Excess water discharge: Crandon Project waste disposal system: [project report 12]. v. 12 1981

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EXCESS WATER DISCHARGE

CRANDON PROJECT

WASTE DISPOSAL SYSTE

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

DRAFT REPORT ON

EXCESS WATER DISCHARGE
CRANDON PROJECT
WASTE DISPOSAL SYSTE

Submitted to:

Exxon Minerals Company
655 Washington Street
Post Office Box 813
Rhinelander, Wisconsin 54501

DISTRIBUTION:

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December, 1981 814-1287

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Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

TRANSMITTAL LETTER

To Exxon Minerals Company
655 Washington Street
Post Office Box 813
Rhinelander, Wisconsin 54501

Attention: Mr. L. Blair

Date December 9, 1981
Project No. 814-1287

Sent by Messrs. J. Edmund Baker & John V. Kinsella

- ☐ Mail
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Remarks

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Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

December 9, 1981 814-1287

Exxon Minerals Company
655 Washington Street
Post Office Box 813
Rhinelander, Wisconsin 54501

Attention: Mr. L. Blair

Reference: Exxon Crandon Project
Excess Water Discharge
Crandon, Wisconsin

Gentlemen:

We are pleased to submit the first draft of our Interim Report on Excess Water Discharge, Crandon Project for your review and comment. This report reviews and analyzes various methods for disposing of excess water at the Crandon site.

Should you have any questions, please call.

Yours truly,

GOLDER ASSOCIATES

W. F. Brumund

William F. Brumund, P.E.
Principal

JVK:WFB:ljw

TABLE OF CONTENTS

1.0 INTRODUCTION

Golder Associates was authorized on October 21, 1981, to study and evaluate alternative locations, methods, and systems for discharge of treated water from the proposed Crandon mining project to the groundwater system. Our scope of work required us to limit our site selection of potential recharge sites to the northern half of the Pickerel Creek drainage basin and not to directly cover any wetlands. Potential groundwater impacts were to be based on the assumption that 2500 gpm of continuous discharge would be generated by the treatment system.

After making a preliminary review of the alternative disposal sites and potential impacts, it became clear to Golder Associates that any realistic impact assessment must also consider where the 2500 gpm of treated water was coming from. The preliminary findings of this study were presented orally to Crandon personnel on November 16, 1981. It was suggested at that time that Golder Associates prepare a milestone report on this study.

This milestone report was to:

a) identify potential recharge sites in the specified study area

b) discuss some of the possible recharge schemes that are available

c) make a preliminary groundwater impact evaluation for several potential disposal sites

In this report, no consideration was given to the source of the treated water.

This milestone report should be regarded as a preliminary review of some of the possible recharge methods available and a preliminary assessment of the relative impact that recharge into potential disposal areas might have.

2.0 SITE LOCATION

Certain limitations on the selection of recharge sites were stipulated in the contract. These were that (a) the recharge sites should lie within the northern half of the Pickerel Creek drainage basin, (b) the recharge sites will not directly cover any wetlands, (c) the recharge sites will be a sufficient distance from groundwater discharge areas to prevent adverse surface water impact. In addition to the above limitations, it was considered that an attractive disposal area would have a thick stratum of stratified drift (aquifer) relatively close to the ground surface. Minor consideration was given to not locating disposal areas in Langlade County.

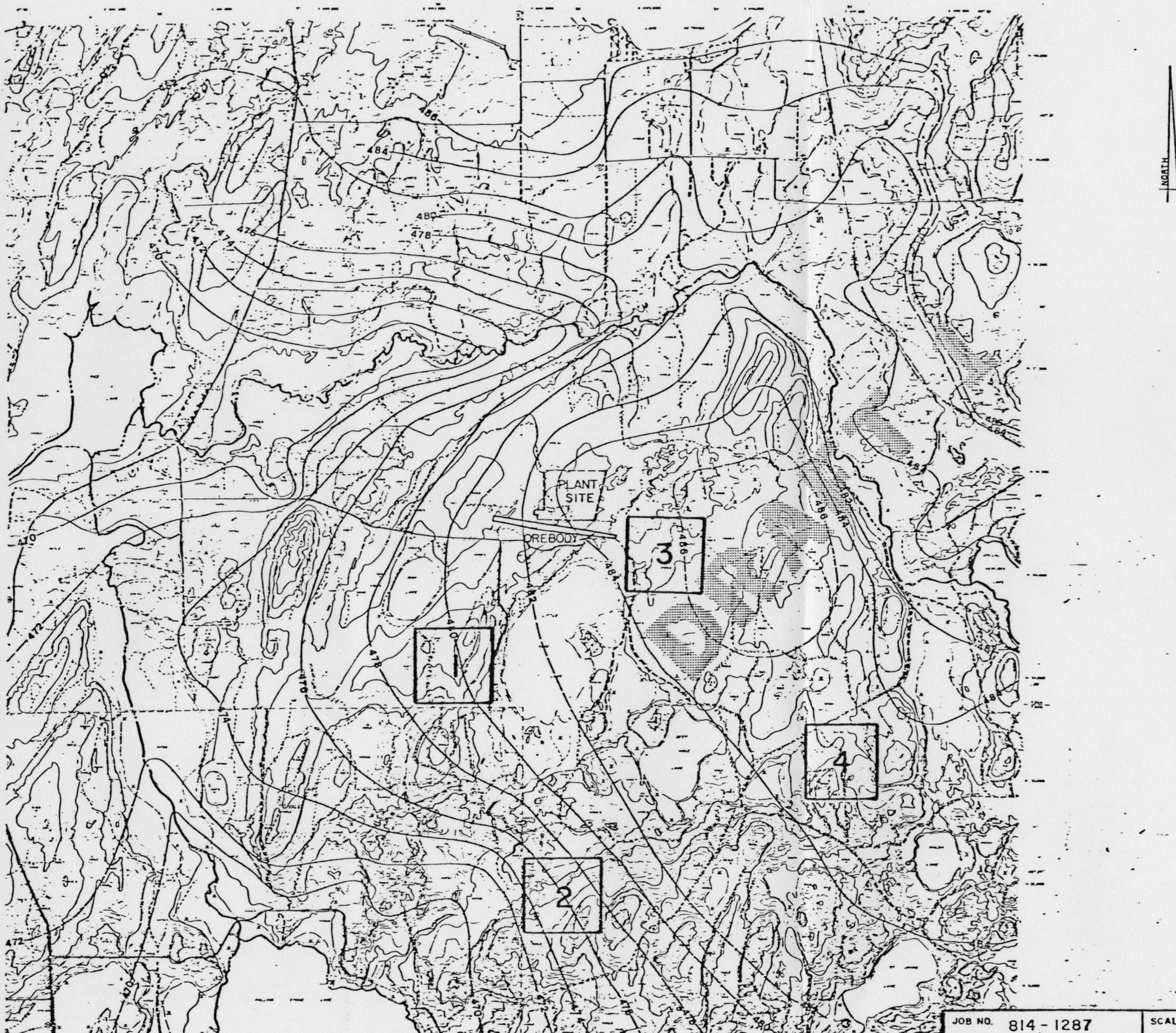
Using the above criteria, four potential excess water disposal areas were selected. These areas are shown in Figure 1. The surficial soils at each potential disposal area, based on information available at this time, is briefly as follows:

a) Area 1 - Southwest of Little Sand Lake

The surficial soils at this site consist of approximately 10 m (33 ft.) of till which is underlain by about 55 m (180 ft.) of stratified drift aquifer. There are four boreholes and one test pit within this area from which geotechnical information can be gathered. However, none of the boreholes in this area went to rock, therefore, accurate estimates of the thickness of stratified drift cannot be made at this time.

b) Area 2 - Northeast of Rolling Stone Lake

The two borings taken near this area suggest that there is no till cover and that the stratified drift outcrops in this area. Although the two borings are shallow,



LEGEND

[1] POTENTIAL RECHARGE AREA

GROUNDWATER ISOPLETHS (contours) IN METERS ABOVE MSL

GROUNDWATER ISOPLETHS IN METERS ABOVE MSL, INTERPRETED FROM LIMITED DATA

GROUNDWATER ISOPLETH 486 METERS ABOVE MSL AS ESTIMATED EXCLUDING EFFECTS OF JUNE-JULY 1980 PUMP TEST

NOTE

GROUNDWATER CONTOURS INTERPRETED BY GOLDER ASSOCIATES AND DAMES & MOORE BASED ON THE FOLLOWING DATA:

- a GOLDER ASSOCIATES AND DAMES & MOORE OBSERVATION WELL MEASUREMENTS ON SEPT 10 AND 11, 1980
- b WATER CHEMISTRY DATA FROM D&M AND DNR
- c SURFACE TOPOGRAPHY
- d USGS WELL DATA AND GOLDER WELL DATA FROM DIFFERENT TIME PERIODS

BASE MAP PROVIDED BY EXXON MINERALS COMPANY

JOB NO. 814-1287	SCALE AS SHOWN	PROPOSED RECHARGE AREAS	
DRAWN CAB	DATE 11-20-81		
CHECKED J.V.K.	DWG. NO. 050-1-80540		
Golder Associates		EXXON MINERALS COMPANY	FIGURE 1

it is estimated that the thickness of the stratified drift is about 40 m (140 ft.) in this area. Some ablation till may exist near the ground surface in this area.

c) Area 3 - North of Little Sand Lake

Three borings and three test pits have been advanced in this area; however, all of these borings are shallow. These data suggest that the stratified drift may exist at the ground surface. However, more detailed surface observations suggest that the surficial soils at this site may consist of an ablation till sheet overlying "ordinary" till, all of which is underlain by stratified drift. It is estimated that the stratified drift in this area ranges from 30 m (100 ft.) to 55 m (180 ft.) in thickness.

d) Area 4 - East of Deep Hole Lake

Four borings exist within this area. Three of these borings extend to bedrock. The surficial soils in this area consist of about 20 m (66 ft.) of till which is underlain by about 40 m (140 ft.) of stratified drift.

3.0 METHODS OF ARTIFICIAL RECHARGE

Artifical recharge of groundwater can be achieved using a variety of methods, e.g. water spreading via basins, channels, ditches and irrigation or recharging through wells. The choice of a particular method will depend on the local topographic, geologic and soil conditions. The two main methods, surface basins and injection wells, are described below.

3.1 Recharge Basins

Infiltration basins are typically used to recharge unconfined or semiconfined aquifers (Bouwer, 1977). The basins should be located so that:

(a) the surface soil is sufficiently permeable to yield acceptable infiltration rates;

(b) there are no low hydraulic conductivity zones present within the unsaturated zone that would cause perched groundwater mounds to rise into the basins and restrict infiltration;

(c) the regional groundwater table is sufficiently far below ground level to keep the resultant groundwater mound below the bottom of the basins;

(d) the aquifer is unconfined and has a relatively high transmissivity to allow lateral flow of the recharge water without building up groundwater mounds that rise into the basins.

Of the areas being considered as suitable for groundwater recharge, both Areas 2 and 3 satisfy condition (a) above. The subsurface geology is poorly defined in the vicinity of Area 2; the presence or absence of any low hydraulic conductivity layers here is not known. Geological section B-B of the 'Geotechnical Review,' Golder Associates (1981), shows there to be a layer of till underlying the surface drift at Area 3, which would make this an unsuitable location for a recharge basin in accordance with (b) above. Conditions (c) and (d) will become apparent as a particular recharge site is examined in detail (discussed below). In addition to the general considerations (a through d) above, the Crandon area experiences adverse climatic conditions (mean annual temperature ranges from -30°F to +90°F). Such low winter temperatures may result in freezing of the recharge basin(s), thereby effectively reducing infiltration to zero for a period of time.

A major practical problem with recharge basins is a reduction in the infiltration rate caused by an accumulation of sediment and other fine material on the bottom and sides of the basins. To minimize this "clogging effect" the sediment content of the recharged water should be as low as possible (this requirement will obviously be met at the Crandon site where water of drinking quality standard will be used). However, clogging will eventually occur over a period of time. A typical curve showing the reduction in infiltration rate is shown in Figure 2 (Bear, 1979). The initial reduction in infiltration rate is caused by dispersion and swelling of soil particles after wetting, the subsequent increase resulting from elimination of entrapped air by solution in the water. The steady reduction (approximately exponential) in infiltration is due to clogging of the soil pores at the bottom of the basin and just beneath it. The clogging will be due to:

(a) retention of suspended solids;

(b) algal and bacteria growth;

(c) entrained or dissolved gasses released from the water;

(d) precipitation of dissolved solids.

To restore infiltration rates to their original levels it is necessary to dry the basin and scour the top 1-2 in. (2-5 cm) of bottom material.

The frequency of cleaning will be a function of the local conditions (type of water and soil) and will effectively be determined by trial and error at Crandon. No published frequency of cleaning rates was found for specific material types, however, anticipated frequency of cleaning range from three months to 2-3 years.

From the foregoing discussion it may be necessary to have two drainage basins installed at any given location so that one is available for recharge during cleaning/maintenance of the other.

3.2 Injection Wells

Artifical groundwater recharge using injection wells is for recharge of confined aquifers and of unconfined aquifers overlain by lower hydraulic conductivity layers in the unsaturated zone. It is also an obvious choice where the topography makes basin recharge impractical or too expensive. All four areas being considered as sites for artifical recharge would accommodate injection well systems.

Injection wells are constructed in the same manner as pumped wells, with careful attention being paid to grouting of the well to avoid leakage around the casing and seepage to the surface.

Recharge wells will also suffer from a reduction in their recharge rate due to clogging from processes similar to those that take place in recharge basins. Clogging may be reduced by jetting, air surging and chemical cleaning to remove bacterial growth and encrustation products.

4.0 EVALUATION OF GROUNDWATER RECHARGE WITHIN THE PROPOSED AREAS

4.1 General Discussion

The following evaluation does not take into account any effects due to groundwater extraction and should only be regarded as a comparison between the various recharge sites and not as a definitive prediction of the response of the groundwater regime to artifical recharge. A detailed evaluation of the preferred site or sites is required to accurately define the impact of the system on the hydrology of the disposal area.

4.2 Recharge Basin Within Area 2

Of the areas evaluated, Area 2 would appear to be the most suitable for siting a recharge basin. The area required to infiltrate 13,626 m^3/d (2,500 gpm) will be a function of the rate of infiltration through the underlying soil. The infiltration will be governed, in part, by the vertical hydraulic conductivity of the unsaturated zone of the coarse grained stratified drift. There are no existing direct measurements of unsaturated zone hydraulic conductivity at the Crandon site. However, limited experimental data indicate that the hydraulic conductivity after artifical wetting may be one-half the hydraulic conductivity at complete saturation (Bouwer, 1966). From the pumping test report (Golder Associates, 1981), the saturated vertical hydraulic conductivity of the coarse grained stratified drift was estimated to be 1.12 m/d (3.72 ft./day). Assuming that the unsaturated vertical hydraulic conductivity is 50% of the saturated value, this value reduces to 0.56 m/d (1.86 ft./day), and the recharge area required would be 24,332 m^2 (261,812 ft.^{2} or 6 acres). A pond with the dimensions of 200m by 130m (660 ft. by 430 ft.) would meet this requirement. This estimate does not consider the processes of wetting front development and other transient effects, but is a reasonable estimate of the required pond area after normal operation has been established.

Leakage from the recharge pond will cause the underlying water table to rise and form a groundwater mound. Analytical methods to predict the rise of groundwater mounds have been developed by Hantush (1967). The equation describing the rise of the center of the mound in unconfined aquifers below rectangular recharge basins can be written as (symbols and definitions are listed at the end of this report and shown in Figure 3):

$$h_t - H = \frac{V_a \cdot t}{4 \cdot f} \left(4 \cdot F\left(\frac{W \cdot n}{2}, \frac{L \cdot n}{2}\right) \right) \qquad (4.1)$$

$F(\alpha, \beta)$ = error function as tabulated by Hantush (1967).

For the Crandon site, disposal via a recharge pond appears to be applicable only to Area 2. To estimate how far the center of the mound will rise after six months of infiltration, the following parameters apply:

$H = 40$ m
$V_a = 0.56$ m/d
$t = 182$ days
$f = 0.07$
$T = 448\ m^2/d$
$L = 200$m
$W = 130$m
$n = (4tT/f)^{-1/2} = 4.6 \times 10^{-4}$

For the above conditions, the center of the groundwater mound would be approximately 14.8 m (45.1 ft.) above the initial groundwater level after six months of recharging. The above analytical approach is limited to a relatively short recharge time span. The rate of rise of the groundwater mound will decrease with time as it approaches steady-state. To see whether the above mound is approaching this equilibrium position after six months of recharge, values of $h_t - H$ versus time were plotted (Figure 4). From this it is apparent that after six months of recharging, the groundwater mound is essentially at a steady-state condition.

It should be noted that this analytical solution has the following limitations:

(a) the equation is only valid if $(h_t - H) < 0.5H$;

(b) it assumes a horizontal groundwater table;

(c) it does not take account of any regional stresses placed on the aquifer.

4.3 Injection Wells Within All the Proposed Areas

The injection of 13,626 m^3/d (2,500 gpm) through a recharge well will produce a groundwater mound which is the inverse of a pumped well drawdown cone. On a sloping water table, this mound will be skewed downgradient an amount defined by the gradient and aquifer characteristics. Figure 5 represents this pictorially and defines the variables involved. The shaded area represents the region in which indigenous groundwater will eventually be replaced by recharge water. This zone extends to the nearest downgradient discharge boundary (stream or lake).

The edges parallel to the flow direction of the recharge area are bounded by limits which asymptotically approach the lines defined by the following equation (Todd, 1959):

$$y = \pm \frac{Q_w}{2K_h bi} \qquad (4.2)$$

All symbols and definitions are given at the end of this report. The upgradient boundary of the recharge area extends to a stagnation point, at a distance defined by the following equation (Todd, 1959):

$$x = - \frac{Q_w}{2\ K_h bi} \qquad (4.3)$$

These relationships are also shown in Figure 5.

To compare the relative effects of recharging at the various locations, areas of groundwater influence were computed using the above equations. Table 1 gives the limits for each of the recharge areas and Figures 6 and 7 are plan views of these influence zones.

TABLE 1

INJECTION WELL RECHARGE ZONES

Area	Hydraulic Conductivity (m/d)	Saturated Thickness (m)	Flow (m^3/d)	Gradient	Y Distance (m)	X Distance* (m)
1	11.2	40.0	13,626	0.0014	10,900	-3,500
2	11.2	40.0	13,626	0.0030	5,100	-1,600
3	11.2	60.0	13,626	0.0018	5,600	-1,800
4	11.2	60.0	13,626	0.0064	1,600	- 500

*Note that the negative X distances denote upgradient distance to stagration point.

From this comparison it is apparent that well recharge has a minimal areal impact when conducted in Area 2 (see Figure 7). However, there will be a considerable impact on Rolling Stone Lake from recharge in this area since it receives all of the recharge water. The average annual throughflow of Rolling Stone Lake has been estimated to be 0.48 m^3/s (17 cfs). The rate of well recharge is equivalent to 0.15 m^3/s (5.5 cfs), a 30 percent increase in average annual throughflow.

Recharge at the other three locations will have a significant impact on the existing groundwater system but they will be spread over a wider area. All three locations will increase streamflow rates in Swamp Creek. Using the method of Jenkins (1977) for a recharging system, the increase in Swamp Creek streamflow has been calculated for each of the relevant recharge well sites (Table 2). Since the Swamp Creek accretion will increase through time, values are presented for 1, 10 and 30 years into the operation of the system. It should be noted that this method of analysis does not consider regional groundwater gradients or variable aquifer properties.

TABLE 2

SWAMP CREEK/HEMLOCK CREEK ACCRETION

Recharge Well Location	Distance to Creek (m)	Stream Accretion Rate 1 year (m^3/s)	10 years (m^3/s)	30 years (m^3/s)
Area 1	3000	0.027	0.103	0.126
Area 3	1600	0.074	0.130	0.142
Area 4	1900	0.06	0.126	0.140

The observed low flow of Swamp Creek at County Road 55 is about 0.55 m^3/sec. indicating a maximum increase of approximately 25 percent flow through Rice Lake. For all of the proposed recharge areas, well injection of excess water will have a considerable effect on the ground/surface water system when recharged at the maximum rate at one well. This impact may be spread by having several recharge locations and/or using several methods of groundwater recharge. To illustrate the effect of a reduced injection rate, the zone for a recharge rate of 8,105 m^3/d (1500 gpm) at Area 3 was computed. The well recharge zone has been diminished as shown in Figure 6 and stream accretion reduced to 0.044 m^3/s (1.57 cfs) for one year to 0.076 m^3/s (2.7 cfs) in ten years and to 0.084 m^3/sec. (2.99 cfs) in thirty years.

The foregoing discussion is intended to compare the relative effect of recharging at the various locations. The computations performed indicate that recharge of the full amount of excess water at any one location will have a significant effect on the hydrogeological environment of the proposed Crandon mine site. This effect may be "damped" by using a hybrid system composed of basins and wells in various combinations and at several locations. These options are discussed in detail in Section 5.0.

5.0 POTENTIAL RECHARGE SCHEMES FOR THE CRANDON SITE

Three of the proposed recharge sites have low permeability till overlying the more permeable coarse grained stratified drift. As a less costly (and possibly more acceptable) alternative to using an injection well at these sites, recharge shafts may be considered (Figure 8A). They may be lined or unlined, open or filled with coarse material, and be of variable size. They may be constructed using a variety of methods (draglines and backhoes or bored). Recharge shafts are commonly used in conjunction with pits (Figure 8B). In common with other recharge methods they suffer from decreased recharge rates due to accumulation of fine grained materials in the shafts.

A successful shaft/pit recharge system is currently being used by the town of Minot, North Dakota (Pettijohn, 1968) to dispose of 15,160 m^3/d (2,781 gpm) of excess water. The facility consists of a recharge pit that feeds into a Y-shaped canal system (Figure 9A). Along the base of the canal are thirty-six 0.76 m (30 in.) diameter gravel filled holes and four large 4 m (12 ft.) diameter gravel filled shafts. Figure 9B is a cross-section of one of the recharge shafts. The shafts permit water to infiltrate from the canals down through a layer of silt and clay into the aquifer. This system operates in a hydrogeological environment similar to that at Crandon, and recharges a similar quantity of water.

For the remaining recharge site (Area 2, Section 4.1) the recharge basin proposed could be designed to consist of a series of smaller basins. The basins would be interconnected with overflow gates to allow transfer of water from one basin to another. Thus the excess water could be diverted into any combination of basins, allowing simultaneous basin recharge and maintenance to take place.

A variety of recharge options are available, some of which would be more suitable for use at the Crandon site than others. However, no realistic schemes can be proposed unless all variable aquifer stresses (groundwater withdrawal, tailings ponds infiltration, mine dewatering, etc.) are taken into account. From a consideration of the proposed aquifer use, an overall hydrological management plan may be formulated. This may indicate that due to heavy groundwater extraction at one location, it would be desirable to design a recharge system that would mitigate possible stream depletion as a result of such extraction. Alternatively, artifical recharge at a specific site might act to reduce pond seepage concentrations in both the ground and surface waters at a given location. Use of a comprehensive groundwater computer model would allow all hydrogeologic impacts to be taken into account and the optimum recharge system proposed.

6.0 SUMMARY AND CONCLUSIONS

In this report several potential excess water disposal sites within the Pickerel Creek watershed were selected for disposal of 2500 gpm of treated water. Also, several potential recharge techniques which Golder Associates considers have merit for the project are proposed and discussed. The relative groundwater impact that disposal in the various areas would have is estimated.

Four potential disposal areas are identified as shown in Figure 1. These are as follows:

a. Area 1 - Southwest of Little Sand Lake
b. Area 2 - Northeast of Rolling Stone Lake
c. Area 3 - North of Little Sand Lake
d. Area 4 - East of Deep Hole Lake

These areas satisfy all the constraints imposed in this study for disposal areas and available information suggests that substantial thicknesses of stratified drift exists in these areas. Additional detailed geological information will be required in the selected disposal area before an accurate groundwater impact assessment can be made.

The hand calculated analyses of areal effects on the groundwater system from the injection of 2500 gpm of water suggest that the changes in groundwater levels will be quite extensive. Therefore, it may be specious and unduly restrictive to specify disposal areas only in the Northern half of the Pickerel Creek watershed. The impact on the groundwater system is not controlled by the surface watershed area of the disposal system. The results of these analyses also suggest that it is not appropriate, in our opinion, to perform detailed impact analyses without considering the source of the 2500 gpm and the impact of this withdrawal on the groundwater system.

We consider that infiltration basins or various types of infiltration wells can be used for this project. Several conceptual designs for recharge systems are presented. The choice of system depends to a significant degree on the proximity of the stratified drift to the ground surface. In addition, the choice of a preferred system may depend upon other hydrologic activities which will be ongoing through the life of the mine and how these various activities interrelate.

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Principal

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SYMBOLS AND DEFINITIONS

b = saturated aquifer thickness

f = fillable porosity ($1>f>0$)

h_t = height of center of water table mound above impermeable layer at time t

H = original static height of water table above impermeable layer

i = gradient of water table

K_h = horizontal hydraulic conductivity

K_v = vertical hydraulic conductivity

L = length of rectangular recharge basin (in y direction)

Qw = pumping rate into injection well

T = transmissivity ($K_h \cdot b$)

t = time since recharge began

V_a = unit area infiltration rate into water table

W = width of rectangular recharge basin (in x direction)

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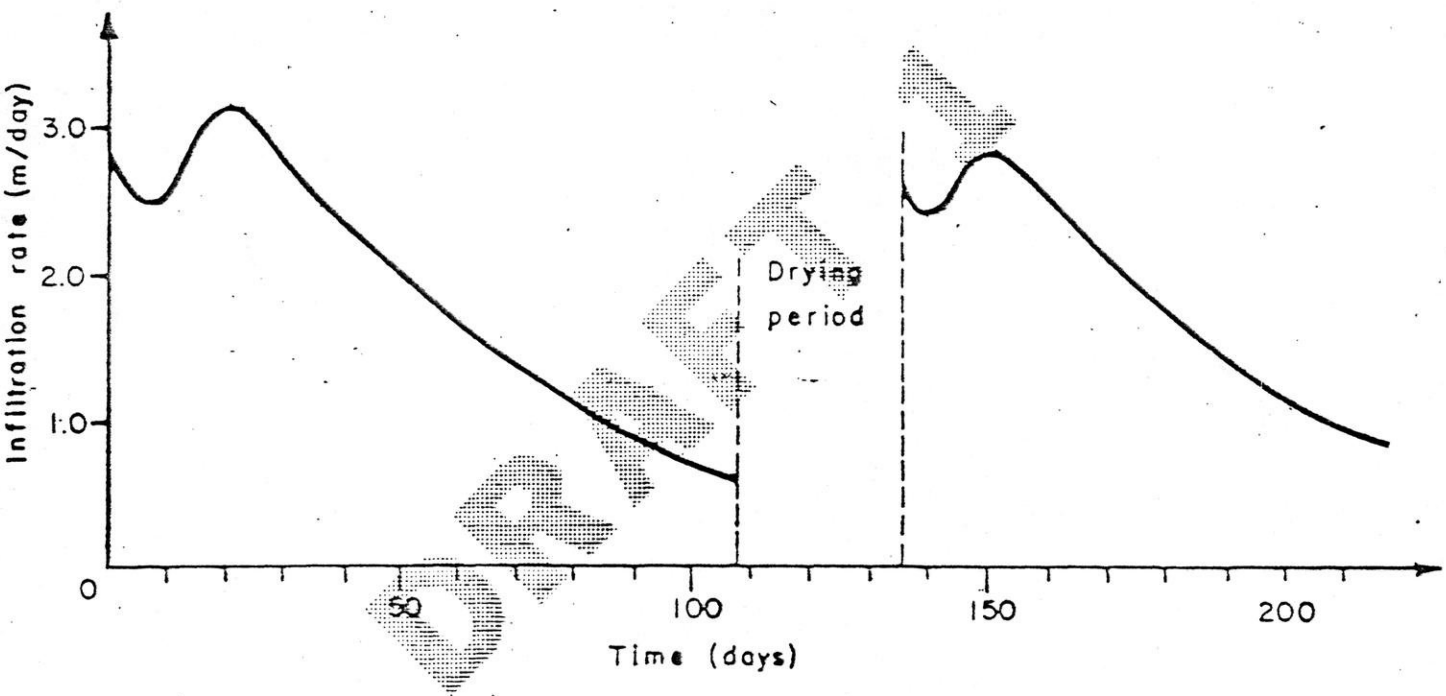
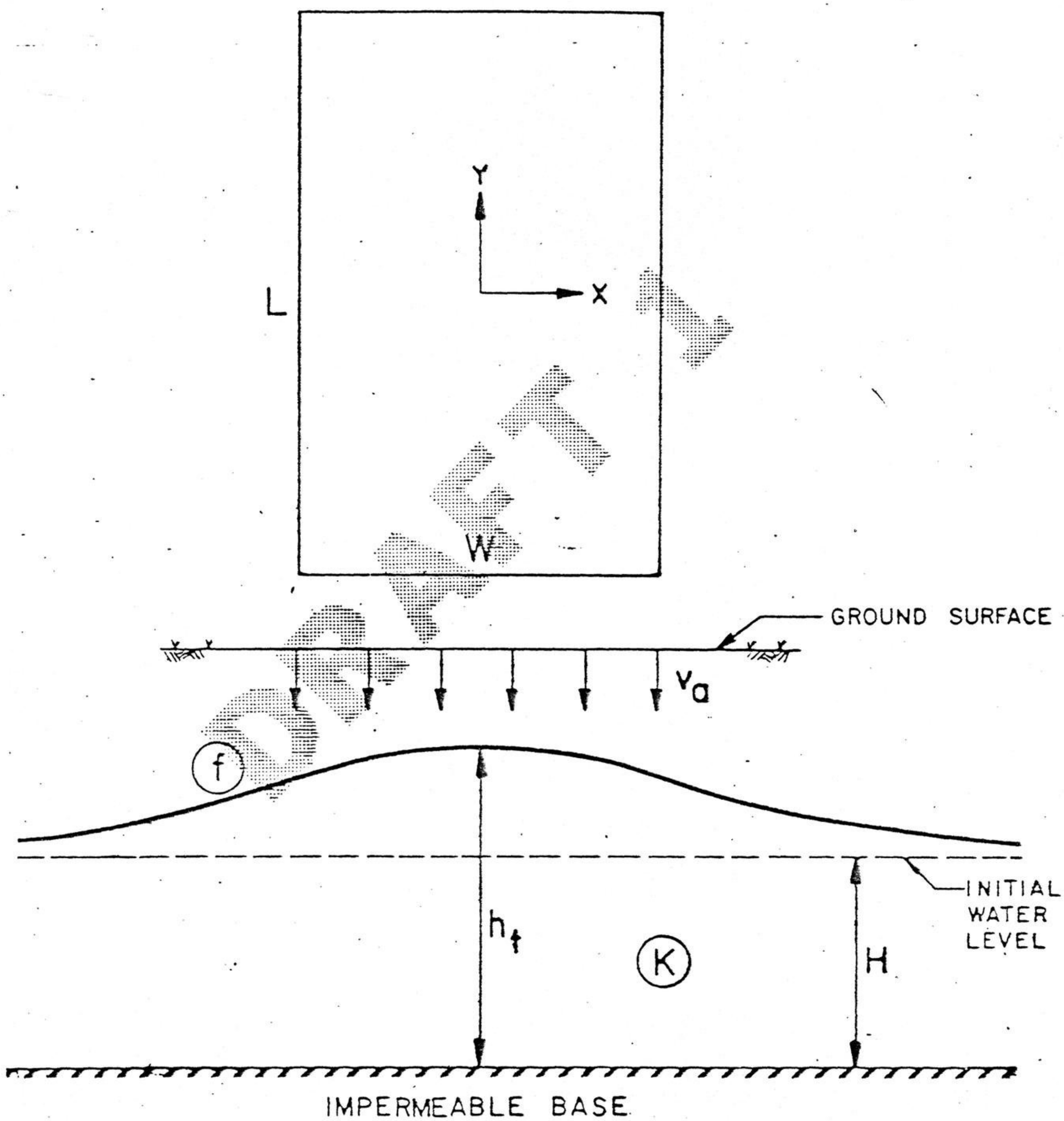


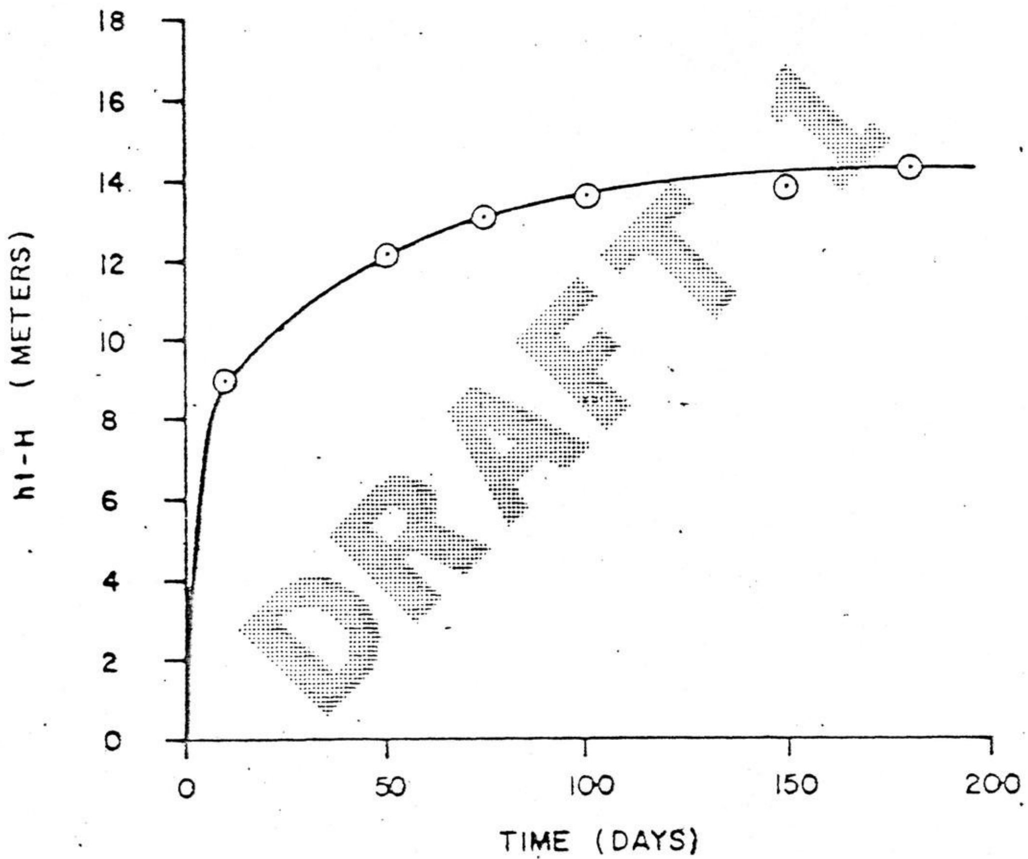
NOTE:
EXAMPLE OF DECREASE IN INFILTRATION RATE FROM RECHARGE BASINS AS A FUNCTION OF TIME DUE TO A DECREASE IN HYDRAULIC CONDUCTIVITY (AFTER BEAR, 1979)

JOB NO. 814-1287	SCALE AS SHOWN	EXAMPLE OF VARIATION OF INFILTRATION RATE WITH TIME
DRAWN SKB	DATE 11-18-81	
CHECKED JvK.	DWG. NO. 050-1-80556	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 2

AF 20440A-B



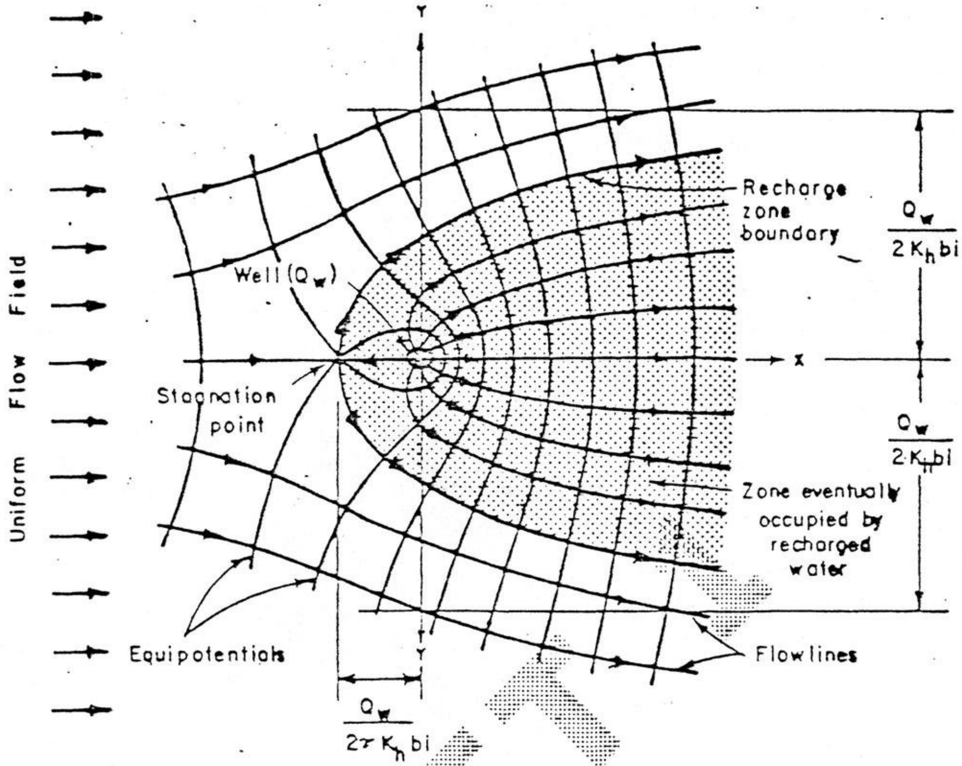
JOB NO. 814-1287	SCALE NOT TO SCALE	ARTIFICIAL RECHARGE OF UNCONFINED AQUIFER FROM RECTANGULAR AREA
DRAWN SKB	DATE 11-19-81	
CHECKED J.v.K.	DWG. NO. 050-1-80557	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 3

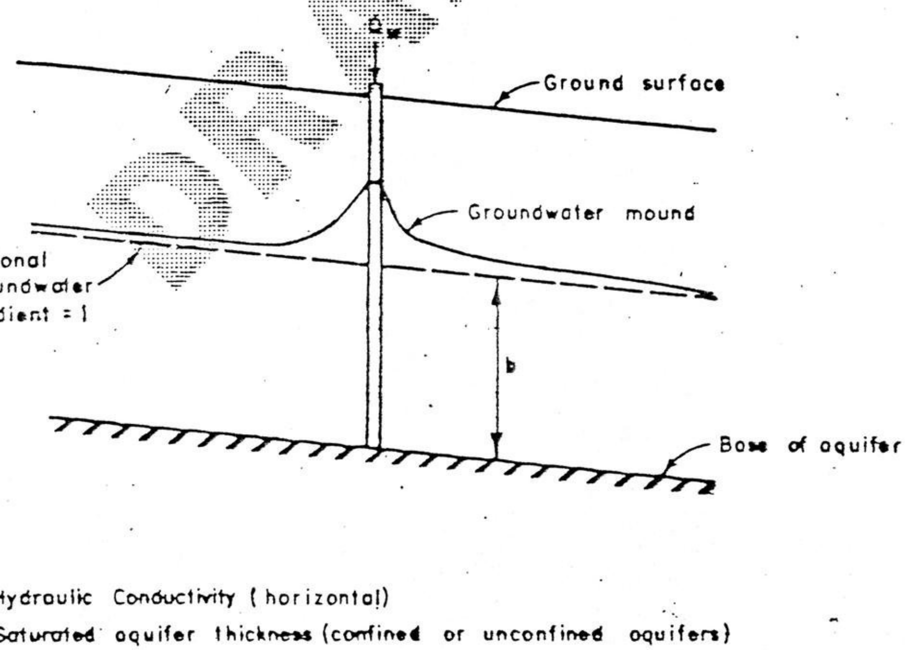


NOTE:
Increase in $h_f - H$ over time shows steady-state condition essentially reached after 6 months.

JOB NO. 814 - 1287	SCALE AS SHOWN	RATE OF RECHARGE MOUND ACCRETION
DRAWN CAB	DATE 11-23-81	
CHECKED J.V.K.	DWG. NO. 050-1-80564	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 4

A = 20440A-B

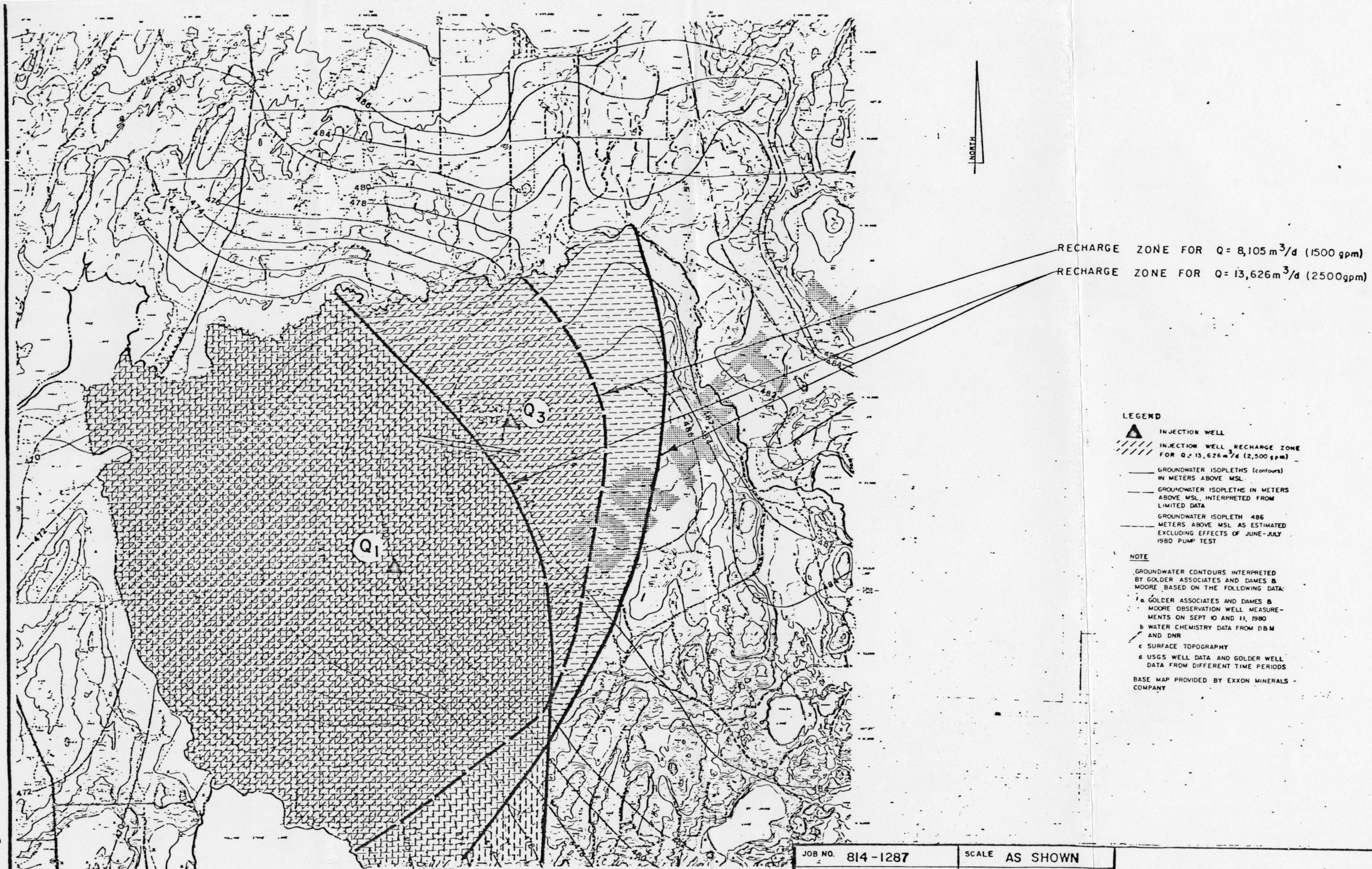




K_h = Hydraulic Conductivity (horizontal)

b = Saturated aquifer thickness (confined or unconfined aquifers)

JOB NO. 814 - 1287	SCALE NOT TO SCALE	A SINGLE WELL RECHARGING IN UNIFORM FLOW
DRAWN SKB	DATE 11 - 24 - 81	
CHECKED J.V.K.	DWG. NO. 050-1-80558	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 5



LEGEND

- INJECTION WELL
- INJECTION WELL RECHARGE ZONE FOR Q = 13,626 m³/d (2,500 gpm)
- GROUNDWATER ISOPLETHS (contours) IN METERS ABOVE MSL
- GROUNDWATER ISOPLETHS IN METERS ABOVE MSL, INTERPRETED FROM LIMITED DATA
- GROUNDWATER ISOPLETH 486 METERS ABOVE MSL AS ESTIMATED EXCLUDING EFFECTS OF JUNE-JULY 1980 PUMP TEST

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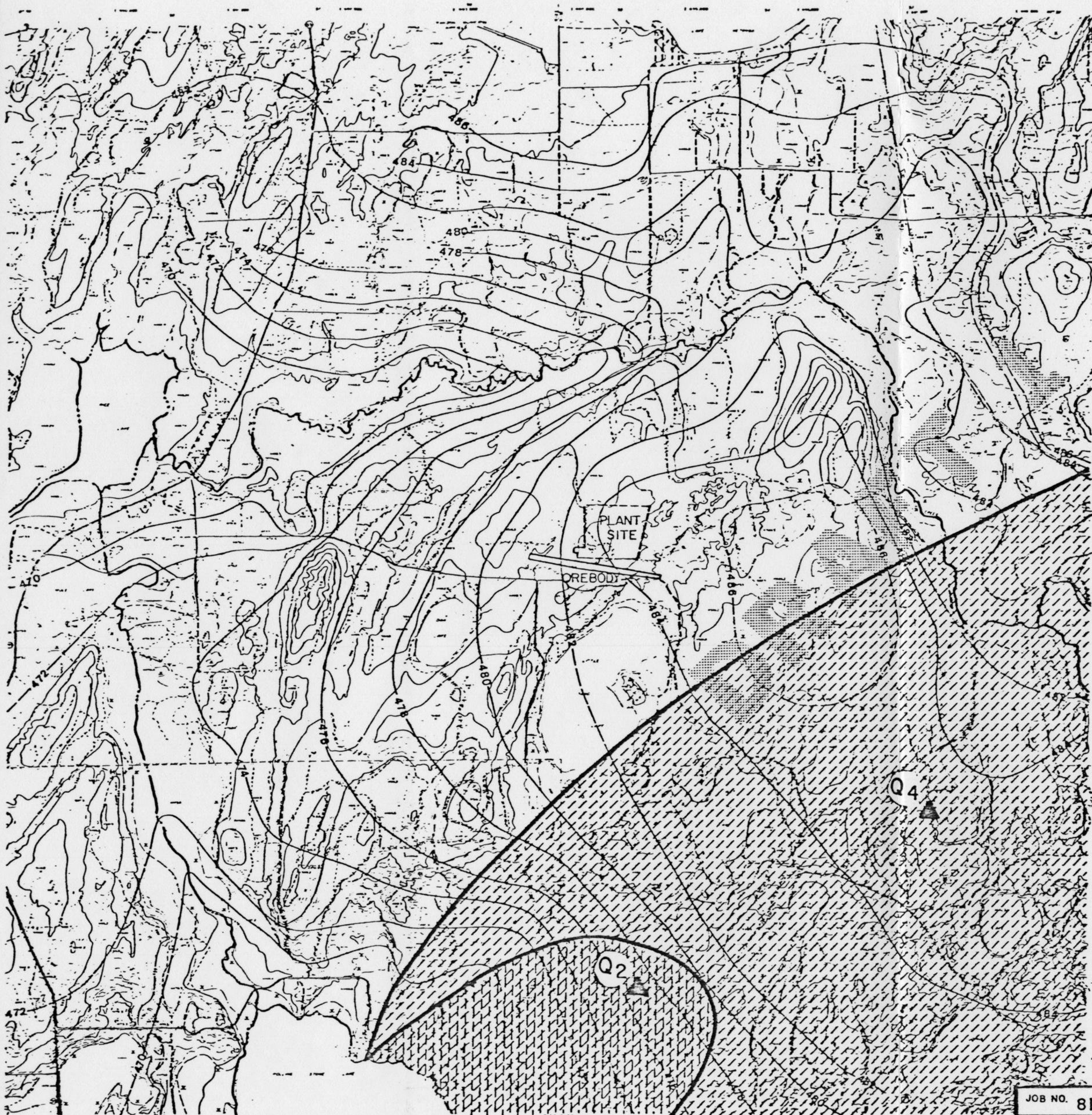
a GOLDER ASSOCIATES AND DAMES & MOORE OBSERVATION WELL MEASUREMENTS ON SEPT 10 AND 11, 1980
b WATER CHEMISTRY DATA FROM D&M AND DNR
c SURFACE TOPOGRAPHY
d USGS WELL DATA AND GOLDER WELL DATA FROM DIFFERENT TIME PERIODS

BASE MAP PROVIDED BY EXXON MINERALS COMPANY

JOB NO. 814-1287	SCALE AS SHOWN	INJECTION WELL RECHARGE ZONE
DRAWN CAB	DATE 11-25-81	
CHECKED J.V.K.	DWG. NO. 050-1-80554	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 6



LEGEND

- ▲ INJECTION WELL
- INJECTION WELL RECHARGE ZONE FOR Q = 13,626 m^3/d (2,500 gpm)
- GROUNDWATER ISOPLETHS (contours) IN METERS ABOVE MSL
- GROUNDWATER ISOPLETHS IN METERS ABOVE MSL, INTERPRETED FROM LIMITED DATA
- GROUNDWATER ISOPLETH 486 METERS ABOVE MSL AS ESTIMATED EXCLUDING EFFECTS OF JUNE-JULY 1980 PUMP TEST

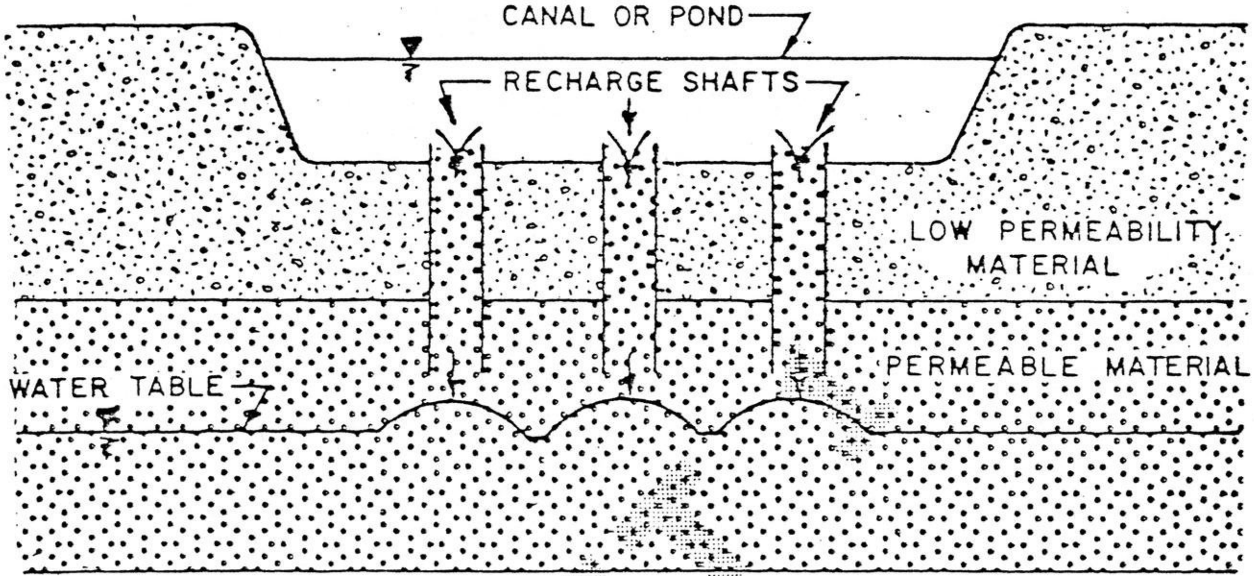
NOTE

GROUNDWATER CONTOURS INTERPRETED BY GOLDER ASSOCIATES AND DAMES & MOORE BASED ON THE FOLLOWING DATA:

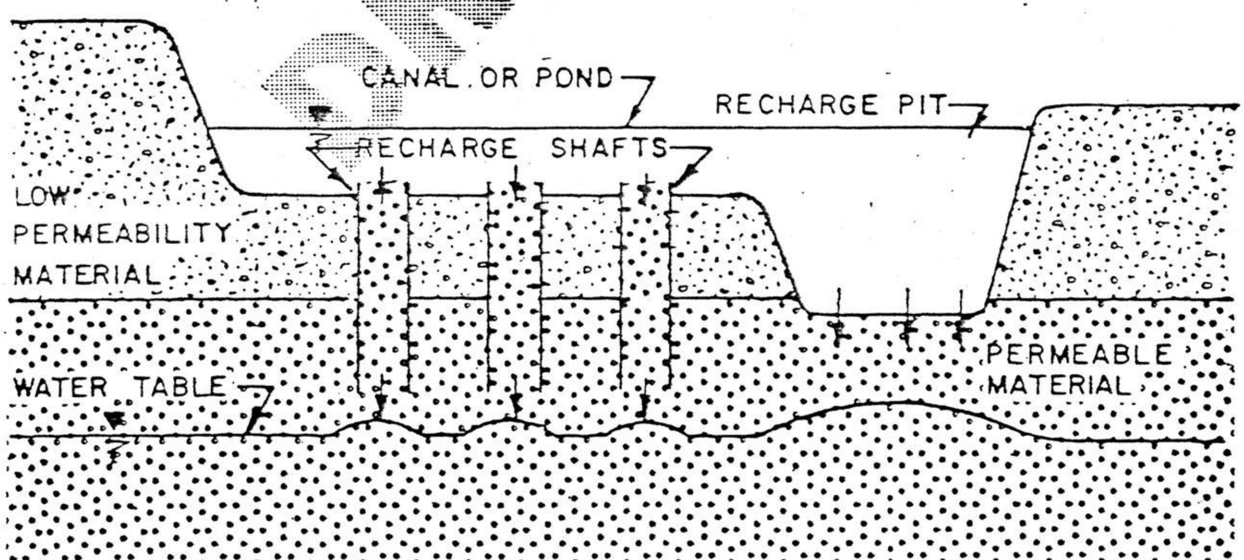
a. GOLDER ASSOCIATES AND DAMES & MOORE OBSERVATION WELL MEASUREMENTS ON SEPT. 10 AND 11, 1980
b. WATER CHEMISTRY DATA FROM D&M AND DNR
c. SURFACE TOPOGRAPHY
d. USGS WELL DATA AND GOLDER WELL DATA FROM DIFFERENT TIME PERIODS

BASE MAP PROVIDED BY EXXON MINERALS COMPANY

JOB NO. 814 - 1287	SCALE AS SHOWN	INJECTION WELL RECHARGE ZONE
DRAWN CAB	DATE 11 - 25 - 81	
CHECKED JVK	DWG. NO. 050-1-80555	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 7

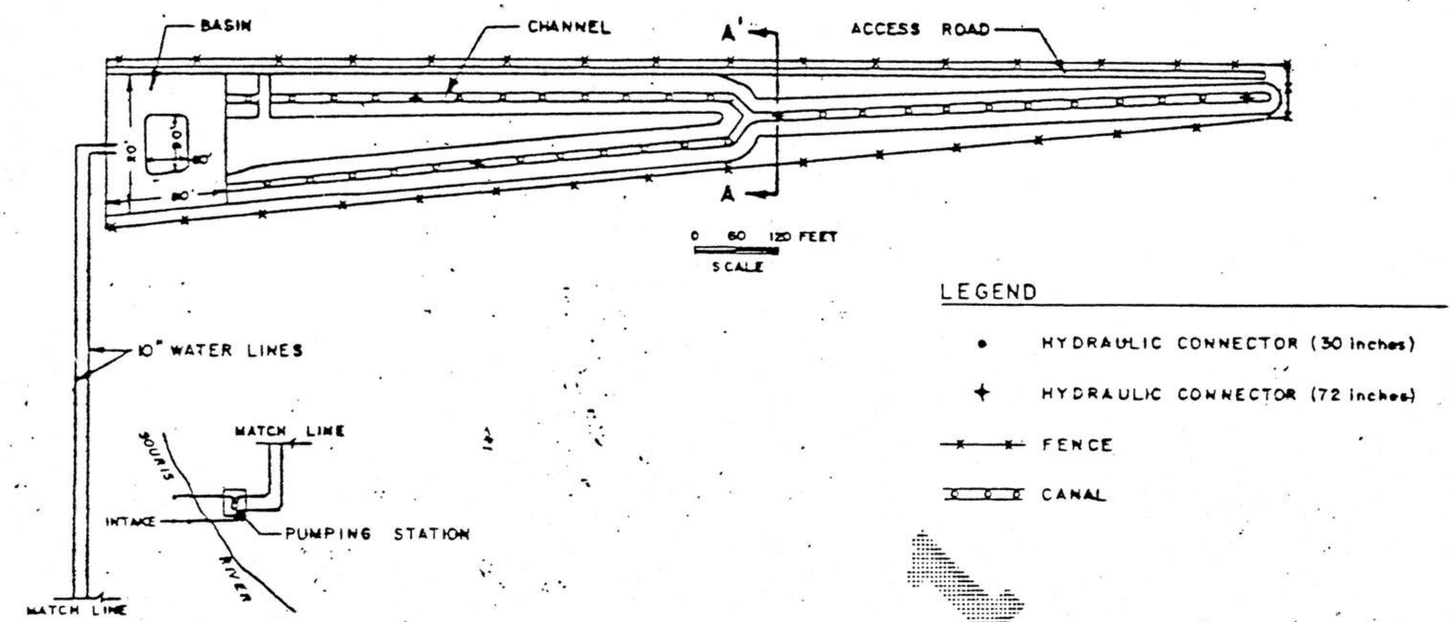


SCHEMATIC REPRESENTATION OF RECHARGE SHAFTS
8A



CONJUNCTIVE SHAFT/PIT SYSTEM
8B

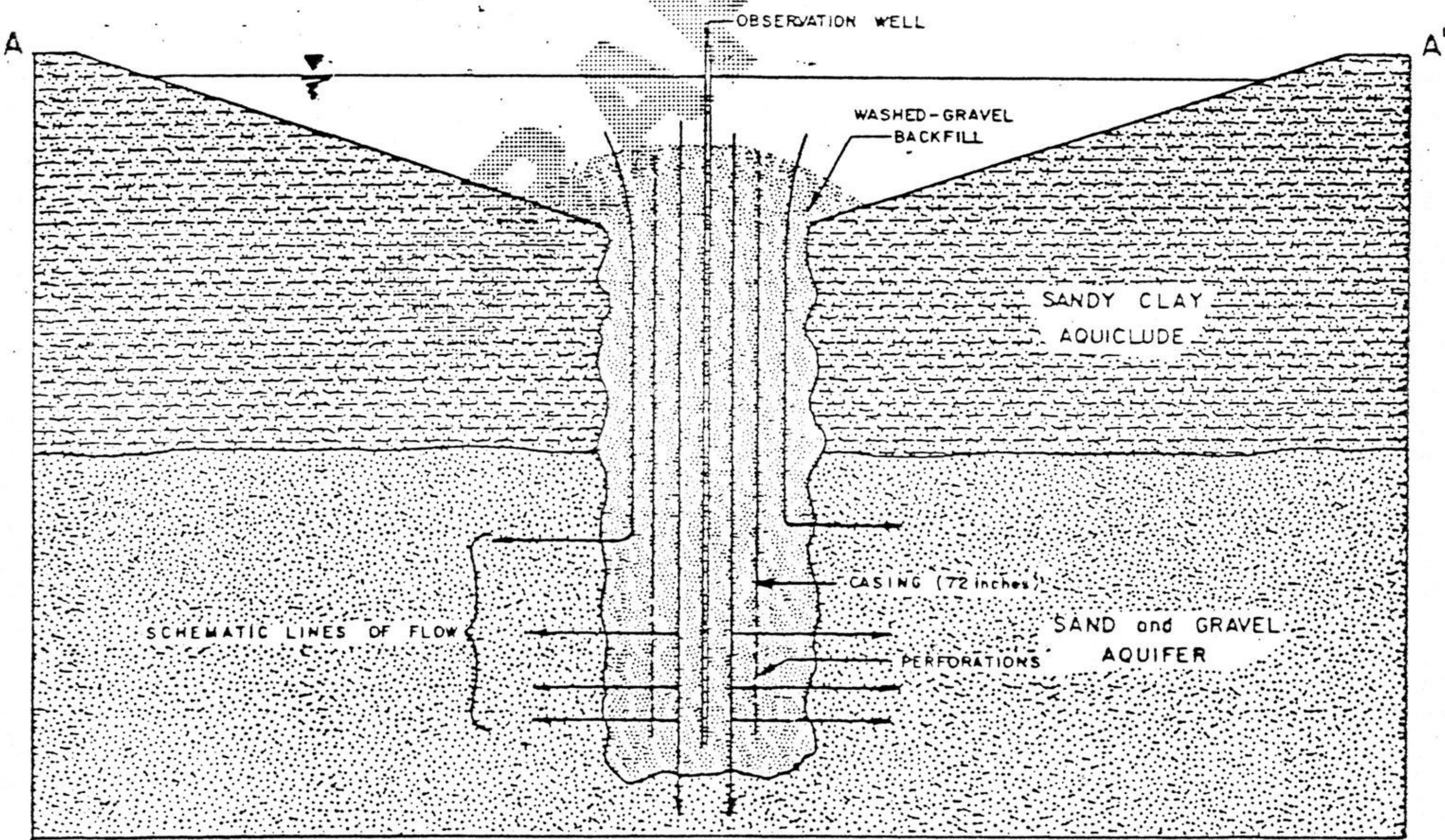
JOB NO. 814 - 1287	SCALE NOT TO SCALE	RECHARGE SHAFT SYSTEM
DRAWN SKB	DATE 11-25-81	
CHECKED JVK	DWG. NO. 050-1-80560	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 8



PLAN LAYOUT OF MINOT RECHARGE SCHEME

(after Pettijohn 1968)

9A



CROSS-SECTION OF MINOT RECHARGE SHAFT, A-A'

(after Pettijohn 1968)

9B

JOB NO. 814-1287	SCALE AS SHOWN	MINOT RECHARGE SYSTEM
DRAWN SKB	DATE 11-24-81	
CHECKED J.v.K.	DWG. NO. 050-1-80559	
Golder Associates		EXXON MINERALS COMPANY — FIGURE 9