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INTERIM REPORT ON THE FEASIBILITY STUDY FOR DEWATERING THE OVERBURDEN IN GCOS LEASE 86

by

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SUMMARY AND CONCLUSION

The study, undertaken by the author to determine the feasibility of dewatering the GCOS overburden, included the mapping of groundwater features in the lease and its vicinity, the collection of groundwater sample throughout the study area, the recording of water levels in a number of wells, and the construction of an electric model. As a result of this work the author has come to the conclusion that the water entering the GCOS lease, at the present, is mostly from precipitation, and it is removed from the lease mainly by evapotranspiration. Some water is believed to enter the lease through the tar sand but the total volume is small. However this water may be entering the lease through localized areas which, where encountered by equipment removing overburden, may present some traction problems. Relatively small volumes of water are entering or leaving the lease through the overburden. The net result of water movement in the overburden is believed to be a small loss in water by the lease. The major portion of water that has to be removed for dewatering the overburden is groundwater in storage and induced groundwater flow to the area caused by the dewatering operations. The latter cannot be estimated until the completion of the proposed testing program. The former was estimated to be less than 605 billion imperial gallons.

In the southern part of the lease the A_I and B_I units form the main aquifers. As these are the lowest Cenozoic units they constitute a good method of dewatering the overburden in the southern part of the lease. The thin E unit and uneconomical tar sand may have to be dewatered separately in that area. In the northern part of the lease the B_{II} unit is the unit best suited for pumping water out of the overburden, because of its permeability and location in the topographic depressions. However its limited thickness and its position above C, E and uneconomical tar sand units makes it less than ideal. It would be advantageous to determine if the C or E units have permeable zones of sufficiently large lateral extent for one to use them for dewatering the overburden. If these are present and are hydraulically connected to the overburden units above them then they would be more desirable than the B_{II} unit because of their lower depth. Between the southern extent of the B_{II} unit and the northern extent of the B_I and A_I units, is an area where only the A_{II}, C, E, and uneconomical tar sand units are present. In this area it is necessary to find if there are permeable zones within these units and whether these zones are hydraulically connected. If these these zones are not present this area may not have to be dewatered. While if they are present but not continuous they may have to be dewatered individually.

The location of the most permeable zones, as well as a detailed knowledge of their permeability is necessary for the planning of an efficient dewatering scheme, and for predicting the volume of induced groundwater flow. To determine the latter the present direction of groundwater movement will have to be known. The proposed testing program is designed to determine these factors. Approximately 32 test holes are believed to be necessary for the testing program, of which 16 will be bail tested. All the holes will be cased and used to monitor dewatering operations. The proposed study also includes two week long pump test to determint the transmissivity of the overburden and its specific yield. The testing program was estimated to cost approximately $41.000.

INTRODUCTION

This report is a summary of the knowledge acquired during the 1968 summer field season, relative to the feasibility of dewatering the overburden in the GCOS Lease 86, as well as a proposal for a testing program to determine and clarify certain important aspects relating to the hydraulic properties and geology of the overburden. The report has therefore been divided into two parts. The first part, labeled A, summarizes the work that was done during the 1968 field season and in the laboratory and the information obtained from already published material. Most of the conclusions present in this section pertain to groundwater under natural condition. They are not to be considered final for they are based on information that will be upgraded as the study continues. In the second portion of the report, labeled B, the proposed drilling and aquifer testing is described in detail, giving reasons for its necessity.

Location of Area

The areastudied is located approximately 22 miles north of Ft. McMurray. It includes all of the GCOS Lease 86, as well as a portion of the area surrounding it (Fig. 1).

A. SUMMARY OF PRESENT KNOWLEDGE

Hydrological Environment

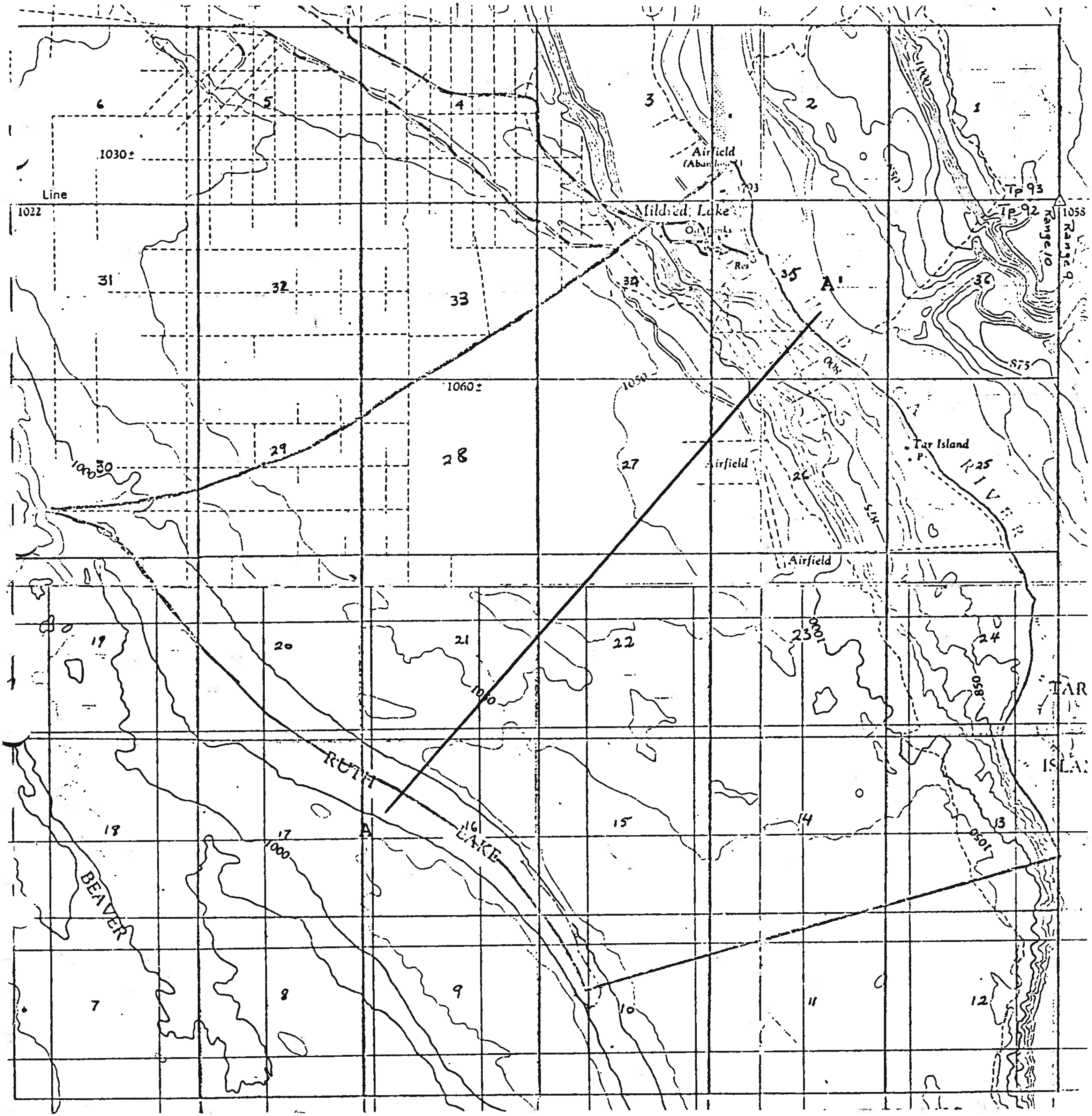
Topography

Most of the GCOS Lease lies at an elevation of about 1,000 feet, on the Second Prairie Level. To the West and northwest is a remnant of the High Plains of Alberta, called the Birch Mountains, which generally has relatively steep flanks and rises to about 2,600 feet in the vicinity of the lease area. Southward the land surface rises more gently to about 1,700 feet to form a gently rounded hill called the Thickwood Hills.

The Lease area has an undulating topography which is composed of low, elongated arcuate ridges alternating with broad shallow troughs. Ruth Lake (Fig. 1) is a trough which is deep enough to intercept the water table.

Drainage

The area studied is in contact with two rivers. On the east side is the Athabasca River, and in the northwest corner is Beaver River (Fig. 1). However, there appears to be no significant natural drainage from the lease into these rivers, therefore, most of the water precipitated on the lease remains there or is removed by evapotranspiration.



Scale 1:50,000
C.I. Upper half 25 ft., Lower half 50 ft.

Fig. 1 Map showing area included in study, and location of electric model section (A-A') (modified from map sheets: Ft. McKay, Hartley Creek, Cache Creek and Wood Creek).

The only other significant rivers in the area are the Ells, the Dover, and the McKay River which are located between the Birch Mountains and the GCOS Lease. These rivers are important because they form major depressions between the Birch Mountains and the area studied. Such depressions are believed to intercept groundwater originating in the Birch Mountains, and to prevent it from entering the lease. Ruth Lake and Beaver River are believed to perform the same function for groundwater originating in the Thickwood Hills.

Climate

The weather station closest to the GCOS area is, at the present, located at Ft. McMurray airport, about 26 miles south of the GCOS Lease. The station has been established long enough to enable the federal weather bureau to calculate climatic normals for the area. Normals from the station are believed to be representative of conditions at the GSOC lease, and therefore will be used to calculate the evapotranspiration in the study area.

Vegetation

The vegetation is the area studied is predominantly muskeg, which is, for most part, saturated with water during the summer months. The muskeg is generally located in the depressions.

Muskeg has the seemingly paradoxical properties of containing large quantities of water and yet having a low permeability. The latter property makes it impossible to dry muskeg by gravity draining. The only manner in which muskeg can be dried in the field is by evaporation. The low permeability of muskeg will retard the infiltration of precipitated water into the ground and because of its property of retaining large quantities of water, it will prevent a significant portion of water from entering the underlying sediments. These two factors will have the effect of keeping a large amount of water in contact with the atmosphere for a long period of time. This in turn will produce high evapotranspiration rates, even if the water table is well below the land surface, and thus reduce the amount of water to be pumped out of the overburden. The presence of muskeg over a large portion of the lease, therefore, in this sense, is advantageous to the dewatering operations. Overburden removal may, however, be complicated by the presence of wet muskeg. The problem can be minimized if muskeg removal is restricted to the late fall when it should be in its driest state.

Moisture

The water table in GCOS area is in all places very close to the surface; rarely was it found below 5 feet from the surface,

System or Series	Formation or Group	Member	Lithology
Pleistocene and Recent			Glacial and post-glacial deposits of till, silt, and sand
	Erosional unconformity		
Cretaceous	Clearwater		Shale and sandstone
		Wabiskaw	Sandstone, glauconitic
	McMurray	No. 3 (Upper)	Fine-grained quartz sands, oil-cemented, horizontally-bedded; fossiliferous (brackish-water fauna)
		No. 2 (Middle)	Medium-grained quartz sands, oil-cemented, lenticular beds of siltstone, shale, and coal; numerous beds of ironstone, cemented sandstone, vegetable remains, pyrite nodules
		No. 1 (Lower)	Conglomerate, detrital clays and shales, siltstone and coarse-grained sands; some wood, lignite, and coal
	Erosional unconformity		
Devonian	Woodbend Group Grosmont		Limestone reef
	Ireton		Shale and argillaceous limestone
	Duvernay		Brown limestone and shale
	Cooking Lake		Limestone
	Beaverhill Lake	Mildred	Grey-green and buff, argillaceous limestone
		Moberly	Grey-buff, mottled limestone
		Christina	Green-grey, calcareous shale
		Calumet	Clastic limestone
		Firebag	Argillaceous limestone
	Paraconformity		
	Slave Point equivalent		Buff-brown limestone and dolomite
	Paraconformity		
	Dawson Bay equivalent		Reddish siltstone with interbeds of dolomite and anhydrite
	Elk Point Group Prairie evaporite		Halite, anhydrite, gypsum, and dolomite
	Methy (generally includes Elm Point equivalent)		Buff dolomite, reefal, argillaceous; and evaporitic and fossiliferous limestone
	Ashern equivalent		Green dolomitic claystone, and beds of anhydrite
	Paraconformity?		
	Meadow Lake equivalent		Red claystone, siltstone, and sandstones; arkose at base
	Erosional unconformity		
Paleozoic or Precambrian	Athabasca		Orthoquartzite
	Erosional unconformity		
Precambrian			Metasedimentary rocks intruded by granites and cut by diabase dykes

Table 1. Summary of the stratigraphy of the GCOS Area. (Modified after Carrigg 1959 p. 4 and 5).

even in areas close to the Athabasca River escarpment. It is generally at the surface in depressions and a few feet below the surface in the highs. The closeness of the water table to the surface makes it possible to approximate the water table map with a topographic map. This factor is especially helpfull when constructing electrical models.

Geology

The stratigraphic column of the GCOS area is given in table 1. The following is a description of the Cretaceous and Cenozoic sediments above the uneconomical McMurray Formation.

Cretaceous deposits

Uneconomical Tar Sand Unit

Tar sand with less than 8% bitumen (dry weight) is uneconomical and is therefore considered part of the overburden. Although this overburden unit is a sand, its more permeable zones as partially impregnated with bitumen which greatly reduces its permeability to water. Clarke (1959) has determined the permeability of the uneconomical McMurray Formation (Table 6 and 7). The permeability is much lower than any of the other overburden units. Therefore this unit is not useful to dewater the overburden. However its permeability has to be determined accurately because it will be necessary to drain it of groundwater present in it.

E Unit

The Clearwater Shale was named the E unit by Linkens (1965). It has been described in several of the well logs drilled in the GCOS lease as a sand, containing glauconite. In other wells it was found to be a shale or clay also containing glauconite. If the sandy areas of the Clearwater Shale are continuous and permeable, then this unit could be used to dewater the overburden. Extensive permeable zones in this unit would be very desirable because it is the lowest overburden unit above the uneconomical tar sand, and therefore pumping it would gravity drain the overlying units.

Cenozoic deposits

Cenozoic deposits in the GCOS area consist of unconsolidated gravels, sands, silts, and clays. They have been separated by Linkens (1965) into six units based on their lithology and stratigraphic position. As these units have been consistently used to map the Cenozoic deposits in the GCOS lease, it is considered desirable at the present to retain the nomenclature used by Linkens, with the exception of the descriptive terms. The descriptive terms such as "boulder sand", "sand" and "boulder clay" are excluded because they are misleading. This is especially true in the case of the "boulder clay" (unit C) which, in many cases, is mostly sand. The general lithology and spatial superposition of these units as described by Linkens (1965, p. 22) are given in table 2.

A_I Unit

Most of the A_I unit is present along an elongated deposit extending in an northeast-southwest direction in southern part of the lease. Other smaller deposits have a generally circular outline and are distributed predominantly along the eastern border of the lease (Linkens 1965; Ward 1968). According to Linkens (1965) the unit has an average thickness of 9.6 feet and ranges in thickness between zero and 35 feet.

The A_I unit is composed of a mixture of boulders and sand usually with little clay and silt. It is commonly bedded and/or laminated. The grain size distribution and permeability of two samples of the A_I unit were provided by Materials Testing Labratories Ltd. These are given in table 3. Although portions of the A_I unit may be less permeable than portions of the other units, its ability to transmit water over large distances is probably greater than any of the other units in the southern part of the lease. The

COLUMNAR OVERBURDEN SECTION

-LEASE 86-

BIII	SAND, light tan to light grey, with some pebbles and cobbles, traces of small boulders and rare medium and large boulders.
AII	BOULDER-SAND, light to tan to rusty-brown, loose, unsorted, contains varying amounts of boulders, cobbles, pebbles, and sand. Includes gravel deposits.
BII	SAND, same as BIII description.
C	BOULDER-CLAY, grey to brown, unsorted, dense, commonly very sandy with small amounts of pebbles, cobbles, and very few boulders although the occasional bed contains up to 20% volume medium and large boulders. Boulder-clay is often calcareous and/or petroliferous. Also includes rock free and sand free bluish-grey clay.
BI	SAND, same as BIII description.
AI	BOULDER-SAND, same as AII description.

te: Columnar section is strictly schematic and is only meant to show the superposition of the Cenozoic deposits present on Lease #4.

Table 2 Columnar section of Cenozoic sediments in the GCOS area, north of Ft. McMurray. (Modified after Linkens, 1965).

A_I unit being one of the most permeable units and one of the lowest in the stratigraphic column, makes it ideal for use as the main aquifer for dewatering the overburden. However its limited geographic extent makes it generally only useful in the southern portion of the lease.

B_I Unit

The B_I unit overlies the A_I unit and is present predominantly on the southern part of the lease (Linkens, 1965; Ward 1968). It is reported by Linkens (1965) to have an average thickness of 8.6 feet and to range in thickness from 0 to 35 feet. It usually consists of a fine to coarse sand, commonly containing very little silt or clay and having only occasional pebble or cobble size fragments. The sand is mostly moderately well sorted, rounded, and has a very high quartz content. Materials Testing Laboratories Ltd. determined the grain size distribution and estimated the permeability of three samples of this unit. The results are given on table 3, along with the location of the samples they have analyzed. The importance of the B_I unit in the dewatering operation is in its ability, through its high permeability, to extend the effect of pumping the A_I unit. However because it is almost as limited in geographic extent as the A_I unit, and as it

Table 3. Grain size distribution and estimated permeability of selected samples from GCOS Lease 86 (from report of M.I.T. presented to GCOS)

H. .	Depth (feet)	Unit	Per-cent gravel	Per-cent sand	Per cent silt	Per cent clay	Estimated permeability (ft/yr)	Location of well-plant co-ordinates
9B	6-10	C	22	63	13	2	1 x 10^5	3895L950
9B	10-16	C	49	45	5	1	1 x 10^5	"
9B	16-32	C	4	64	19	13	0.5	"
9B	32-42	C	0	15	49	36	0.1	"
2	10-40	B_I	0	95	3	2	50	3895R2950
2	40-56	B_I	35	56	9		1 x 10^5	"
2	56-72	A_I	68	26	4		1 x 10^4	"
2	72-90	A_I	78	18	4		1 x 10^4	"
2B	21-48	B_I	16	74	7	3	1 x 10^5	5762L3760
0B	9-16	C	0	50	43	7	10	2488L440
0B	16-24	C	0	57	36	7	10	"
36B	32-36	A_I	33	66	0.5	0.5		4828R5
7B	37-40	E		71	16	13		8639L4680

also mainly located in the southern portion of the lease, its value is greatly reduced.

C Unit

The C unit outcrops in many areas within the lease and its vicinity. An examination of these outcrops indicates a great variation in its grain size and composition. The unit ranges from a compact bluish clay (wet sample) to a silty, gravelly sand containing little clay. In most cases the unit contains pebble size fragments and often boulder and cobble size fragments, most of which are rounded and some exhibit glacial striations. The six samples of the C unit analyzed by Materials Testing Laboratories Ltd. exemplify the great variation in the grain size composition, and consequently the permeability of this unit (Table 3). The difference in the grain size composition of the analyzed samples is even more striking when it is noted that the samples were collected from two core holes only 500 yards apart.

The C unit forms a more or less continuous layer within the GCOS lease, having an average thickness of 28 feet and ranging in thickness from 0 to 130 feet (Linkens, 1965). Gaps are mostly restricted to the eastern and southern portion of the lease (Linkens 1965).

Because of the large variation in the lithologic composition of the unit, an estimate of the large-scale permeability of the C unit from a small number of samples may be misleading, for the continuity and interconnection of the permeable zones within the unit are not known. Unless a pumping test is conducted, or a large number of samples collected from the C unit throughout the study area are analyzed, no reliable permeability can be estimated. The C unit is rarely entirely impermeable. At the northeast end of the sump, where the unit is very clayey and dense, seepages and springs are present in the C unit. One spring has an estimated flow of about 5 gpm. The importance of the C unit in the dewatering operations cannot be properly evaluated at the present for it depends on the extent of the permeable zones within the unit and their interconnections. This aspect will be studied during the drilling and aquifer testing operations.

B_{II} Unit

The B_{II} unit which overlies the C unit outcrops over large parts of the lease, especially in its northern portion. It is reported by Linkens (1965) to have an average thickness of 11.4 feet and to range from 0 to 60 feet. In the southern part of the lease, the B_{II} deposits are small and disconnected from one another. Most of the B_{II} unit in the northern portion of the lease has been mapped by Linkens (1965) as part of elongated deposits generally underlying the troughs. For reasons indicated below (under Groundwater Movement) it is more efficient to pump water out of the topographically lower areas of the lease. Therefore the B_{II} unit may become the unit through which most of the water will be removed in the northern part of the lease, unless extensive permeable zones are present in the C or E units below.it. Using the B_{II} unit as the main aquifer in the northern portion is not the most desirable situation for it is not the bottommost unit in the overburden in many cases. The B_{II} unit consists mostly of a moderately well sorted, medium to coarse sand, with a very high quartz content, commonly in the 80 per cent or higher range. The roundness of the sand grains ranges from angular to rounded. The B_{II} unit contains some fragments coarser than sand; however these are not very common and are often not present. The permeability of the B_{II} unit has not been estimated by Materials Testing Laboratories Ltd. This unit is lithologically very similar to the B_{I} unit, except for a slightly finer grain size; therefore its permeability is assumed to be slightly less than that of the B_{I} unit.

A_{II} Unit

The A_{II} unit, which overlies the B_{II} unit, is present mostly in a single elongated deposits trending in a northwest-southeast direction through the center of the lease (Linken, 1965). Other deposits of the A_{II} unit are present on the northeast and southwest of the main deposit. These also exhibit a northwest-southeast trend. The A_{II} unit is composed of a clayey, silty, poorly sorted, and commonly noncalcareous sand, usually containing a large number of fragments larger than sand. The sand grains are angular to rounded, and are predominantly composed of quartz. The permeability of the A_{II} unit has not been estimated by Materials Testing Laboratories Ltd. Because of the presence of a relatively high content of fine grained sediments with the unit, it is believed that it is less permeable than the A_I, B_I, or B_{II} units.

The A_{II} unit is shown by Linkens (1965) to be mostly present under ridges. If this unit is hydraulically connected to the B_{II} unit in the northern portion of the lease, as it appears to be, groundwater will generally be draining from the A_{II} unit into B_{II} unit. In the southern part of the lease where the B_{II} unit is absent groundwater in the A_{II} drains into the B_I, A_I or permeable portions of the C unit.

B_{III} Unit

The B_{III} unit overlies the A_{II} unit and has been mapped by

Linkens (1965) as present only in the southern portion of the lease, where it crops out over a large area. The B_{III} unit is composed of poorly sorted sand, commonly very silty and containing no pebble or cobble size fragments. Because of the high silt content, the B_{III} unit is believed to be less permeable than the other B units. The mineral geographic extent of the unit, its restriction to the southern part of the lease, and its sufficiently high permeability not to form a impermeable cap on the overburden, makes this unit relatively unimportant.

Evapotranspiration Calculations
for GCOS area

Evapotranspiration is the amount of water removed from the area through vaporization of water by the combined effect of evaporation and transpiration from plants. The evapotranspiration for the Ft. McMurrary weather station was calculated using the method devised by Thornthwaite and Mather (1955). The calculations and the results given in table 4. As the Ft. McMurray weather station is only about 26 miles from the study area it was assumed that the evapotranspiration results are representative of the area studied. It was found that 428 mm of water enters the lease through precipitation each year and about 428 mm are removed through evapotranspiration each year. Thus evapotranspiration appears to be able to cope with most, if not all, of the precipitation. This factor is an important consideration in the water budget, and in determining the amount of groundwater contributed to the study area from outside it.

Groundwater Chemistry

It was concluded from a study of the chemical composition of approximately 70 groundwater samples collected throughout the study area, that groundwater contribution to the GCOS lease through the tar sand is generally insignificant in volume. It was discovered that almost all of the samples collected from the overburden were of calcium carbonate and bicarbonate type, while all the tar sand water collected were of calcium and magnesium sulfate and chloride type. This marked difference indicates that there is little mixing of the two types of groundwater and, therefore, little water going from the tar sand into the overburden. There appears, however, to be a small amount of water that is contributed by the tar sand, for at least two groundwater samples from the overburden had compositions approximating that of the tar sand water. These areas should be further investigated for they may be areas where overburden removal operations may encounter some difficulties. If significant quantities of groundwater is coming through the tar

Table 4: Calculation of evapotranspiration from data from Ft. McMurray weather station using the method devised by Thornthwaite and Mather (1955)

	J	F	M	A	M	J	J	A	S	O	N	D	Y	Total	
Temp. °F (average)	-6.3	1.0	15.3	34.8	48.9	55.9	61.6	58.3	48.3	36.7	16.5	0.5	31.0		
Temp. °C	-21.3	-17.2	-9.3	1.6	9.4	13.3	16.4	14.6	9.1	2.6	-8.6	-17.5	-0.6		
I				0.18	2.60	4.40	6.04	5.04	2.48	0.37				21.14	
PE	0	0	0	11.7	54.8	74.0	88.0	79.9	53.0	18.0	0	0		379.4	
Correction factor for PE	0.74	0.78	1.02	1.15	1.33	1.36	1.37	1.25	1.06	0.92	0.76	0.70			
Corrected PE	0	0	0	13.6	72.8	100.6	120.5	98.3	56.2	16.6	0	0		479.1	
Precipitation in inches (total)	0.84	0.65	0.88	0.75	1.31	2.36	2.93	2.36	1.93	1.03	0.93	0.88	16.85		
Precipitation in mm (total)	21	17	22	14	33	60	74	60	49	26	24	22	428	428	←
Precipitation - PE	21	17	22	5	-40	-41	-46	-39	-7	10	24	22		-51.2	
Acc. Pot. water loss				(-50)	-90	-131	-177	-216	-223						
Storage	217	234	256	254	222	193	166	145	142	150	174	196			
Δ storage	21	17	22	-2	-32	-29	-27	-21	-3	8	24	22			
Actual evapotranspiration	0	0	0	21	65	89	101	81	52	18	0	0		428	←
Moisture deficit	0	0	0	0	8	13	19	19	2	0	0	0			
Moisture surplus	0	0	0	0	0	0	0	0	0	0	0	0			
Runoff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

sand at these places, it would be extremely difficult to drain the areas by pumping water from the overburden. The total dissolved solid content of the overburden water is generally less than 500 ppm while that of the tar sand is greater than 500 ppm. If a significant amount of water was contributed by the tar sand, there would be an accumulation of salts in the overburden, for, as has been noted above, most of the water is removed from the area through evapotranspiration. The presence of a low total dissolved solid content in the overburden water proves that this does not happen.

It was also concluded from a study of the groundwater chemistry that there is only a small contribution of grounwater to the GCOS lease from outside the lease through the overburden. Groundwater with a predominantly calcium carbonate and bicarbonate composition is considered "youthful" in that it has not travelled a great distance in the ground. The fact that a great majority of the overburden samples are of this type suggests that most of the groundwater movement is along short flow systems, and therefore does not move a great distance from where it has been precipitated. Thus groundwater contribution from outside the lease comes from the highs immediately outside the area. Its volume is roughly proportional to the quantity of water precipitated on the flank of the high facing the lease.

It should be noted that the conditions described above pertain to natural conditions which may be greatly altered when dewatering operations are put into effect. The information to be collected in the proposed drilling and aquifer testing program will have to be obtained before the effect of dewatering operations can be predicted with any degree of confidence.

Groundwater Movement

Introduction

As any other substance, water will move only if a drive is present; in other words, if a potential difference exists. Water will then tend to move from area of higher potential to lower potential along the highest potential gradient, i.e. taking the shortest path. Thus it will flow perpendicular to equipotential lines in the same way that water will flow perpendicular to contour lines on an impermeable surface. The potential that drives water or any other fluid in the ground has been called the fluid potential. Thus if it were possible to determine the fluid potential for water at any point within a permeable medium it would be possible to predict the flow path of water in that medium. Mathematically, the fluid potential can be expressed as:

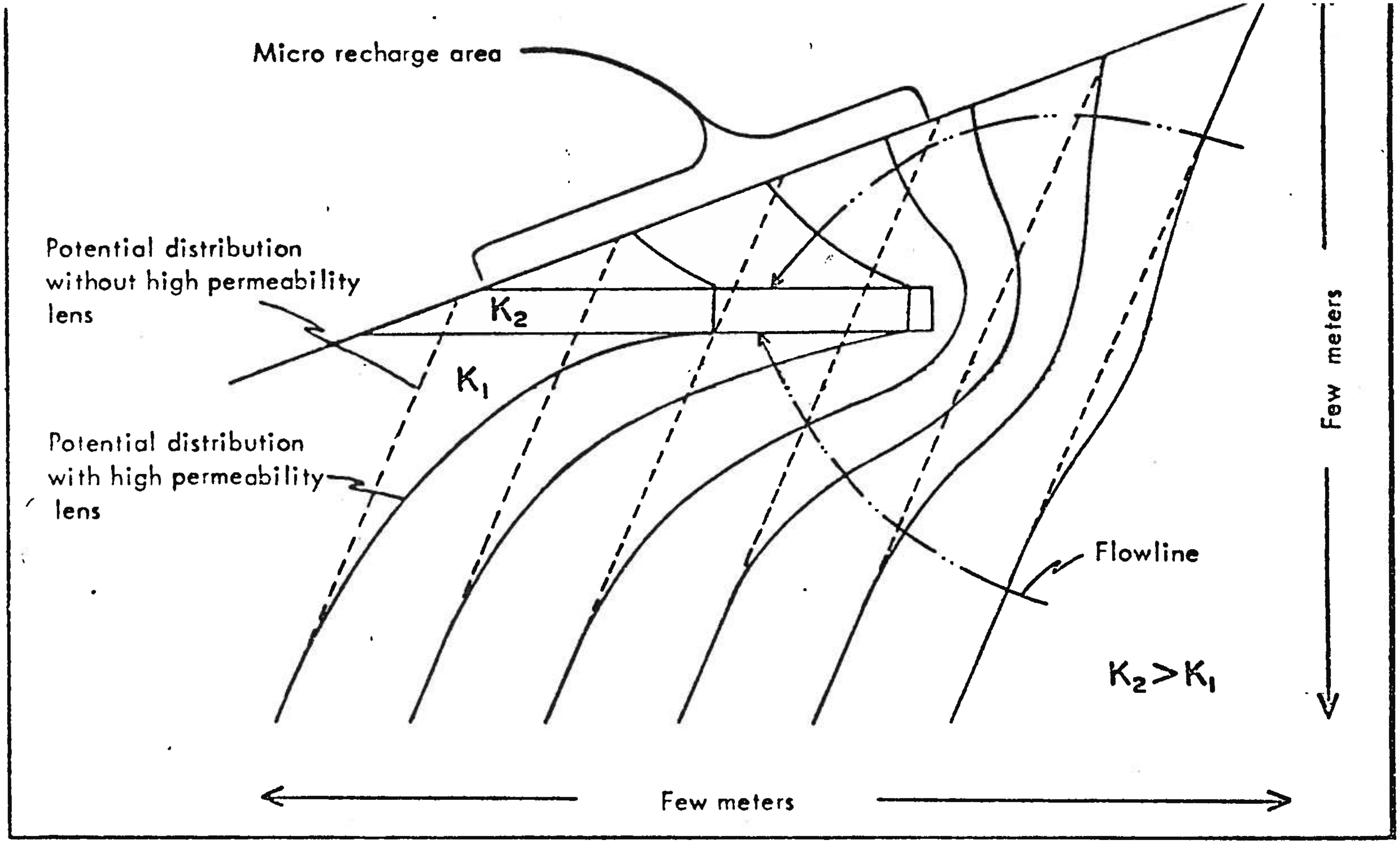


Figure 4. Diagrammatic representation of the flow pattern associated with a small high permeability lens in a general discharge area (after Clissold, 1967, p. 10)

$$\phi = gh$$

where ϕ is the fluid potential, g is acceleration due to gravity, and h is the elevation to which the fluid rises above standard datum (commonly called head). From this equation it can be seen that the fluid potential is a form of potential energy. Thus, it can be said that in general water will flow underground from areas of higher topographic elevation to areas of topographically lower elevation. The path which water takes should be considered next. This problem was studied by Hubbert (1940) and later by Toth (1962; 1963). One example of possible groundwater flow patterns is shown in figure 3. From this figure it can be seen that a slope can be divided into three zones:

1) An area in which water moves away from the water table, called the recharge zone.

2) An area in which water flows parallel to the water table, called the hingeline or midline.

3) An area in which water flows towards the water table, called the discharge area.

From figure 3 it can be seen that if a well were drilled in the recharge area it would be encountering equipotential lines of decreasing value. Therefore the water level in the well would be dropping as the well was deepend. For the same reason the water level in a well drilled at the hingeline will not change with depth, while the water level of a well drilled in the discharge area will rise as the well is deepened. This phenomenon is true in most situations. Thus it is much more favourable to drill a production well, or sump, in the discharge area because the available drawdown will be relatively greater than in the recharge area. Another reason, is that if the well was drilled in a recharge area and then pumped, the well will be acting to reverse the flow of groundwater and thus be much less efficient than one drilled in the discharge area.

Cases where inhomogeneities are present in the permeable medium have been calculated by Freeze (1966) by the use of a digital computer. The effect of a more permeable zone in a homogeneous medium on the distribution of the fluid potential was calculated by Freeze (1966), a diagrammatic drawing of such a case is given in figure 4 (Clissold, 1967, p. 10). Note that the effect of the permeable zone is to deflect the equipotential lines and thus increase the hydraulic gradient in the less permeable material. This has the double effect of increasing the flow rate and directing the flow towards the more permeable zone. It is therefore more efficient to drill a well in a permeable zone.

From the above discussion it becomes clear that it is very important to determine the direction of groundwater motion and to determine the location of permeable zones if one is to have an efficient dewatering program. A detailed knowledge of groundwater movement is also important to determine the volumes of water entering and leaving the lease, and the direction from which it is entering or leaving. It is also possible to obtain a general idea of the permeability of the overburden if water level fluctuation are known in conjunction with a knowledge of groundwater movement.

Electric Model

One method of studying groundwater motion is by use of an electric model. The electric model that was used in this study is of the conductive-sheet type. This model gives a two dimensional representation of the flow through a homogeneous medium within a selected cross-section. It is constructed by cutting a section of conductive paper to represent a scaled-down version of a cross-section to the depth of the effectively impermeable boundery - in this case the tar sand with 8% bitumen or more. At selected points along the top of model, a potential is applied proportional to the elevation of the water table at that point. Once this is done the electric equipotential lines within the model are traced using a

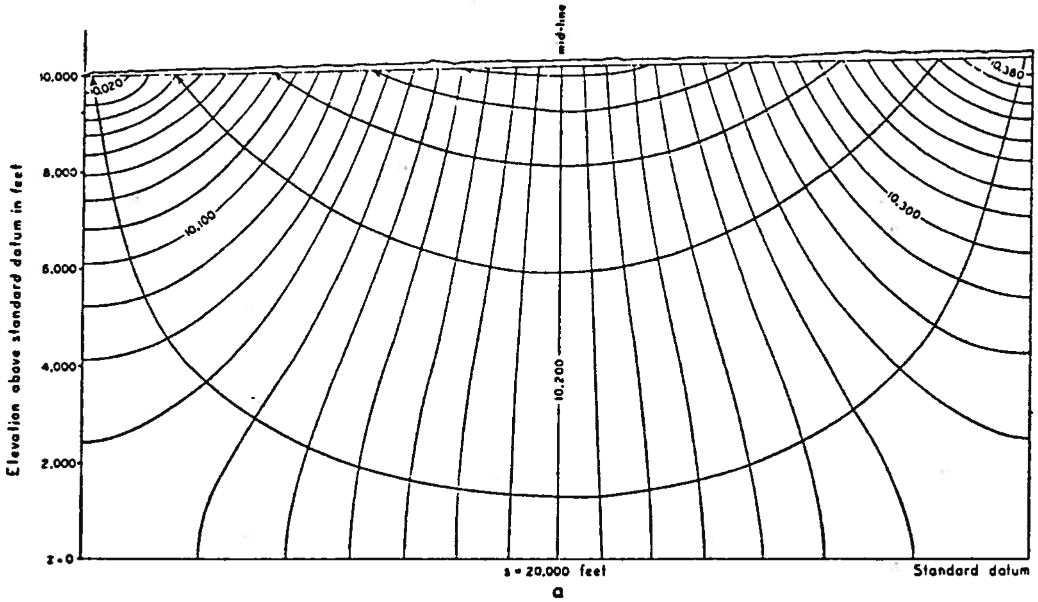


Figure 3. Distribution of recharge and discharge areas with respect to the hinge line (midline) (modified after Toth, 1962, Fig. 3)

probe and a voltmeter. The current flow lines can now be traced, for current flows from higher to lower potential values perpendicular to the equipotential lines. As there is a direct correspondence between the laws governing current flow and groundwater flow, the current flow lines and equipotential lines can be considered to be similar to those of groundwater. The electric model is reproduced as figure 4 (in pocket) in this report.

One major feature that can be noticed in the model is that the active flow systems are relatively short. The only flow lines that extend for any distance are the deepest ones, and they flow through a fairly restricted zone. Consequently only a small volume of water flows through this zone. The major portion of the flow takes place in the local flow system which envolve a topographic high and its adjacent low.

Though the electric model only gives us information about groundwater flow along a two-dimensional cross-section and for a homogeneous medium, the information gained from the model combined with field observation and a knowledge of the geology makes it possible to determine grounwater flow throughout the area with a moderate degree of accuracy.

Estimate of Groundwater Entering the Lease from Outside

a. Through the Tar Sand

An estimate of water entering the lease through the tar sand is important for if the quantity is large it may be difficult to provide dry conditions for the removal of overburden. The author has come to the conclusion that flow through the tar sand is generally minor and should not contribute significant amount of water to the overburden. However it is believed that a small quantity of water is contributed by the tar sand and this water may enter the overburden through localized areas. In these areas the flow may be large enough to present problems to heavy equipment removing the overburden. The only way in which these areas can be located, if they are present, is by groundwater chemistry possible followed by additional drilling and bail testing.

Some of the reasons for which the author believes that little water is contributed by the tar sand have already been presented above. These and other evidence will be briefly discussed. Because the permeability of the tar sand is low (Table 6), flow through the McMurray Formation may take place but would be sluggish. Such flow would start either in the Birch Mountains or the

Table 6. Porosity and permeability of tar sand with bitumen content of less than 8 per cent (after Clark, 1959)

Oil content % wt.	Porosity %	Saturation		Water content %	Perm. mill:Darcy
		Oil %	Water %		
7.3	37.5	38	46	17.25	8
7.6	32.6	47	31	10.11	35
7.0	30.8	47	47	14.48	2
7.3	33.0	44	27	8.91	8
7.0	34.5	40	39	13.46	0.3
6.8	34.0	40	39	13.26	5
6.1	33.7	35	28	9.44	60
5.2	32.9	30	13	4.38	50
5.0	31.1	32	37	11.51	0.5
5.0	33.0	30	36	11.88	10
4.9	34.1	29	57	19.44	2.5
4.8	27.6	37	40	11.04	4.0
4.8	30.5	31	11	3.36	Nil
4.7	32.0	29	43	13.76	6
4.0	31.5	26	45	14.18	3.5
4.0	27.3	31	47	12.83	1.0
3.9	30.7	26	60	18.42	1.0
3.7	27.8	28	57	15.85	0.1
3.4	27.6	26	52	14.35	0.9
3.1	32.0	19	43	13.76	Nil
2.8	24.4	25	48	11.71	1.0
2.4	27.4	19	53	14.52	3.5
1.4	20.2	16	74	14.95	Nil
1.2	30.7	8	82	25.17	2.5
0.8	25.6	7	76	19.46	0.6
0	27.7	0	96	26.59	Nil
	30.392			14.00	9.0 average

Thickwood Hills and end in the GCOS Lease area. Water originating in the Birch Mountains has to flow under the Ells, Dover, and Mackay Rivers before it reaches the lease, and water originating in the Thickwood Hills has to flow under Beaver River and Ruth Lake. Such depressions as the rivers and the lake have the tendency of diverting flow lines towards them and thus act as barriers to all but the deepest flow lines. Thus the volume of groundwater originating in the Birch Mountains or the Thickwood Hills is considerably reduced by the time it reached the lease area. One possibility that has not been considered until now is that the groundwater may flow in the Devonian Beaverhill Lake Formation, which mostly composed of limestone and underlies the McMurray Formation. Such a formation may have solution channels that would be very effecient in transporting water from one area to the other, and would probably be deep enough not to be affected by the aforementioned rivers and lake. There are several independent lines of evidence that suggest that this does not occur. None of the evidence is conclusive by itself, but when they are considered together they are fairly convincing. One source of evidence is the evapotranspiration calculations which indicate that most of the water precipitated in the area can be removed by evapotranspiration. As there is not evidence of significant amounts of water draining out of the area as surface drainage, and no springs were observed by the author on the Athabasca River escarpment or on the southeast bank of Ruth Lake, subsurface drainage must not be significant. Thus one is led to the conclusion that there is very little if any water contributed to the area through the McMurray Formation. Groundwater chemistry presents another source of evidence. As has previously been indicated, there is a marked difference between the composition of the groundwater in the McMurray Formation and those collected from the overburden. This in itself is indicative of little or no groundwater contribution from the McMurray Formation. A more convincing argument, which has already been presented above, is that if most of the water was removed from the area by evapotranspiration any inflow of significant quantity of dissolved solids would produce very saline conditions, for the solids would rapidly accumulate. The low total dissolved content of the overburden water indicated that this does not happen. In certain locations in the lease where the overburden has been removed, water has been found to seep out of the tar sand. Though the volume of water seeping is not large it is slightly greater than that expected by the author to be contributed by the tar sand. The larger volume of water could be due to the reduction of head above the tar sand caused by the removal of the overburden. If the area of exposed tar sand is representative of the lease, then the water contributed by the tar sand will be of minor concern.

b. Through the Overburden

The permeability of the overburden, as a unit, is greater than that of the underlying tar sand (Table 8), therefore the major portion of groundwater movement occurs in the Cenozoic deposits above the McMurray Formation. This zone being only about 200 feet at its thickest points allows the flow of active flow systems that are relatively short - approximately 1,000 yards (Figure 4, in pocket). Thus the major portion of groundwater in the overburden moves from a high to the adjacent low, and consequently does not travel long distances. This is the same conclusion arrived at when considering the groundwater chemistry of the overburden. As a rough generality it can be said that when the lease boundary passes between a topographic high and a topographic low, if the high is within the lease groundwater is moving out of the lease, while if the high is outside the lease groundwater is moving into the lease. The volume of water moving in and out of the lease is approximately equal to the volume of water precipitated on the flanks of the high adjacent to the lease boundary. As there appears to

Table 7. Calculations of total water stored in overburden sedimentary units, assuming saturation

Unit	Average porosity percent voids	Estimated Specific Yield percent	Volume of unit in million cubic feet[3]	Volume of water in million cubic feet
B_{III}	35	35	117	40.95
A_{II}	33	33	374	123.42
B_{II}	36[I]	36	587	210.32
C	38	38	2,914	1,107.32
B_{I}	33	33	98	32.34
A_{I}	30	30	201	60.30
E	40	40	752	300.80
		Average water content		1,875.45
TS	14[2]	14	6,812	95,368.00
				97.243.45

Total estimated volume of water stored in GCOS overburden, exclusive of muskeg = 97,243.45 x 10^6 cubic feet or 605 billion imperial gallons.

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[1] Estimated visually by author

[2] Calculated average content by volume after Clark (1959) (see table 6 in this report)

[3] Linkens (1965)

[4] Assuming saturation

be a slight excess of areas where groundwater is leaving the lease it is possible that the lease may have a net loss of groundwater flowing through the overburden. This loss however will be relatively small.

Specific Yield of GCOS Overburden Units

The specific yield of an aquifer is the amount of water released by a unit volume of the aquifer under water table conditions when it experiences a unit drop in head. Thus the specific yield of an aquifer is less than the total volume of water in a unit volume of that aquifer because all the water never drains out. This is especially true in this study in the case of the tar sand where water is trapped by an enclosing layer of bitumen.

Until the specific yield can be estimated more accurately from the results of the proposed bail and pump tests the total volume of water that can be mined from the overburden will be assumed to be equal to the volume of water in the individual overburden units. If the overburden units, other than tar sand with less than 8% bitumen, are considered saturated, the amount of water then can be pumped from storage from an overburden unit will be the same as the porosity, expressed in percent (Table 7).

The water content of the McMurray Formation having a bitumen content less than 8% has been determined by Clarke (1959) (Table 6) and therefore saturation does not have to be assumed. The total volume of water that will have to be pumped out of the overburden, exclusive of induced groundwater flow and water in muskeg is 605 x 10^9 imperial gallons. This figure should be considered approximate because of the assumptions made. The source of the greatest inaccuracy in this figure is in estimating the specific yield of the tar sand. This overburden unit has such a large volume that a small error in the specific yield will produce a major error in the total volume. At the present it is believed that the specific yield of the tar sand has been over estimated and therefore the total volume of water to be pumped out of the overburden from storage is smaller than the calculated figure.

Permeability of GCOS Overburden Units

The permeability of the individual units of the Cenozoic deposits were estimated by the author using a chart of permeability ranges for various sediments given by Davi~~e~~s and DeWiest (1966, p. 164). In arriving at the permeability estimates the author made use of the grain size distribution range given by Linkens

(1965), size frequency curves, and permeability estimated provided by Materials Testing Laboratories Ltd., and the author's field observations. The permeability of the McMurray Formation with a bitumen content of less than 8% and that with more than 8% bitumen were taken from Clark (1959).

Table 8 gives the permeabilities that have been temporarily assigned to the individual overburden units. They are believed to represent the unit as a whole and may thus vary greatly from the permeability of a small portion of a unit. This is especially true in the case of the C unit. Because of the extensive deposits of muskeg, its permeability is important. Therefore it has also been included in table 8.

Table 8. Estimated permeability for Cenozoic and Cretaceous lithologic units in GCOS Lease 86

Unit	Permeability Meinzer units (gpd/ft^2)
Muskeg*	20
B_{III}	5×10^3
A_{II}	5×10^2
B_{II}	10^3
C	50 (range between 10^{-4} and 10^3)
B_I	5×10^3
A_I	5×10^3
Clearwater Shale	10
McMurray Formation less than 8% bitumen**	1.6 (9.0 millidarc
McMurray Formation more than 8% bitumen**	0.9

*Estimated from MacFarlane (1961)

**From Clark (1959)

B. PROPOSED DRILLING AND AQUIFER TESTING PROGRAM

Introduction

In this section the proposed test drilling and aquifer testing program is described in detail, noting the information to be gathered and the purpose for gathering it. The method of collecting the information is described in some cases so that the equipment best suited for the purpose can be selected. It has been the experience of the Groundwater Division of the Research Council of Alberta that the cable tool method of drilling is well suited for drilling during a groundwater investigation. Because of the author's familiarity with this method of drilling, the techniques and terms used below refer to the cable tool drilling rig. However it is not the intention of the author to request a specific drilling technique other than one that will allow the collection of the information required, in a satisfactory form.

Test Drilling Program

The purpose of the test drilling program is to determine the areas of greatest permeability and to verify the direction of groundwater motion, as well as to establish a series of observation wells by which the dewatering operations in the overburden can be monitored. As has been indicated previously a zone having permeability greater than its surrounding has the affect of increasing the flow rate and directing the flow towards itself. For this reason, and because water flows with greater ease through a permeable zone, it is desirable to locate these zones in order to pump water from them during the dewatering of the overburden. To determine the location of the more permeable zones and the direction of groundwater movement, three types of information should be recorded during the drilling of a well. a) The lithology, b) The nonpumping water level, and c) The difference between the working water level and the nonpumping water level.

Lithologic descriptions are made in order to establish the geologic framework to determine the permeability of the various zones. As the nonpumping water level in a well represents the fluid potential, a dropping water level indicates that the fluid potential decreases with depth and therefore water is flowing downwards, i.e. the well is probably being drilled in a recharge area. The opposite is true, a rising fluid potential with depth indicates a discharge area. The working water level, refers to the water level in the hole which is being drilled by the cable tool method. A certain amount of water is being removed at a regular interval from the hole as a part of the drilling operation, the water level in the hole is therefore at a balance between the amount of water being removed from the hole and the ability of the formation to replace it. If the formation has a low permeability, the water level will be low, and vice versa. The important aspect in recording the working water levels is to note sudden changes in the level of the water. These indicate that a formation or lense with a significantly different permeability has been encountered.

Aquifer Testing Program

Bail Tests

Bail tests are a very convenient method of determining the transmissivity and the specific yield of an aquifer, rapidly and inexpensively. The small inherent inaccuracy in the results obtained, due to assumptions made in the derivation of the equation used, is overcompensated by the advantages provided by this method. Because the test requires only one hole it can be conducted in several location uniformily distributed throughout an area. In this way trends in transmissivity of an aquifer can be determined.

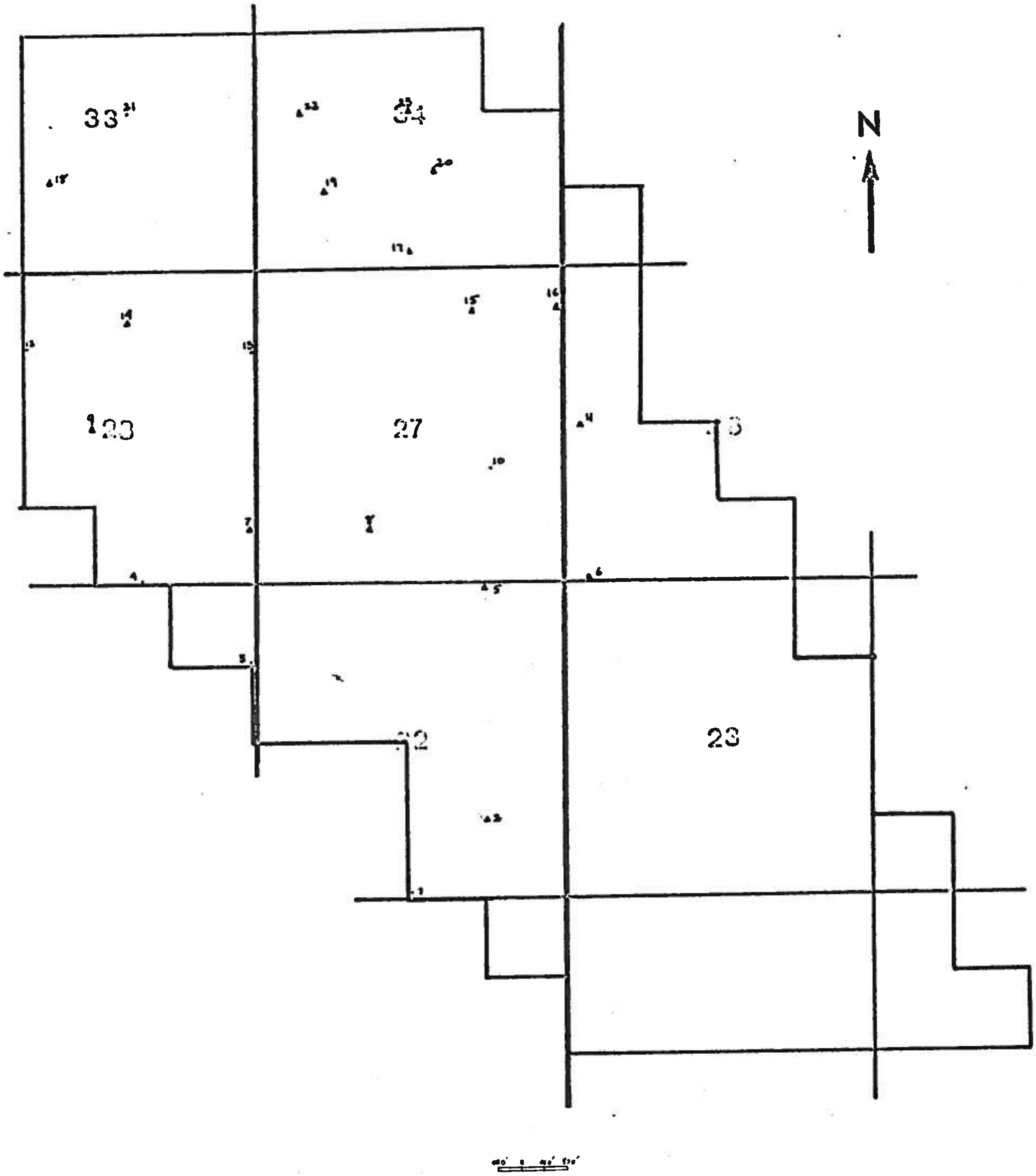
"Bail testing is the periodic removal of constant amounts of water out of a well, with a long tabular container equipped with a foot value. According to current methods of bail testing, recovering water levels are measured repreatedly after bailing has gone on for a given length of time". (Toth, 1966, p. 73). Bail testing provides a good method of determining coefficients of transmissivity of a formation close to the test site. The coefficient of transmissivity indicates how much water will move through a formation. It is essentially the permeability of the formation multiplied by its thickness. On the basis of results obtained from bail test, the location for future, more extensive pump tests can be determined. Figure 5 gives the proposed location for bail tests.

Pump Tests

Pump tests are similar to bail tests in that they are used to determine the transmissivity and specific yield of an aquifer. Because they are conducted for a long period of time (about a week) the cone of depression has a chance to expand over a much larger area than in a bail test. Thus the results are representative of a large portion of the overburden and are therefore more significant. The equations used to interpret pump tests contain fewer assumptions than those for a bail test and the results are therefore more accurate.

Pump testing is a continuous removal of water from a well for a period sufficiently long to encounter all boundary conditions. During pumping, water level measurements are taken in one, or preferably more, observation wells. Water level measurements are also made during recovery time, starting immediately after the pump has stopped. The data obtained from a pumping test is used to determine the coefficent of transmissivity and the specific yield of the formation over a larger area than is possible with a bail test. With the aid of a pump test one is, thus, in a better position to predict the effect of a continuous removal of water from a moderately large portion of the overburden.

Table 9 gives the proposed number of test holes, bail tests, and pumping tests believed to be necessary for studying the overburden. The estimated cost of the testing program is also included in the table. The location of 23 of the proposed test holes are given in figure 5 indicating which are to be bail tested. The location of the remaining 9 test holes and the pump tests will be based on the information obtained from these test holes. All tests holes are drilled to tar sand except for test hole 5, 14 and 21 which are to be drilled to economical tar sand. The location of these test holes will be subject to change as the study procedes.



▲ Test hole to be bail tested.
• Test hole not to be bail tested.

Fig. 5 Location of proposed test holes and bail tests

NOTE: There are 9 additional wells to be drilled. Their location, as well as the location of the pump tests will be decided when the results of the test holes located in this figure and the bail tests.

Table 9. Proposed test drilling program and estimated costs for GCOS groundwater study

	Footage	Casing Ft.	Size In.
1. Observational wells and production wells for two pumping tests.			
4 observation wells for each pump test = 8 observation wells	800	800	6
1 production well for each pump test = 2 production wells	200	200	8
2. Piezometer-nest installation; 3 nests, each containing 2 wells = 6 wells	600	600	6
3. 15 observation wells to monitor dewatering operations	1500	1500	6
Total	3100	2900 200	6 8

Costs:

3100 feet @ $5.00 per foot for drilling =	$15,500
3100 feet of casing @ $5.00 per foot =	15,500
Cost of 6 hours of development for each production well = 12 hrs. @ $20.00 per hour =	240
Cost of two 168 hr. pump tests = 336 hrs. @ $20.00 per hour =	6,720
Cost of 4 hrs. of bailing tests, for 26 wells = 104 hrs. @ $20.00 per hr.	2,080
Cost of moving rig to and from McMurray (from Red Deer) @ $1.00 per mile = 800 x 1 =	800
Total	$40,840

Total cost of drilling program is $40,840 for the drilling and installation of 32 piezometers and observation wells, two production wells, two pump tests and 26 bail tests.

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