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# The Yield and Development of a Supply from a Sandstone Aquifer Near Red Deer

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by

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Alberta
RESEARCH COUNCIL

# THE YIELD OF THE RED DEER SANDSTONE AQUIFER

by

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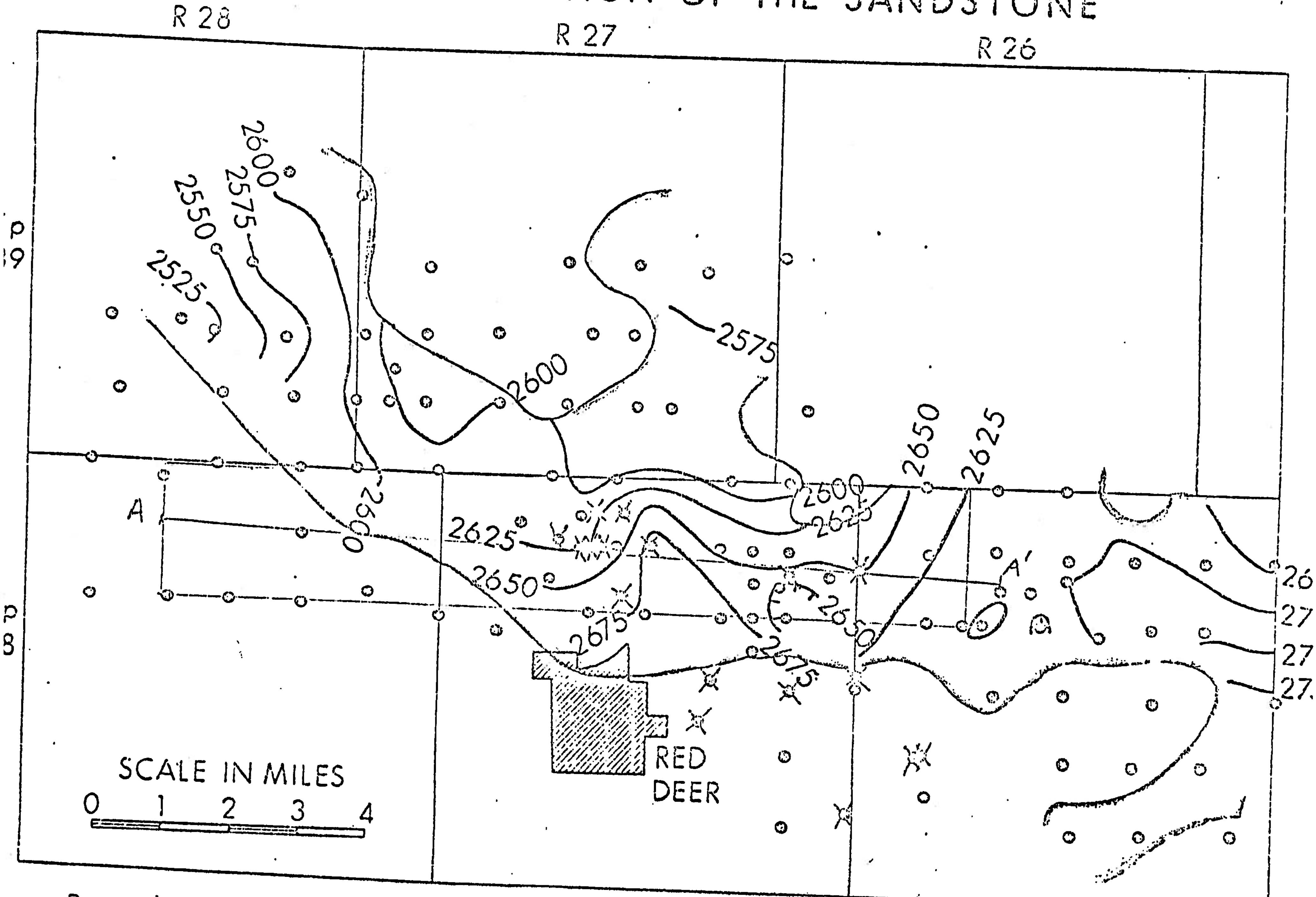
As an introduction to the topic "The Yield of the Red Deer Sandstone Aquifer," allow me to define the aquifer.

The Red Deer sandstone aquifer is found in the subsurface in an area north of the City of Red Deer. The mappable areal extent of the aquifer (Fig. 1) covers about 55 square miles. The aquifer ranges from 10 to 40 feet in thickness and occurs at depths of 134 feet in the Red Deer River valley area and up to 600 feet below surface at the major topographic divide east of the city. The aquifer material consists mainly of medium-grained, uniformly sized quartz grains. Permeability of the aquifer has been determined at points within a five square mile area north of Red Deer. The average hydraulic conductivity value for the aquifer outside the river valley area is 225 gpd/ft$^2$ but a higher value of 561 gpd/ft$^2$ was determined for the aquifer in the river valley area. A representative coefficient of storage for the aquifer is $1.6 \times 10^{-4}$. The relative permeabilities of the aquifer in the river valley area and outside the river valley area are 45 and 23, respectively, if the lowest permeability value in the geological sediments is considered to be 1.

The purpose of this presentation is to outline a method of calculating the yield of an aquifer, in this case the Red Deer sandstone. The method requires the construction of a vertical two-dimensional quantitative flow net representing regional groundwater flow, the application of Darcy's Law, and consideration of the concept of "natural basin yield" as defined by Freeze (1969). A suitable hydrogeological model is required before a flow net can be drawn. Ideally the hydrogeological model consists of a hori-

# LATERAL DISTRIBUTION OF THE SANDSTONE




Boundary of sandstone aquifer

Control point

zontal impermeable basement, an upper surface defined by the water table, and imaginary, vertical, impermeable boundaries representing major groundwater divides. Each three-dimensional closed hydrologic unit bounded on all sides by such boundaries is a groundwater basin. Freeze and Witherspoon (1967) state that a two-dimensional section through a groundwater basin is representative of the three-dimensional basin if it is taken parallel to the direction of dip of the water-table slope. North of Red Deer where the aquifer is present in the subsurface a 12-mile long hydrogeological cross section was drawn parallel to the direction of dip of the topographic slope through the area of test hole control (Fig. 2). The lower impermeable boundary was taken as the lower boundary of the Paskapoo Formation and the upper surface of the cross section was considered to be the topography because the water table closely approximates the land surface. The imaginary, vertical boundaries were assumed to be coincident with the topographic divides and positions of the Red Deer River valley and canyon. A refinement in the cross section was attained by the introduction of geologic detail based essentially on consideration of permeability contrasts and their vertical and lateral distribution. An electric analogue model was constructed from the hydrogeological cross section and the potential pattern representing regional groundwater flow was drawn. A quantitative flow net was drawn from the potential pattern (Fig. 3).

The discharge in each flow channel can be calculated by Darcy's Law:

$$Q = K \cdot \frac{\Delta \phi}{\Delta s} \cdot \Delta m w$$

where $Q$ = discharge through a segment of the flow net;

$K$ = permeability;

$\Delta \phi$ = drop in hydraulic head between equipotential surfaces;

$\Delta s$ = length of flow path in the segment of the flow net;

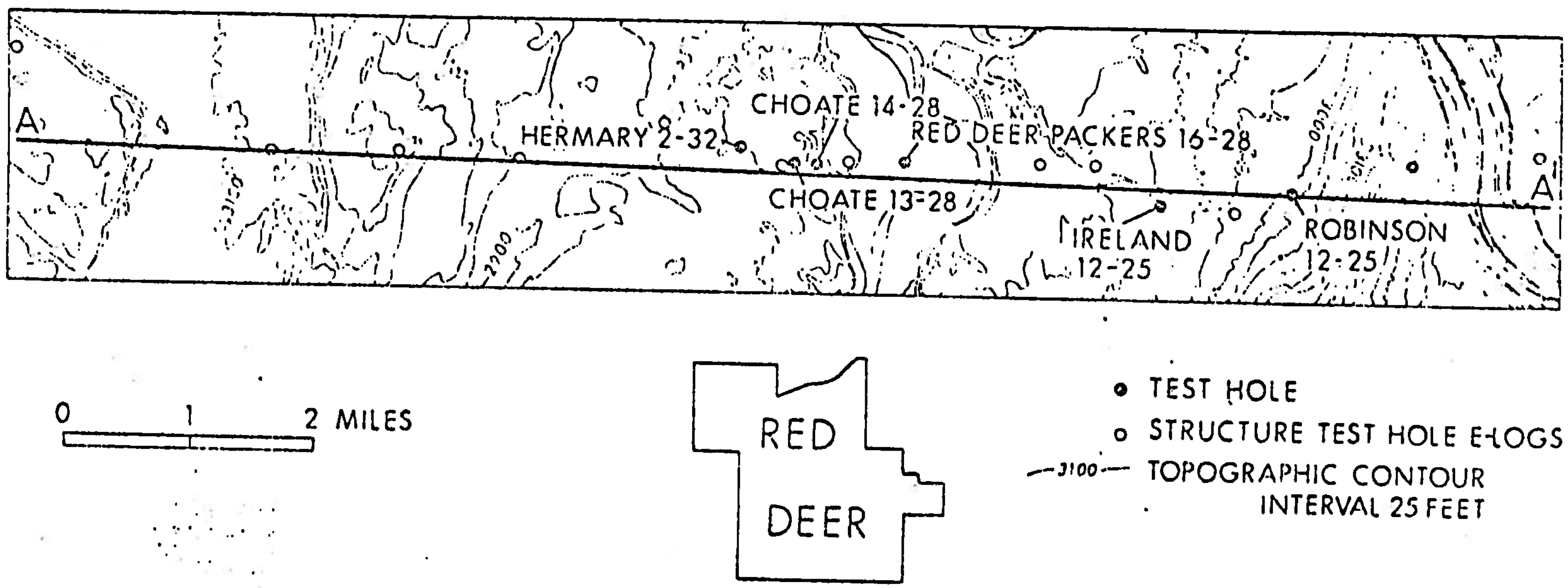



FIGURE 2. HYDROGEOLOGICAL CROSS SECTION LOCATION

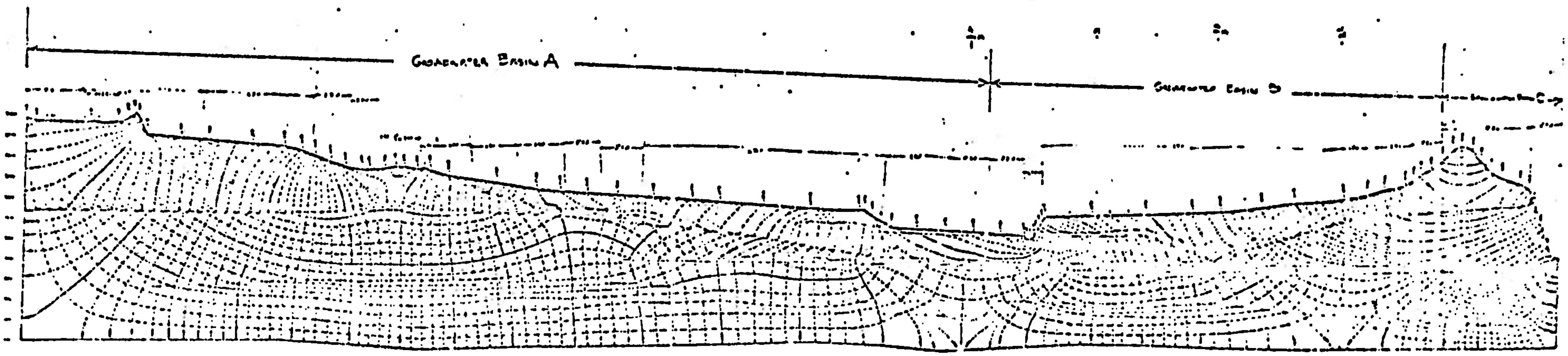


FIGURE 3. TWO-DIMENSIONAL QUANTITATIVE FLOW NET. SANDSTONE AQUIFER

NATURAL CONDITIONS

$\Delta m$ = width of the segment of the flow net perpendicular to direction of flow;

w = thickness of the flow system perpendicular to the plane of the diagram.

For the square portion of the flow net (where K = 1) $\Delta s = \Delta m$ and considering a unit thickness of the system (w = 1):

$$Q = K \cdot \Delta \varnothing.$$

The discharge in each flow channel remains constant throughout its length and the discharge in all flow channels is equal. The total quantity of groundwater flow through an aquifer is equal to the number of flow channels entering the aquifer times the discharge through a segment of the flow net.

For the regional flow net $\Delta \varnothing$ = 25 feet and a K value of 0.25 gpd/ft$^2$ was assumed a representative value for the material of lowest permeability since the lowest K value calculated, 0.6 gpd/ft$^2$ was for a 7-foot thick, slightly more permeable zone in a 145-foot interval of lower permeability material. This gives a flow channel discharge of:

$$Q = K \cdot \Delta \varnothing$$

$$= 0.25 \cdot 25$$

$$= 6.25 \text{ gpd/ft}$$ (foot of thickness $\perp$ to the two-dimensional flow net).

It is necessary now to explain the concept of "natural basin yield" defined by Freeze (1969) as the quantity of flow through an undeveloped basin with a given water-table configuration and geologic configuration. The natural basin yield is therefore a consequence of the existing potential field. It is a unique property of a groundwater basin that can be considered as a measure of the quantity of water which a given basin can accept, and is therefore a measure of the groundwater recharge to the basin. Assuming a steady-state water table, the natural basin yield will represent constant discharge which does not change with time and is relatively independent of rainfall conditions. That portion of the natural basin yield or quantity of flow entering the aquifer is equal to the natural yield of the aquifer.

## Initial Development Yield for the Aquifer

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Development yields are often stated in respect of a definite time period but if yields are related to the natural basin yield the period of withdrawal is of little importance because natural basin yield is a near-constant quantity. Considering the three groundwater basins defined in the flow net and the distribution of the aquifer in the subsurface, an initial development yield equal to the natural yield of the aquifer can be calculated for a strip of land two miles wide centered on and the length of the cross section. The results of these calculations are shown below:

| Groundwater Basin | Number of Flow Channels Entering Aquifer | Initial Development Yield of Aquifer in gpd |
|---|---|---|
| A | 6.2 | 409,200 |
| B | 7.6 | 501,600 |
| C | 20.5 | 1,353,053 |
| Totals | 34.3 | 2,263,853 |

The initial development yield of the aquifer is equal to 13.8 per cent of the available precipitation calculated from a mean annual precipitation of 18 inches over the area considered.

## Maximum Development Yields

MAXIM DEVEL YIELDS

A further modification of the hydrogeological model was necessary to provide a means of estimating the yield at maximum resource development of a groundwater basin or of an aquifer. This could be accomplished as Freeze (1969) suggested by progressively calculating new maximum development yields for a groundwater basin for new positions of the water table caused by the lowering of water levels during pumping. This approach requires that some initial development of a groundwater basin take place prior to estimating the magnitude of the maximum development yield. To calculate an early, predevelopment estimate of ultimate groundwater yield from a groundwater basin or aquifer some other technique must be used. The main effect of pumping on a confined aquifer is the lowering of fluid potentials around that portion of a well open to the aquifer. This increases the total volume discharge of groundwater in a basin, or applied more specifically, in an aquifer. The lowering of potential around a well can be simulated in an electric analogue model by introducing a low potential across the aquifer. The lowest elevation on the upper surface (water table) of the model is the minimum potential value that can be used, providing it occurs above the top of the aquifer. For the hydrogeological model of the study area, this would represent an elevation of 2685 feet (that is, the elevation of the bottom of the Red Deer Canyon). This elevation is 28 feet above the top of the aquifer at the location of the Red Deer Packers well. The pumping level in the Red Deer Packers well is known to be greater than 50 feet below surface, a level corresponding to an elevation of 2741+ feet. Therefore the point of lowest elevation on the surface of the model represents a probable future pumping level for wells completed in the sandstone aquifer at the Red Deer Packers location. The position and configuration of the water table remains fixed and, although it is realized this may not be strictly correct mathematically, the method outlined is the only means of objectively determining, by use of the electric analogue model, an early estimate of the maximum potential yield of a groundwater basin or an aquifer under pumping conditions. Furthermore, the following points lend

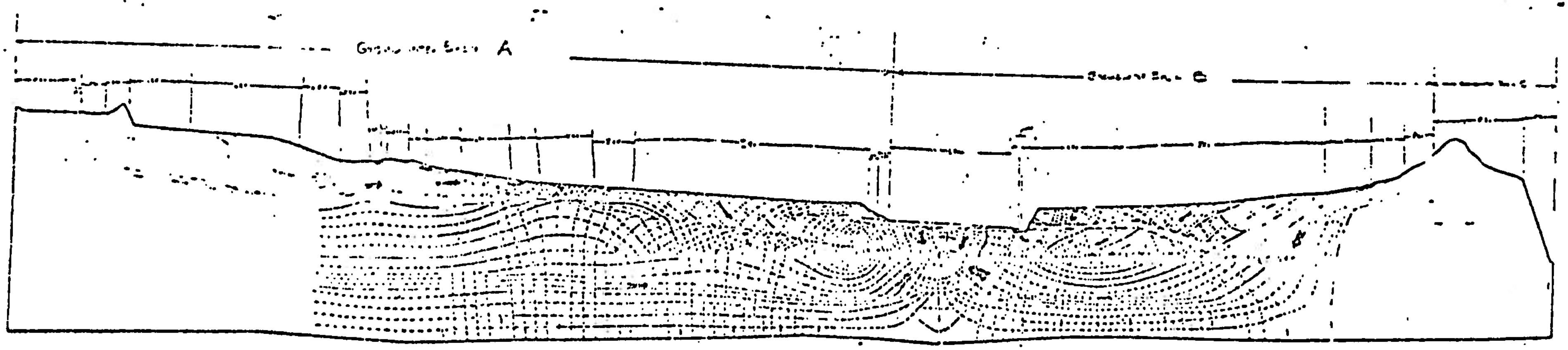


FIGURE 4. TWO-DIMENSIONAL FLOW NET — PUMPING WELL CONDITIONS.

some justification to ignoring any change in the water-table configuration, particularly in the vicinity of the pumping well of the present case.

1. On a regional scale the change in water levels due to pumping are not significant considering the dimensions of the groundwater basins.

2. Five or six years of nearly-continuous pumping from the Red Deer Packers well at an approximate rate of 250,000 gallons per day has resulted in a relatively stable pumping level and has apparently caused no drastic change in the position of the water table in the vicinity of the pumping well.

3. The amounts of water available for maintaining a high water table in the river valley area are great because of the presence of partially saturated or saturated, high permeability material at or close to the surface.

Estimates of the maximum development yields for the aquifer in groundwater basins A and B can be calculated by consideration of the new quantitative flow net resulting from the change in potential distribution due to pumping (Fig. 4). Groundwater basin C is not influenced by the effect of the pumping well. Calculated values of maximum development yields for the aquifer are shown below.

| Groundwater Basin | Number of Flow Channels Entering Aquifer | Maximum Development Yield of Aquifer in gpd |
|---|---|---|
| A | 28.0 | 1,848,000 |
| B | 26.0 | 1,716,000 |
| Totals | 54.0 | 3,564,000 |

Under pumping conditions the yield of the Red Deer sandstone aquifer in groundwater basins A and B has increased by 291 per cent. This yield is equal to 21.7 per cent of the available precipitation calculated from an average annual precipitation of 18 inches over the area outlined previously, whereas the initial development yield for the aquifer in groundwater basins A and B was 5.6 per cent of the

## Conclusions

1/ The study of the hydrogeology of major aquifers in a regional context rather than a local one provides a meaningful method to calculate estimates of initial and maximum development yields of an aquifer.

2/ Under pumping conditions the total volume discharge of groundwater in extensive, high permeability aquifers can be increased by several orders of magnitude.

## References

Freeze, R. A. and Witherspoon, P. A. (1967): Theoretical analysis of regional groundwater flow. 2. Effect of water-table configuration and subsurface permeability variations; Water Resources Res., Vol. 3, No. 2, pp. 623-634.

Freeze, R. A. (1969): Theoretical analysis of regional groundwater flow; Inland Waters Branch Sci. Ser. No. 3, Dept. Energy, Mines and Resources, Ottawa, Can., 147 pages.

# DEVELOPMENT OF A WATER SUPPLY FROM A SANDSTONE AQUIFER NEAR RED DEER

by
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## INTRODUCTION

A three-year program involving the exploration and evaluation of groundwater resources near Red Deer, Alberta, has resulted in the discovery and partial delineation of the areal extent of a sandstone aquifer or water-bearing bed. In considering the development of this aquifer as a source of water supply at least three criteria must be met:

1) The chemical and sanitary quality of the water must be acceptable.
2) The quantity of water that can be obtained must be known.
3) The supply must be dependable for a stated length of time.

The chemical quality of the water, except for the fluorine content, is within the limits recommended by the Department of Public Health. The water has a hardness of less than 10 parts per million (expressed as $CaCO_3$) and a temperature ranging from 42 to 47 degrees Fahrenheit. A typical chemical analysis of the water is shown in Table 1. The quantity of water obtainable and the dependability of this supply constitutes the body of the following discussion. Information is presented in a form that will lend itself to the determination of practical costs estimates of water-supply development.

## THE AQUIFER

The aquifer is a sandstone which underlies an area north of Red Deer. The known areal extent of the aquifer is shown in Figure 1. The sandstone ranges from [illegible]0 to 40 feet in thickness and is encountered during drilling at depths ranging from 180 feet in the river valley to 275 feet one and one-half miles east of the river.

## Table 1. Water Analysis Report

| | ppm |
|---|---|
| Total dissolved solids | 600 |
| Total hardness as Ca $CO_3$ | 7.4 |
| Total alkalinity ($CaCO_3$) | 412 |
| Residue on evaporation | 300 |
| pH | 8.80 |
| Iron (Fe) in solution | 0.23 |
| Fluorine (F) | 4.1 |
| Calcium ($Ca^{++}$) | 1.8 |
| Magnesium ($Mg^{++}$) | 0.7 |
| Sodium ($Na^{+}$) | 215 |
| Potassium ($K^{+}$) | 0.8 |
| Carbonate ($CO_3^{--}$) | 32 ($CaCO_3$) |
| Bicarbonate ($HCO_3^{-}$) | 380 ($CaCO_3$) |
| Sulfate ($SO_4^{--}$) | 19 |
| Chloride ($Cl^{-}$) | 21 |
| Nitrate ($NO_3^{--}$) | 1.3 |

The hatched areas in Figure 1 represent areas over which the transmissivity and storage coefficient of the aquifer have been determined from analysis of pump test data. Transmissivity is a measure of the aquifer's ability to transmit water and is defined as the rate of flow in gallons per day of water through a vertical strip of the aquifer one foot wide and extending the saturated thickness of the aquifer under a hydraulic gradient of one foot per foot at the prevailing water temperature. The storage coefficient is the volume of water the aquifer takes into or releases from storage per unit change in hydraulic head perpendicular to that surface. Transmissivity of the aquifer is about 9,000 gpd/ft except for an area in the river valley where the transmissivity is about 20,000 gpd/ft. Continuity of the sandstone between the two areas where pump testing has been carried out is assumed because pumping of wells at the Red Deer Packers location in Lsd. 16-23-38-27-W4 causes drawdown in a well completed in the aquifer in Lsd. 12-25-38-27-W4. This shows no induced infiltration is obtained from the river. East of Red Deer the aquifer is not found south of a line trending west-southwest (Fig. 1). It is tentatively assumed that the topographic low presently occupied by the Red Deer River may have existed through Tertiary time (the time when sand was deposited and later consolidated to form the sandstone that now comprises the aquifer) up to the present. A valley on the bedrock surface is definitely present in this area and was "buried" by drift deposited during the Pleistocene epoch. If the above hypothesis is correct, the aquifer may extend southwestward along the present topographic low. A test well will be drilled in February at the Deerhome location in the NW 1/4-15-38-27-W4 that should provide additional evidence regarding the areal extent of the aquifer. Available drawdown, which is the difference between the nonpumped water level in a well and the top of the aquifer, is about 85 feet. Approximately 250,000 gallons per day for a 5-day week have been pumped at the Red Deer Packers location over the last four years. Based on present knowledge of the aquifer the maximum amount of water that can be withdrawn with some guarantee of dependability over a 20-year period is about one million gallons per day.

## WELL FIELD DESIGN

The feasibility of producing one million gallons per day over a period of 20 years requires that information regarding the number of wells, well spacing, well locations, and production rates be determined using results obtained from analysis of well and aquifer tests. The technique used to design a well field to withdraw one million gallons per day (about 700 gpm) from the aquifer at Red Deer has recently been prepared for use in California (Mount, J. Russell, 1969). The technique requires that wells be placed in a "square" array of rows and columns at regular spacing. Figure 2 illustrates the arrangement of wells.

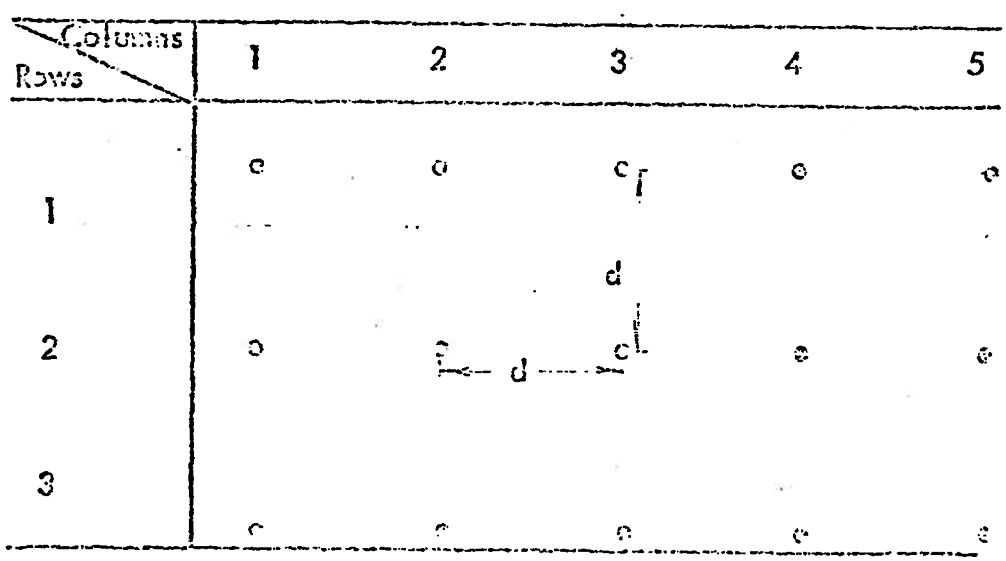



FIGURE 2. "Square" array pattern of wells

The technique determines the drawdown for the wells nearest the center of a well field, in this case after 20 years of continuous pumping. This drawdown, which includes interference between wells, cannot exceed the total available drawdown. Drawdown for several arrangements of wells producing at various pumping rates are listed in Table 2. The best arrangements for withdrawal of water from the aquifer are trials 2 and 5. Spacing of 1,000 feet has been used because it can be demonstrated that increasing this spacing by a factor of 2 or 3 does not result in a significant decrease in interference between wells which would justify the expense of greater spacing. The suggested location for the wells are shown in Figure 1. This constitutes two well fields, one a row of 3 wells pumping at 100 gallons per minute each near the river, and a second block of 8 wells pumping at 50 gpm each at a location east of the river.

## WELL CONSTRUCTION

Wells should be constructed with casing not less than 8 inches in diameter. The casing should be set to the top of the aquifer and cemented in place. The aquifer material is rather competent and wells can be completed open hole. However, if open hole completion proves impossible, then continuous-slot screens will have to be installed across the aquifer interval.

## COMPLICATING FACTORS

The above well design proposal is subject to a number of uncontrollable factors that could result in more rapid decline in pumping levels in the aquifer than calculated in trials 2 and 5 in Table 2. The main factors are:

1) Competing water users constructing wells in the aquifer. The existing Red Deer Packers' wells have been ignored in the above calculations. The Packers'

TABLE 2. WELL FIELD DESIGN

| Trial | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rows | 2 | 2 | 2 | 4 | 1 | 1 | 2 | 2 | 2 | 1 | 1 |
| Columns | 3 | 4 | 7 | 4 | 3 | 5 | 3 | 7 | 7 | 2 | 3 |
| Well spacing (ft) | 1000 | 1000 | 1000 | 1000 | 1000 | 3000 | 1000 | 1000 | 2000 | 5000 | 000 |
| Production rate (gpm) | 50 | 50 | 50 | 50 | 100 | 100 | 100 | 100 | 100 | 200 | 150 |
| Drawdown (ft) | 52.90 | 65.97 | 103.24 | 119.71 | 62.62 | 89.04 | 105.80 | 206.49 | 144.67 | 86.67 | 98.57 |

NOTE: 1) All trials are calculated using values of $T = 9{,}000$ gpd/ft and $S = 1.6 \times 10^{-4}$ with the exception of trial 9 in which $T = 20{,}000$ gpd/ft.

2) Drawdown at the end of a 20-year period of continuous pumping at the rates indicated.

best well (the one nearest the river), if taken over by the city, could be used as one of the group of three wells in well field No. 1 (Fig. 1).

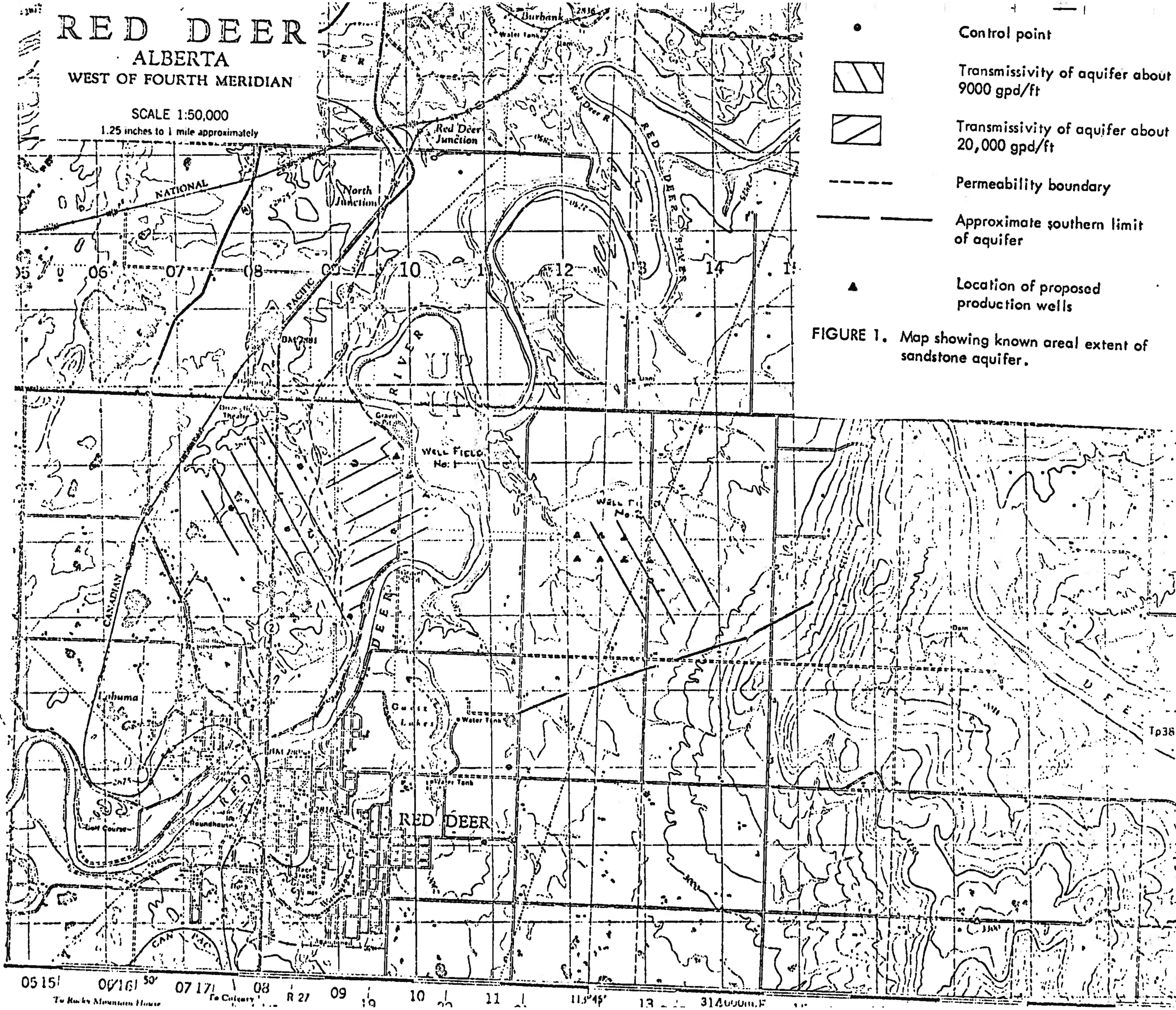
2) The existence of presently unknown hydrogeologic barrier boundaries. These boundaries are usually marked changes in permeability in the aquifer. The line showing the southern extent of the aquifer east of Red Deer is in essence a barrier boundary. The effect of this boundary was not considered in the calculations of drawdown in designing the well field. Compensation for these effects is, however, worked into the well field design by allowing for use of only about 75 per cent of the total available drawdown of 85 feet. The accuracy of predicted future water levels in the aquifer as a result of water withdrawal at set rates can only be judged by analysis of actual detailed production records and data on the change of water levels in the aquifer with time.

Recharge to the aquifer by the downward percolation of rainwater to the saturated zone has not been considered over the 20-year period.

The presence of natural gas in the aquifer at some locations creates a problem in that it apparently reduces the permeability in the vicinity of the pumping well. This means wells at locations where gas is present must be pumped at lower production rates than calculated to prevent rapid drawdown. Test drilling and production tests in the area suggest the gas is most prevalent in the area of the river valley and areas immediately adjacent to the valley. Gas was not a problem at the test site in Lsd. 12-25-38-27-W4.

<u>REFERENCES CITED</u>

Mount, J. Russell (1969): A simplified technique for well-field design; Ground Water, Vol. 7, No. 3, p. 5-8.




• Control point

Transmissivity of aquifer about 9000 gpd/ft

Transmissivity of aquifer about 20,000 gpd/ft

- - - - - Permeability boundary

——— ——— Approximate southern limit of aquifer

▲ Location of proposed production wells

FIGURE 1. Map showing known areal extent of sandstone aquifer.