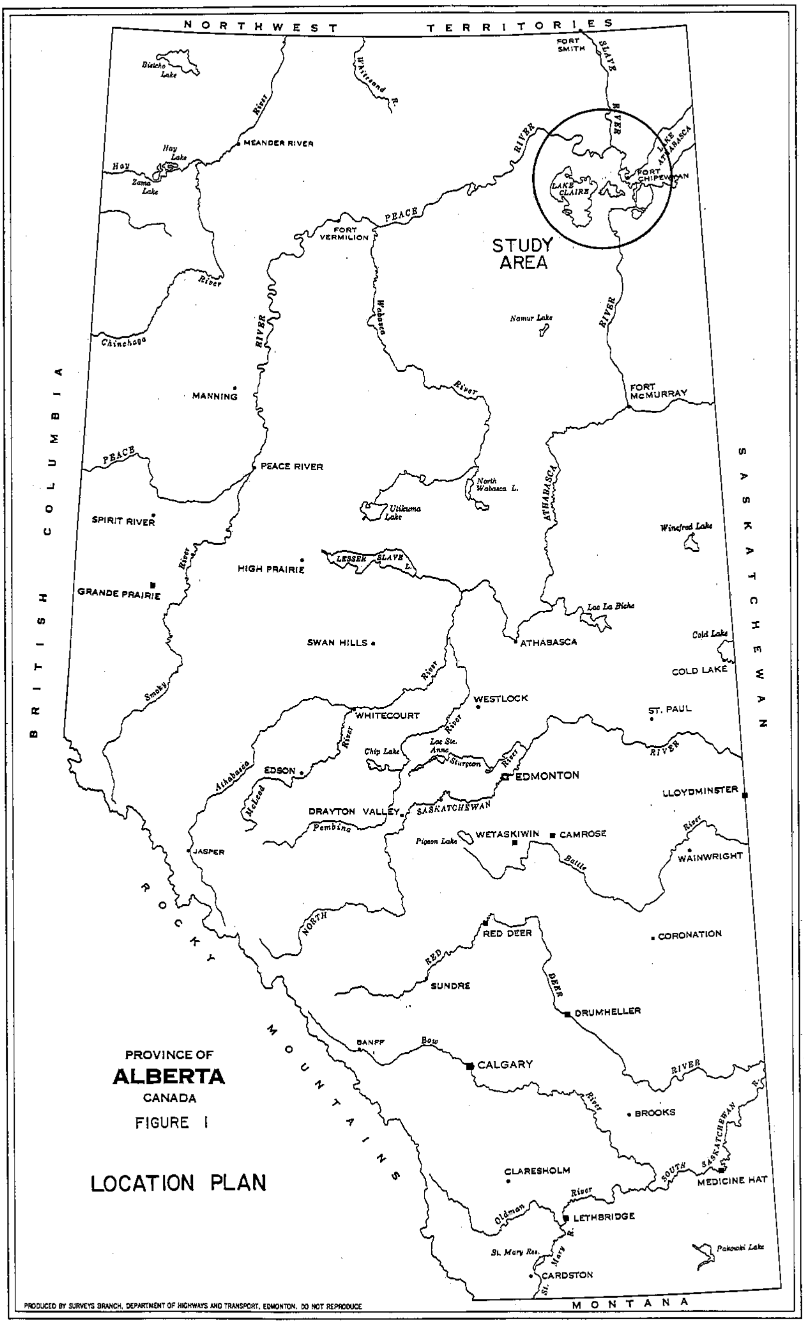
Access is difficult, except by boat or air. No all-weather road connects Fort Chipewyan, the base of operations, with the outside world. Exploration is therefore done mainly by helicopter and is costly. A few roads are used in winter when the ground is frozen, but harsh winter weather renders outside work virtually impossible.

To implement this study, 21 shallow water-table wells were installed in 7 strategic profiles. In addition, information from 10 other wells was made available by Canadian Wildlife Service. All were 10 feet or less in depth, and all were constructed of four-inch-diameter slotted plastic pipe. The profiles were assigned letters A to G for identification purposes, except the one installed by Canadian Wildlife Service, which was labelled "Transect 4." Elevations of the wells were surveyed, and water levels were measured from early August until freeze-up in late October 1971. Water temperatures were measured twice in 17 wells, and water samples were taken from selected wells for analysis.

In addition, six deep test holes, numbered H-1 to H-6, were drilled near Lake Claire to explore for a suspected preglacial valley that might have a profound influence on the groundwater regime of the Delta. All wells and test holes are shown on Plate 1.

ACKNOWLEDGMENTS

The author is deeply indebted to William Walton, University of Minnesota, who formulated the problem and suggested the program for its inves-



TEXT-FIGURE 1.—Location plan.

tigation. The work of Bayrock and Root, of the Research Council of Alberta, was invaluable in providing the hydrogeological framework. This report could not have been written without the efforts of the several engineers and technicians who installed and read the observation wells, often in trying circumstances. Becker Drilling, of Calgary, carried out the March 1972 drilling program. Their unique equipment obtained information which could have been obtained by no other means. Dr. Herman Dirschl, of the Canadian Wildlife Service, kindly provided from his Transect 4 information that was invaluable in estimating groundwater recharge. William Walton, Doug Hornby, and L.D.M. Sadler critically reviewed the manuscript.

PREVIOUS INVESTIGATIONS

The bedrock geology of the western edges of the Canadian Shield and of the adjacent Devonian carbonate sequence have been the subject of many investigations, starting with those of Macoun in 1877. Such studies are continuing today, particularly at the Research Council of Alberta, to decipher the complex Devonian stratigraphy of the area. Although no previous groundwater research has been done within the Delta, R. Green, of the Research Council of Alberta, has noted hydrogeological phenomena such as karst topography and saline springs in adjacent areas.

Bayrock and Root (1972), of the Research Council of Alberta, have mapped surficial geology and have interpreted the Quaternary history of the Delta area. Novakowski (1967) installed five water-table wells at various locations, but only one reading was taken at each site.

HYDROGEOLOGY

Bedrock Formations

Precambrian plutonic rocks. These rocks of the Canadian Shield are exposed in numerous small hills in the northeastern part of the Delta. The relief of the Shield in adjacent areas is in the order of 200 feet, so it seems probable that similar relief is also present within the eastern part of the Delta (Bayrock and Root, 1972). Except for some permeability along fault or breccia zones, these rocks can be considered a virtually impermeable base for all groundwater movement.

Athabasca Formation. The Athabasca Formation, being of Precambrian age, does not outcrop but is suspected to underlie at least a part of the Chipewyan Indian Reserve. It consists of white, grey, and red, medium- to coarse-grained sandstone, flat lying to strongly cross-bedded (Green, 1970). Permeability is highly variable, some areas being tightly cemented and others completely uncemented.

This formation is buried below an estimated 100 to 200 feet of deltaic sediments and therefore probably takes little active part in the groundwater movement of the Delta itself.

Devonian Formations. The Devonian sequence of this area consists mainly of sedimentary carbonates and evaporites. Outcrops in the Peace Point area to the west and those to the south of the Birch River Delta are mainly gypsum. The author also examined a previously unreported gypsum outcrop at Spruce Point. Limestone is abundant in drift of the same area. Green (1971) has mapped many karst features to both the north and the south of the Delta. And saline springs, rivers, and flowing wells are well known, for several hundred miles, to both the north and the south of the Delta. Thus, Devonian groundwater may be highly saline and, by inference from adjacent areas, may discharge in sizeable volumes. Evidence of its influence in the study area will be shown later.

Surficial Deposits

Preglacial alluvium. Virtually no information, except that inferred from surface features, was available on subsurface hydrogeology of the delta before this investigation. Studies in adjacent regions, however, had revealed that several preglacial alluvial valleys were present somewhere in the area. Because preglacial alluvial aquifers typically are highly permeable, their depth and distribution were considered important to the groundwater regime in the Delta. Therefore, a deep-drilling program was undertaken to verify this information; and six deep test holes, numbered H-1 to H-6, were drilled near Lake Claire in March, 1972. Results of the drilling program, supplemented by interpretation of geologic and topographic maps, have shown that preglacial alluvium occupies channels distributed approximately as shown in Plate 1. Table 1 lists the logs of the six test holes and of one hole drilled in 1958. The test holes revealed that these sediments are of limited importance to surface groundwater behavior because they are buried below 89 to 240 feet of glacio-lacustrine sediments. Permafrost is also present in some areas. Moreover, glaciation has overdeepened the channels and has removed alluvium locally (Bayrock and Root, 1972).

Till. Thin till was present in test holes H-1, H-3, and H-4. It was reddish and sandy, and it contained numerous gypsum pebbles and lesser quantities of limestone and gneissic pebbles. The till is likely of intermediate permeability between that of the preglacial alluvium and that of the overlying glacio-lacustrine sediments.

Glacio-lacustrine Sediments. The March 1972 drilling showed that the bulk of postbedrock deposition in the Delta consists of very fine glacio-lacustrine sediments, presumably deposited during and immediately after glacial retreat from the area. These sediments are 300 feet thick or more. Analyses of samples from test hole H-6 show (Table 2) that these deposits are almost entirely in the silt-clay-size range. Todd (1959, p. 53) places their permeability (Ks) in the range of 10^{-1} to 10^{-3} gal./day/ft.^{2}.

Deltaic Sediments. Deltaic deposits represent a relatively thin veneer above the glacio-lacustrine materials in most of the Delta. West and immediately north of Lake Claire such deposits are predominantly sandy and are about 10 to 25 feet thick. At Sweetgrass Landing, however, the 1972 drilling showed a thickness of 76 feet. In this area, deltaic sand is coarse to very coarse at the base and decreases to very fine and silty at the present land surface. Mechanical analyses of samples from test hole H-6 (Table 2) indicate that the deeper sediments were deposited in quiet conditions. More turbulent conditions prevailed during deposition of the top 120 feet of sediment, as evidenced by the lower clay and higher sand contents.

Modern and recent deposition in the Athabasca part of the Delta consists of somewhat finer material (Table 3), as determined by mechanical analyses of the E and F profile samples. Permeabilities (Ks) in this material are in the order of 10^{-1} to 10 (Todd, 1959, p. 53).

TABLE 1

Deep test hole logs, Peace-Athabasca Delta
(Abbreviations used are standard geological symbols)

H-1: SE-6-113-14- W.4. Elev. 686 ft. 12 March 1972

0 - 16	clay, lt brn-gy, sl calc, sft, slty
16 - 32	clay, lt brn-gy, sl calc, v sft, slty
32 - 56	clay, lt gy, calc, v sft, slty
56 - 88	clay, lt gy, calc, sft, slty
88 - 140	clay, lt gy, sl mica (or selenite?), v sft, calc, sdy
140 - 141	sand
141 - 145	clay, lt gy, v sft, calc, sl sdy
145 - 145.5	till, granite bldr
145.5 - 156	till, red, sdy, wht gypsum pbls
156 - 170	sand, qtz, rd-sb rd, v f, poor stg, red clay, pbls, sl calc

Installed 2-inch-diameter observation well at 159 ft., with pressure gauge at top. Flowing.

H-2: SE-4-112-15- W.4. Elev. 686 ft. 13 March 1972

0 - 6	muskeg, blk, sft
6 - 16	clay, lt gy-brn, firm, calc, slty
24 - 32	clay, dk gy-brn, firm, calc, slty
32 - 40	clay, lt gy, v sft, slty
40 - 43	sand, s & p, v f, slty, calc, mica
43 - 89	clay, lt gy, v sft, calc, slty, few pink ptgs
89 - 90	sand, grav, pink clay, sd is clear qtz, f-m, sb ang; pbls are gyps, wht; cht, blk; ls, brn. permafrost at 89, -5°C.

H-3: SE-4-111-15- W.4. Elev. 686 ft. 14 March 1972

0 - 8	clay, sdy, m gy, sft, calc, slty	-
8 - 16	clay, lt brn-gy, sft, calc, slty	4.0°C
16 - 64	clay, lt gy, v sft, sl calc, slty	3.3° - 4.6°
64 - 80	clay, lt gy, sft, sl calc, slty	3.5° - 4.0°
80 - 88	clay, lt gy, v sft, sl calc, slty	3.5°
88 - 96	clay, lt gy-brn, v sft, sl calc, slty	4.0°
96 - 105	clay, gy, sl sdy, sft, calc, slty	4.1°
105 - 112	till, red, v sdy, m-c, ang-sb ang, clear gyps pbls	4.0°
112	gypsum, bedded, wht-clear, c xtalline	-

H-4: NE-7-110-14- W.4. Elev. 686 ft. 14 March 1972

0 - 8	till, gyps, ls, gran cobbles
8 - 11	gypsum, wht, sft, weathered, bedded
11	gypsum, lt bf, bedded

H-5; SW-26-114-12- W.4. Elev. 705 ft. 15 March 1972

0 - 8	sand, wood frag	-
8 - 16	sand, silt, v f, s & p	-1.0°C
16 - 24	sand, f-m, s & p, ang-sb ang, clear - yel qtz	-1.5°
24 - 32	sand, m-vc, s & p, ang-sb ang, clear - yel qtz	-1.0°
32 - 40	sand, m-vc, s & p, ang-sb ang, clear - yel qtz, few ls frag	-0.5°
40 - 48	sand, as above, dark organic debris	-1.0°
48 - 54	sand, m-c, s & p, ang-sb ang, clear-yel qtz, sl calc., end of permafrost	-1.0°
54 - 76	sand, c-vc, s & p, ang-sb ang, clear - lt yel qtz, sl calc	+1.5-9.8°
76 - 112	clay, lt gy, sticky, sft, sl calc, slty	0.5-0.7°
112 - 128	clay, lt gy, sticky, sft, sl calc, slty, pink ptgs	0.9°
128 - 152	clay, m gy, sticky, v sft, slty	0.9-1.6°
152 - 208	clay, lt pink-gy, sticky, sft, sl calc, slty	1.5-1.6°
208 - 232	clay, m pink-gy, sticky, sft, sdy	-
232 - 240	clay, m gy, sticky, harder, sdy	-
240 - 243	pea grav and sd, gneissic, purple qtz, wht qtzite, brn ls.	-
243	bedrock? too hard to collect smpl.	

Table 1 (Continued)

H-6; SW-28-113-13- W.4. Elev. 690 ft. 16 March 1972

0 - 6	muskeg, blk, sft	-
6 - 8	silt, dk gy, sticky, sft, sl org	+3.0°C
8 - 16	silt, lt gy, sl sdy, sft, sticky, sl calc	3.9°
16 - 24	silt, buff, rusty stks, sticky, sft, calc	3. 4°
24 - 56	clay, lt gy, sticky, v sft, sl calc	3.3-3.4°
56 - 80	clay, lt gy, sticky, v sft, sl calc, pink ptgs	3.2-3.5°
80 - 96	clay, lt gy, sticky, v sft, sl calc	3.8°
96 - 120	clay, lt gy, sticky, sft, calc, slty	3.7-3.9°
120 - 200	clay, lt gy, sticky, sft ,calc, slty, pink ptgs	3.5-4.6°
200 - 227	clay, m gy, sdy, sft, calc, pink ptgs	4.6-4.9°
227 - 232	clay stones, brick red, abnd frag gyps, v hd	4.8°

Test hole; NW-29-113-12- W.4. Elev. 690 ft. July 1958

0 - 25	fine sand
25 - 391	soft silty clay
391 - 392	granite boulders
392 - 394	red clay
394 - 400	soft clay (shale?)

TABLE 2
Mechanical Analyses of Samples, Test Hole H-6

Depth (ft.)	Sand (%)	Silt (%)	Clay (%)
24	6	45	49
40	8	62	30
64	3	49	48
80	2	73	25
104	2	58	40
120	4	65	31
136	0	45	55
168	0	45	55
184	0	24	76
192	0	4	96
216	5	34	61

TABLE 3
Mechanical Analyses of Samples, Profiles E and F

	E-1			E-2			E-3		
Depth (ft.)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
2	20	68	12	5	77	18	3	74	23
4	13	70	17	19	66	15	3	66	31
6	8	71	21	7	73	20	3	63	34
8	7	71	22	3	74	23	5	75	20
10	5	69	26	5	71	24	3	74	23

	F-1			F-2		
Depth (ft.)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
2	10	73	17	6	65	29
4	8	71	21	0	57	43
6	8	68	24	4	54	42
8	4	69	27	9	63	28
10	6	72	22	41	35	24

GROUNDWATER REGIME

Permafrost

The Peace-Athabasca Delta is climatically within the zone of discontinuous permafrost as defined by R.J.E. Brown (1967). Brown defines permafrost as "the thermal condition of earth materials such as soil and rock when their temperature remains below 32°F continuously for a number of years." Its presence has been verified for the first time at several locations in the Delta. In September 1971 permafrost was encountered in test hole G-3 at 3.5 feet. This occurrence may be continuous with the permafrost occurring between 10 and 54 feet at Sweetgrass Landing (test hole H-5), as discovered in the March 1972 drilling. In test hole H-5 frozen ground was at a temperature of -1°C. Operators of the sawmill at Sweetgrass reported the presence of permafrost for several miles along the banks of the Peace River.

Test-hole H-2 encountered permafrost at 89 feet, where the temperature was -5°C. Hard drilling in H-1 at 170 feet may also have been permafrost, but this remains unverified. Dr. H. Dirschl, Canadian Wildlife Service (pers. comm.) encountered frost lenses in August 1971 while drilling observation wells in Transect 4. These may also have been permanently frozen.

Conditions favoring permafrost include a heavy vegetative cover to insulate the ground from solar radiation. This cover is present in Transect 4 and was so at Sweetgrass Landing until about 1958, when logging operations began. A northerly aspect at Sweetgrass would also favor permafrost presence.

Permafrost at depth, in hole H-2 and suspected in H-1 is not in equilibrium with the present climate but is a relic from Pleistocene time. Preglacial alluvium at the base of test hole H-5 was not frozen. However, the water contained therein was saline and could have been below 32°F. Its presence in sand and gravel at the several sites investigated suggests that it might be widespread in coarse materials elsewhere in the Delta. None was observed in the glacio-lacustrine silty clay zones, however.

Nature of Flow Systems

The distribution of flow systems is determined partly by the topography of the water table, which creates the head, or driving force, to move groundwater, and partly by the geology, which tends to concentrate flow lines along more permeable strata. Climate and geology jointly determine the volumes of water available for groundwater movement.

In humid regions such as this, the water table is a close approximation of surface topography. Thus, except where modified by geology, groundwater moves normal to the contour from topographically high to low areas.

Regional groundwater systems in this region recharge in the Caribou Mountains to the northwest and in the Birch Mountains southwest of the Delta. Groundwater moves radially down-gradient from these two highs, having a head of at least 2,000 feet. The discharge end of these systems is at Lake Claire and the lower Peace River. Despite the size and head of these two major regional systems, the quantity of groundwater involved is small because practically the entire geologic section from the bed of the Peace River to the top of the two major highs consists of soft marine shale having an extremely low permeability. The bulk of regional groundwater discharge is into the preglacial Shaftsbury Valley (Tokarsky, 1966). That this valley is indeed a discharge feature in the Delta area is confirmed by an observation well installed at H-1: the well was bottomed in preglacial sand at 159 feet, and a pressure gauge installed at the top of the casing showed a head of 16 feet above ground level. The Embarras and Chipewyan Valleys may also be discharge features, but this has not been verified.

Potentially widespread relic permafrost conditions and glacial removal of buried channel alluvium would somewhat restrict the effect of regional flow systems on the Delta. In any case, up to 200 to 300 feet of impermeable glaciolacustrine silty clay covering such alluvium limits the effect of regional flow systems upon local groundwater regime at the land surface.

Because maximum relief in the Delta itself is in the order of 10 feet, no intermediate flow systems exist; but a vast number of local systems are present.

Twenty-seven water-table wells were installed in seven profiles late in July 1971 to study the local groundwater regime of representative sites. Three profiles were chosen at, and adjacent to, Mamawi Lake for evaluating the amount of subsurface flow between large and small lakes when relative water levels are altered. Three more were installed across levees between modern channels and backswamp lakes to evaluate groundwater transfer when levels change in such channels. Transect 4, south of Mamawi Lake, was installed by the Canadian Wildlife Service for its studies. Water levels were read in all the wells and in the adjacent channels and lakes from early August 1971 until freeze-up.

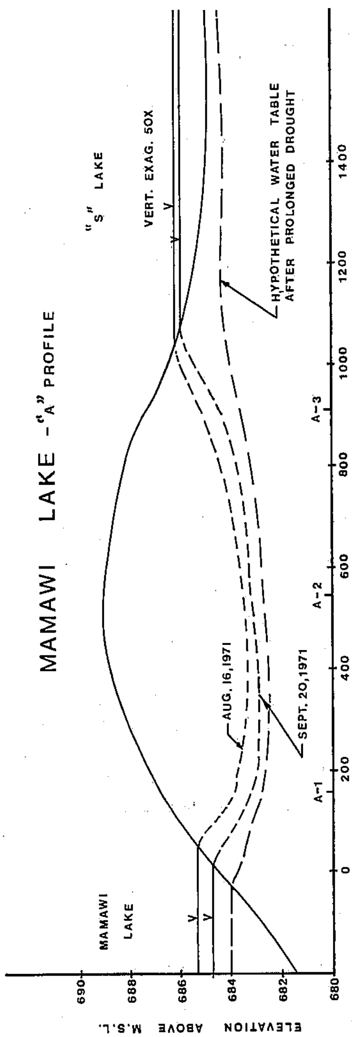
Another four wells (Profile G) were drilled in September 1971 between Lake Claire and Peace River to determine whether subsurface flow occurs between them.

Text-figure 2 shows two groundwater profiles, representative of Profiles A, B, and C, and of Profiles D, E, and F, respectively. Water-table configurations at times of shallowest and of deepest groundwater depths have been plotted. The water table in Profile A is lower everywhere than surface water but only six feet below ground level at the lowest point. Were the water not used by vegetation, this profile would be a groundwater "mound" rather than a depression. Its configuration is a result of water removal by willows at a rate exceeding the rate of infiltration by rainwater.

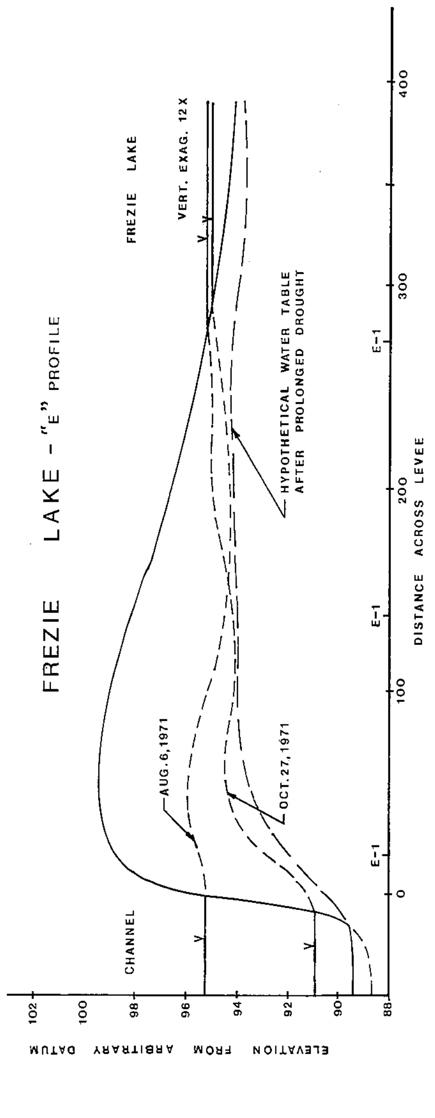
Six sets of water-level readings were taken in Profiles A, B, and C. In all but one set of readings, the water table was lower everywhere than the surface water level at both ends of the profile. The one exception was in Profile C on 4 August 1971, when the water table formed a gradient from "P" Lake down to "S" Lake, a drop of 1.7 feet. Therefore, no subsurface transfer of water takes place from one lake to another in this area, despite differences of several feet in head between lakes.

Profiles D, E, and F were more variable. The early readings, in August 1971, indicated a groundwater mound under the highest part of each levee. In September and October, surface levels in the channels dropped, precipitation was low, and a water table gradient formed from the lake toward the channel in all three profiles. Difference in head gradually increased to slightly over four feet. In Profile E the water table actually rose slightly between well E-2 and Frezie Lake, due to the cessation of water consumption by plants at the end of the growing season.

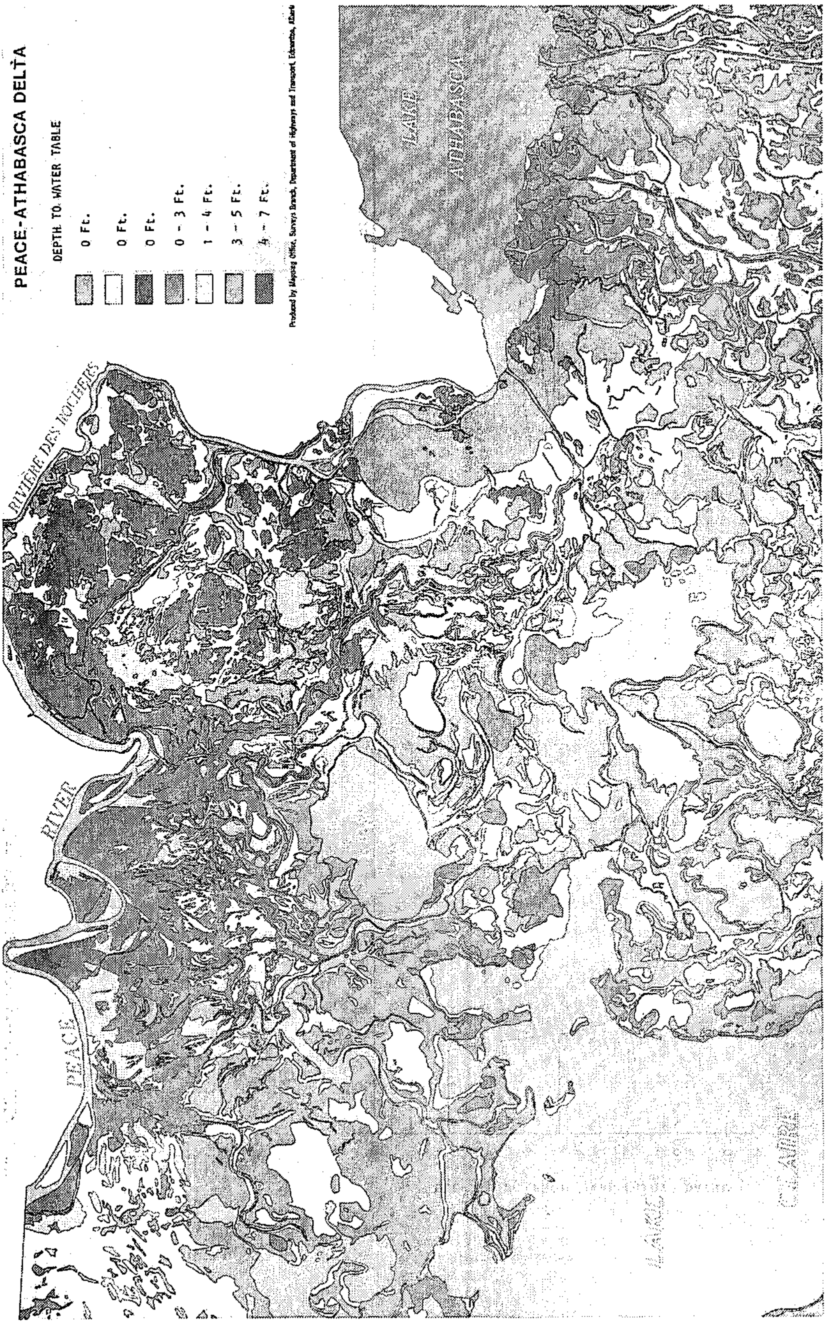
The August readings suggest that groundwater flow at that time was primarily a matter of vertical-downward percolation. The depth to water was a function both of infiltration rate and of consumptive use on the levees. By September, however, owing to consumptive use, lack of rainfall, and lack of downward percolation the gradient was reversed, being from lakes behind levees toward



TEXT-FIGURE 2.—Groundwater profile A.



TEXT-FIGURE 2.—Groundwater profile E.



TEXT-FIGURE 3.—Avereage water-table depth, Peace-Athabasca Delta.

the channels, indicating flow in this direction. The amount of this flow may be estimated, using Darcy's equation:

$Q=PIA$, in which
$Q=$flow, in gallons per day
$P=$permeability, in gallons per day through a one-square-foot cross-section under unit hydraulic gradient
$I=$gradient, in feet per foot
$A=$cross-sectional area, in square feet.

For each mile length of levee (assuming a 10-foot-thick levee is involved in groundwater transfer), with an average head difference of 4 feet, and using an approximate K_s for sandy silt, flow through levees would be:

$Q=(3)\ (4/300)\ (5280 \times 10)$
$=2.112$ gallons per day per mile length

Artificially raising levels in the various channels would roughly double the head difference. Using Todd's higher value for permeability (3) and a head difference of 8 feet, artificial works would cause a water transfer of:

$Q=(3)\ (8/300)\ (5280 \times 20)$
$=8,880$ gallons per day per mile length,
$=6$ gallons per minute per mile length.

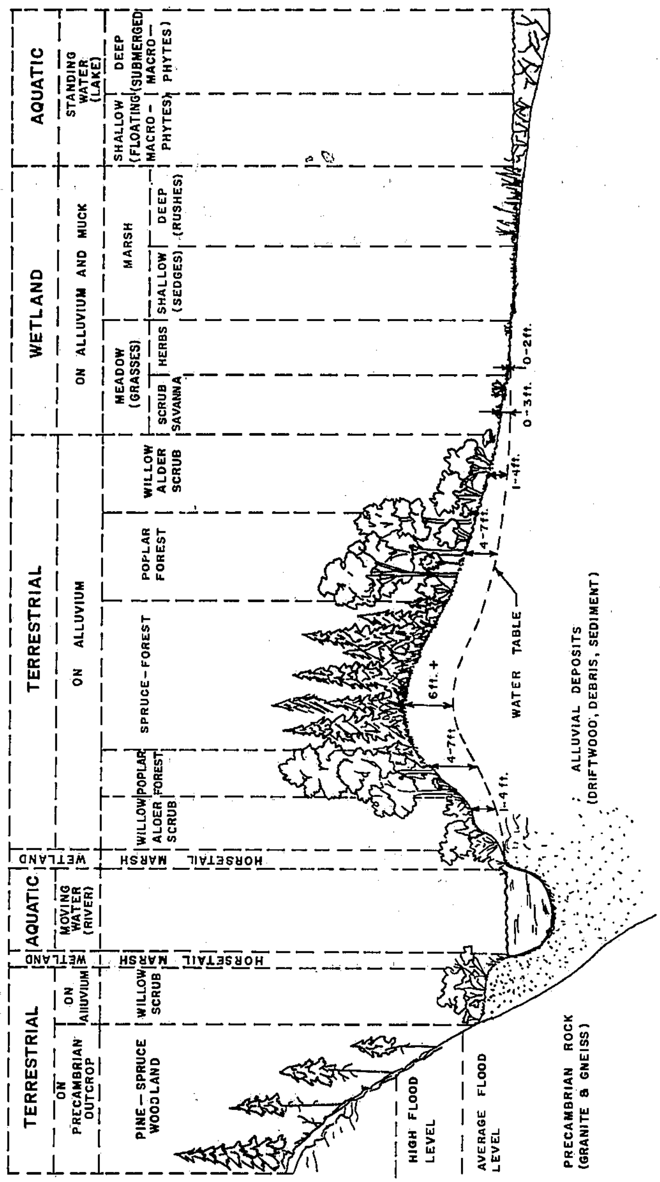
This latter figure, probably the maximum to be expected, shows that subsurface transfer from one water body to another would be negligible.

The configurations of the water table in Profile G and in Dirschl's Transect 4 closely follow the land surface and reflect only the interaction of local infiltration and consumptive use. Permafrost at G-2 and a lack of gradient between Peace River and Lake Claire indicate that no groundwater transfer takes place between them.

Groundwater-Level—Vegetation Relationship

Many plants favor very specific combinations of climatic, hydrologic, and chemical factors. In the Delta, climate and soil chemistry are relatively uniform over large areas. Thus, the main variable in determining plant distribution is the local moisture budget, which in turn is related to microrelief. Plant distribution as of September 1970 has been interpreted by the Canadian Wildlife Service from photographs taken at that time. Text-figure 3 is a water-table map, in which average depth to water table is inferred from the results of the present study and from the interpretation of vegetation distribution. It is based on water-table depth variations shown in Table 4. Text-figure 4 is a diagrammatic profile showing the relationship between water-table and vegetation across a typical levee.

The limited 1971 investigations have shown two general groundwater conditions within the Delta. The first occurs in older, more compacted areas (Bayrock and Root's number 1 and 2 areas) of the Delta. In these areas, microrelief and permeability are lower than in the more recent number 3 and 4 areas. On the basis of three profiles adjacent to Mamawi Lake, the water table in such areas is judged to be a depression between water bodies, as typified by Profile A in Text-figure 2. This configuration held true through three months of observations in the three profiles during 1971.



TEXT-FIGURE 4.—Diagrammatic profile of water-table relationship to vegetation.

TABLE 4
Relationship of Vegetation Type to Depth of Water Table

Plant Type	Water Table Depth (ft.)
Open Water	0
Emergent vegetation in water	0
Mudflat	0
Meadow and immature meadow (including marsh species out of water)	0–3
Low shrubs	1–4
Tall shrubs	3–5
Mixed Forest	
Deciduous forest	4–7
Coniferous forest	>6
Rock outcrop	–

In addition to vertical-downward percolation of precipitation, a very small volume of water flows from Mamawi Lake and "S" Lake toward the lowest part of the profile. Lowering the lake levels and drying up of backswamps such as "S" Lake are causing the water table to drop. Because of a much smaller difference in head, landward percolation of groundwater is minor in comparison to percolation of surface water. Seasonal variations result from the relationship between infiltration rate and consumptive use and will not change significantly with anticipated changes in surface water levels. However, the water table in the shoreline area between A-1 and Mamawi Lake fluctuates in response to surface water changes, the response diminishing in magnitude with increasing distance from the lake.

Plant distribution in the higher part of this profile will probably remain about the same as at present. However, distribution in the lower areas along Mamawi Lake and in the backswamp areas will change significantly as lake levels continue to decline. Many of the backswamp areas, formerly shallow lake beds, have already dried up, and others such as "S" Lake are doing so. As they dry up, the water table drops below the lake-bed surface, and zones of emergent vegetation in open water are replaced by low willow and high willow.

The other general groundwater condition occurs in modern areas of the Delta (Bayrock and Root's number 3 and 4 areas), where sediment compaction is less and permeability is therefore greater. In such areas, recharge in the levees is sufficient to produce a groundwater mound, at least seasonally. This is true in Profiles D, E, and F (Figure 2). Thus, groundwater flows laterally from the levee both to the channel on one side and to the backswamp on the other. The shorter flow path and coarser grain size of sediments toward the channel would divert the bulk of groundwater flow in this direction.

Seasonal and long-term drop of water levels in the various channels causes some lowering of the groundwater "mound" immediately adjacent to the channels in a narrow band (as in well E-1, Figure 2). If water levels in such channels remain permanently low, resultant changes in vegetation will be long term: spruce forest may replace poplar forest. Where already established, however, spruce forest will remain the climax vegetation. The depth to groundwater behind levees will gradually drop below the land surface as backswamps and lakes disappear. Here again, using Text-figure 2 as an example, the zone between wells E-2 and E-3 will gradually be invaded by poplar forest, and emergent vegetation in Frezie Lake will in turn become meadow and then low willow/shrub flats.

Recharge Rate

The 1971 rate of groundwater recharge within the Delta may be estimated and compared with the long-term average. Estimates which follow are based upon measurements of water-table wells for only 1.5 months, in Profiles A, B, and C; and 2.5 months in Profiles D, E, and F and in Transect 4. As only two sets of measurements were obtained from Profile G, they were not used in estimating annual recharge.

During the 1971 calendar year, subsurface frost conditions were present until late May or early June. The water in observation wells again froze in late October, when the final measurements were made. The period during which no ground frost was present and during which groundwater recharge could occur was therefore approximately 4.5 months.

Groundwater recharge was considered to have occurred each time a water-table measurement was higher than the previous one in the same well. The amount of recharge that occurred during the period that measurements were taken was totalled for each well, and the values thus obtained were averaged for each of the three main areas where water-table wells were installed. An average specific yield of 0.1 was assumed for all profiles. Total recharge is shown in Table 5. Thus, average groundwater recharge for all profiles is roughly 13 percent of the annual precipitation of 16.71 inches (as recorded at Fort Chipewyan airport) in 1971.

The interpretation of aerial photography of September 1970 showed that the land area of the Delta was 1,009,013 acres, exclusive of Precambrian outcrops. Assuming that these average groundwater recharge values hold for the entire Delta, total recharge for 1971 was:

$$(1{,}009{,}014)\ (2.12/12) = 176{,}000 \text{ acre-feet.}$$

A comparison of the 1968 and September 1970 aerial photography shows that between those dates 124,320 acres of land were exposed by the lowering of water levels in the Delta. Of this area, 53,843 acres were in mudflats, whose water table is virtually at the land surface. The remaining 70,477 acres is in immature meadow, having an assumed average water-table depth of 1.5 feet. Thus, the decrement of groundwater storage from 1968 to 1970 is about (1.5) (0.1) (70,477) = 10,570 acre-feet or 6% of the 1971 recharge. And the loss in 1971 would probably have been somewhat greater as many lakes con-

TABLE 5

Groundwater Recharge Rates, Peace-Athabasca Delta, 1971

Profile	Average Water-table increment (ft.)	Time period (mo.)	Corrected to 4.5 mo. (ft.)	Water-table increment (in.)	Increment x specific yield (in.)
A, B, C	0.36	1.5	1.08	13.0	1.30
D, E, F	1.72	2.5	3.09	37.1	3.71
Transect 4	0.70	2.5	1.26	15.1	1.51
All profiles	0.98	2.5	1.76	21.2	2.12

tinued to dry up and as the mudflats turned into willow with correspondingly lower water tables.

Admittedly, the above technique for determining groundwater recharge has shortcomings. It ignores for example, the quantities of water lost to consumptive use; and although the specific-yield value is considered reasonable, it has no basis in fact. The frequency of well measurement could have missed some increments in the water table also. Nevertheless, this exercise does yield an order-of-magnitude value for recharge, and allows comparisons of recharge rates in parts of the Delta of differing ages. Profiles A, B, and C, and Transect 4 are all in Bayrock and Root's number 1 area. Profiles D, E, and F, having the highest recharge, are in the most modern (number 4) area.

Groundwater Quality

Because few analyses are available, little is known of groundwater chemistry on a regional basis in the Delta. However, the deep-testing program of March 1972 yielded samples from three different depths in test hole H-1 and two samples from test hole H-5.

Eleven analyses were used from the 1971 investigations from nine water table wells in Profiles A to F. Several of these wells were sampled twice. Temperature was measured at the time of sampling at most sites. All analyses were converted from milligrams per litre (mg/l) to equivalents per million (epm), and percentages of various ions were computed. Analyses from test-holes H-1 and H-5 were done by the Department of Environment Laboratory, Edmonton, and Research Council of Alberta Laboratory, Edmonton. The analyses are tabulated in Tables 6 and 7.

In the southern plains Vanden Berg and Lennox (1969, p. 27-28) found that sodium as a percentage of total cations increases with length of flow path toward the discharge end of the system. This is a result of ion exchange, in which calcium and magnesium are absorbed onto clay platelets in exchange for sodium ions. The opposite seems to occur here: as the depth increases, the sodium decreases from 19% to 15% of total cations. Bedrock formations of the area are highly calcic, being mainly limestone, dolomite, and gypsum. Thus, surficial clays above bedrock might well be already saturated or nearly saturated wi4th res-

TABLE 6

Geochemistry of Deep Groundwater

	H-1, 140'	H-1, 159'	H-1, 170'	H-5, 56'	H-5, 242'
Date of sampling	Mar 12/72	Mar 13/72	Mar 12/72	Mar 15/72	Mar 15/72
Temp. at sampling (°C)	—	7	—	9.8	—
pH	7.7	6.7	7.1	7.1	6.6
E.C.	2.72	3.36	3.20	1.29	12.00
Ca^{++} (mg/1)	504	700	730	296	1280
Mg^{++}	31	90	30	20	180
Fe (total)	<.05	.20	4.50	.20	.05
Na^{+}	154.1	193	161	20	1587
K^{+}	14.0	10.1	16.0	5.0	17.0
$HCO_3=$	280	311	201	659	119
SO_4	1521	1781	1646	288	1603
Cl^{-}	202	319	277	18	4129
T.D.S.	2709	3409	3066	1296	8915
S.A.R.	1.7	1.8	1.6	0.3	10.9

TABLE 7
Geochemistry of Shallow Groundwater
(mg/1)

Location	Temp. (°C)	pH	TDS	Ca	Mg	SO_4	Cl	HCO_3	NO_3	Fe	F	Na	K
A-1	5.2	6.9	788	194	32	230	12	379	2.8	.18	.25	21.3	3.3
A-2	3.9	6.9	920	220	89	165	17	853	7.2	.19	.13	38.8	3.8
A-3	10.0	6.9	536	150	27	45	19	435	17	.14	.19	23.8	1.7
B-2	2.8	6.9	640	250	55	21.5	13	872	2.0	.39	0	23.8	5.0
	4.5	6.7	1880	111	105	900	8	540	0	—	—	—	—
C-2	6.7	7.2	1862	400	100	780	12	650	5.0	1.17	.18	47.5	4.2
D-2	5.6	6.8	678	190	42	41.5	25	595	5.6	.65	.16	25	2.5
E-2	2.8	7.4	1150	220	82	200	30	789	7.3	.39	.08	40	3.0
E-3	6.7	7.4	1074	200	62	324	21	412	2.9	.14	.05	40	2.1
F-1	7.8	6.7	542	142	25	32	31	426	16.3	.29	.1	30	2.1
F-2	2.2	—	960	52	52	30	23	650	0	—	—	—	—

pect to calcium and magnesium, inhibiting further ion exchange. Deeper flow paths coming into closer contact with bedrock would thus pick up greater concentrations of calcium, which cannot be exchanged for sodium in the surficial clays.

The calcium/magnesium ratio increases from 4.6 to 5.6 with increasing depth and longer flow-path, as Vanden Berg and Lennox (1969, p. 29) suggest occurs in the Handhills area.

No clear-cut patterns of flow behavior can be deciphered from examination of the anion ratios. However, high sulphates in all three samples 73 % to 76%) are probably a result of the proximity of gypsum subcrops. All three samples are of the calcium-sodium/chloride-sulphate facies.

In test hole H-5, the sample from 56 feet shows relatively low total dissolved solids (1,296 ppm) with calcium as the dominant cation and bicarbonate as the dominant anion, suggesting a relatively local source for this water. In the sample from 242 feet, sodium is 47% of total cations, and chloride is 77% of total anions. In combination with an extremely high total of dissolved solids (8,915 ppm), this evidence suggests a flow path involving Middle Devonian evaporite rocks (McCrossan and Glaister, 1964, pp. 49-53).

Of the 11 analyses available for shallow wells, 10 are of the calcium-magnesium cation facies, while 8 are bicarbonate-chloride-sulphate, one is bicarbonate, and 2 are chloride-sulphate-bicarbonate anion facies.

These analyses reflect, in general, the shallow nature and short flow paths followed by the near-surface groundwater. Substantial differences in temperature, and therefore of solubility, in adjacent samples help explain differences in their detailed geochemistry.

Groundwater temperature was measured on 11 August 1971 and again on 20 September 1971 at all sites, except one where the level had dropped too low for a second reading. The highest observed temperature was 10°C, and the lowest was 1°C. With two exceptions, groundwater temperature was higher in the September reading, despite much lower air temperatures. Lowest temperatures occurred where the water table was deepest. Groundwater temperature dropped to the freezing point, and readings were discontinued in late October. Water temperature therefore appears to change as a delayed response to air temperature, and the amount of change is a function of the depth to water table.

REFERENCES CITED

Bayrock, L. A., and Root, J. D., 1972, Geology of the Peace-Athabasca River Delta Region, Alberta: Res. Counc. Alta. Interim Rep.
Brown, R. J. E., 1967, Permafrost in Canada: Geol. Sur. Can. Map 1246A, Nat. Res. Counc. Publ. NRC 9769.
Fuller, W. A., and La Roi, G. H., 1971, Historical review of biological resources of the Peace-Athabasca Delta: Proc. Peace-Athabasca Delta Symp., Univ. of Alta., p. 153-173.
Green, R., 1971, Bedrock geology of northern Alberta: Res. Counc. Alta. map.
Macoun, John, 1875-76a, Geological and topographical notes on the lower Peace and Athabaska Rivers. Geol. Sur. Can. Rep. of Progress, p. 87-95.
McCrossan, R. G., and Glaister, R. P., 1964, Geological history of western Canada. Alta. Soc. Pet. Geol.
Novakowski, N. S., 1967, Anticipated ecological effects of the possible changes in the water levels of the Peace-Athabasca River Delta as a result of the damming of the Peace River. Can. Wildlife Ser., Internal Rep.
Todd, D. K., 1959, Groundwater hydrology. John Wiley and Sons, New York.
Tokarsky, O., 1966, Geology and groundwater resources of the Grimshaw-Cardinal Lake area, Alberta. Unpublished M.Sc. thesis, Univ. of Alta., Edmonton.
Vanden Berg, A., and Lennox, D. H., 1969, Groundwater chemistry and hydrology of the Handhills area, Alberta. Res. Counc. Alta. Rep. 69-1.