

**KANSAS GEOLOGICAL SURVEY  
OPEN-FILE REPORT 83-3**

**CURRENT AND POSSIBLE FUTURE HAZARDS TO IRRIGATION IN  
KANSAS: AN OVERVIEW OF SALT WATER INTRUSION FROM  
PERMIAN FORMATIONS**

by

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**Current and Possible Future Hazards to Irrigation in Kansas:  
An Overview of Salt Water Intrusion from Permian Formations**

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An Overview of Salt Water Intrusion from Permian Formations**

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Kansas Irrigation Workshop  
Pratt, Kansas

Introduction

The general public perceives the principal problem of irrigators to be one of water availability, and to a great extent this is accurate. However, the problem of water quality as a limiting factor for irrigated agriculture receives much less attention. There are several regions in Kansas where the problem of availability and quality are correlative; that is, as available water is depleted there is a high probability that the remaining water will be of lesser quality. In fact, the definition of availability is that amount of water which may be appropriated without impairing the quality of the remaining water.

Several regions of Kansas are identified as areas where rather thick consolidated and unconsolidated sediments are in direct contact with Permian formations known to contain salt water. Figure 1 indicates these areas. All are located within the boundaries of Groundwater Management Districts (GWMD) and all support irrigation to some degree. The shaded area in GWMD#3 includes the Crooked Creek drainage basin and the Cimarron River Valley. It is bounded approximately by US 54, Kansas Highway 23, and the Oklahoma state line. The

shaded region in GWMD#5 represents approximately that portion of the Great Bend Prairie east of US Highway 281. The dashed line passing through GWMD#2 indicates the approximate trace of the Wellington aquifer. The width of the aquifer along this trace is from 2 to 15 miles, the northern half being much more narrow than the southern half.

Historically, oil field brine was a greater problem than natural brine. Currently, the disposal of oil field brine is much better regulated than in the past. Most brine is disposed of in deep formations. Problems still exist however, many resulting from events which occurred 20 to 40 years ago. Disposal wells with leaky casings are a problem of unknown scale at this time. Such problems are not usually discovered until quality impairment has already occurred. Of equal concern is the effect of secondary recovery methods where open holes and improperly abandoned oil and gas wells currently exist. They could serve as conduits for brine from the recovery zone. These problems are difficult to address, for they are related to very site specific activities and man-made works. It is difficult to assess their impact, but it is also becoming more practical to differentiate Permian salt water from oil field brine. This paper will for the most part ignore the man-made hazards and concentrate on the natural hazards.

#### Definitions

Fresh water is considered to have less than 1000 mg/l dissolved solids. Water with more than 1000 mg/l dissolved solids is low quality, with quality deteriorating as dissolved solids increase. State law defines water with more than 5000 mg/l dissolved solids as salt water. In this paper, water with over 1000 mg/l dissolved solids or over 250 mg/l chloride is termed low quality or salt water. The concentrations indicated in this discussion are point values,

and may differ from values obtained in large wells in the same area. Large wells tend to mix water from many units and dilute mineral concentrations. The values quoted here are indicators of potential problems if sufficient dilution does not occur.

The differentiation of the upper unconsolidated or upper aquifer from the lower unconsolidated or deep aquifer in the Great Bend Prairie is an attempt to delineate the two major coarse-grained sediment units in the area (see Fig. 2). A relatively impermeable fine-grained unit separates these units, although it is not necessarily uniform throughout its extent. Most of the shallow aquifer is in the 100 feet depth range, while the deep aquifer is often from 150 to 180 feet below land surface.

The term hydraulic head, or head, is used here to indicate the potential energy at a point. Water in a well rises to a level which expresses the potential energy averaged over the screened interval. Water always moves from regions of high head to regions of low head (see Fig. 3A). When waters have different mineral contents, the water levels need to be expressed in terms of a standard fluid (usually fresh water, density equals approximately 1.0 gm/cc) before a determination of the head differences can be made. If two wells have the same static water level, they have the same head only if the waters have the same measured density. Otherwise, the water with the greatest mineral content and hence greatest density has the higher head. In Figure 3B,  $H_c$  represents the corrected head after the density correction is performed on  $H_m$ .

Hydraulic conductivity expresses the ability of a fluid to pass through a sample of material. Size and distribution of pore space is the controlling factor. Under a given head gradient, material with a high value of hydraulic

conductivity allows more water to flow than does a low value. Clay tends to have a low value of hydraulic conductivity, while sand and gravel have relatively high values.

#### Permian Geology

Permian geology in Kansas is represented by marine deposits in the lower formations and marine and non-marine deposits in the upper part. Marine limestones form the lower beds of the Permian. The Flint Hills are the eroded outcrops of these units. To the west of the Flint Hills is a lowland formed by the weathered Wellington Formation. Stratigraphically above the Wellington Formation are the so-called redbeds. These are mostly siltstones, shales, and fine-grained sandstone, but also include units of gypsum, anhydrite and salt. The Red Hills in southern Kansas are the eroded outcrops of the redbeds. The principal salt unit in the Permian is the Hutchinson Salt member of the Wellington. This unit may be as thick as several hundred feet. The occurrence of salt is probably the most important geological feature in the Permian in relation to water quality problems.

#### The Relationship of Fresh and Salt Water

It is well known to scientists and engineers that salt water and fresh water often occur together in both static and dynamic equilibria (see Fig. 4). These systems are often treated as interface problems, even though a transition zone usually occurs between the two zones. Sometimes the separation is primarily controlled by geology. In this case a relatively thin but extensive unit of low permeability material separates the fresh and salt water, although some leakage may occur, the direction depending upon the relative head gradient. The position of the fresh-salt transition zone and

the direction and quantity of leakage is sensitive to changes in the relative fresh and salt heads. Thus, any development of the fresh aquifer implies some degree of change in the salt water regime.

The three areas introduced earlier are subject to problems of salt water pollution. They will be discussed here in detail.

#### The Crooked Creek - Fowler Fault - Cimarron River Area

In the southeastern part of GWMD#4, an area best described as the Crooked Creek - Cimarron River drainage lies in close proximity to the Crooked Creek - Fowler Fault complex (see Fig. 5). The bedrock on the western side of the fault is considerably lower than that on the eastern side. This subsidence and the fault complex are considered to have resulted from the dissolution of Permian salt and gypsum units by circulating groundwater. Evidence exists that dissolution may still be active. Although the downthrown block is covered by thick sediments and contains considerable groundwater, some quality problems are encountered.

A potential irrigation hazard apparently exists between the Crooked Creek - Fowler Fault complex and US Highway 54 (see Fig. 6). Seepage runs made by the U.S. Geological Survey in the Cimarron Valley in 1974 indicate a steady increase in stream flow and dissolved chloride as the stream crosses between US 54 and the fault system (Gutentag, et al., 1981).

Subsurface indications of low quality water hazards include water samples from Permian rocks and the Ogallala Formation. Most of the Permian wells indicate dissolved solids ranging from a few thousand to several tens-of-thousands of milligrams per liter. Some of the Ogallala wells indicate several thousand mg/l dissolved solids. In 1940 Frye noted that groundwater east of the fault complex had as much as 315 mg/l chloride near the fault.

The actual extent and degree of the salt water hazard is not well known from a scientific view point, but the lack of significant irrigation development in that area indicates that a concern exists. Depending upon the amount and concentration of salt water at depth, expansion of irrigation could be expected to cause some additional problems if significant declines in water levels occurred, causing a greater influx of salt water from the Permian. Irrigation wells should be constructed so that they penetrate no more aquifer than necessary to sustain the required yield. The KGS, in cooperation with GWMD#4, is preparing to investigate this area further with drilling and electrical resistivity surveys.

#### The Eastern Great Bend Prairie

Practially the entire Great Bend Prairie east of US Highway 281 is underlain by Permian redbeds (see Fig. 7). The unconsolidated aquifer overlying these formations (see Fig. 8) has been affected to various degrees by discharging salt water. The area and severity of this problem in GWMD#5 is considerably greater than in GWMD#4.

The extent and intensity of salt water instrusion varies over the affected area. Data being collected by the KGS and GWMD#5 show some interesting relations between fresh and salt water in the unconsolidated aquifer. In northeastern Stafford and northwestern Reno counties (Fig. 9) the water quality of the shallow groundwater tends to deteriorate from west to east, while the water near bedrock seems to improve in quality (Fig. 10). One model which might explain these phenomena is to assume that the Cedar Hills Sandstone is discharging low quality water into the unconsolidated aquifer. As this water moves to the east, it is diluted with fresher water flowing from west to east and also recharging the lower aquifer from above where water

movement is favorable. At the same time the upper portion of the unconsolidated aquifer becomes degraded by upward leakage where conditions are favorable. The details of this model are at present lacking, but dilution and mixing clearly occur. Occurrences of gaining streams such as the South Fork Ninnescah River and Rattlesnake Creek may also effect the distribution of water quality. Chloride values get higher near the South Fork. In southeastern Stafford County, southwestern Reno County and eastern Pratt County most shallow groundwater is quite good (Fig. 11), while the deeper parts of the aquifer vary considerably in quality (Fig. 12). The details of this variation is probably directly related to local geological sources and hydrology, rather than a regional source of low quality water. The presence of gaining streams may also have some influence. The KGS and GWMD#5 have been actively investigating this problem for about five years. Based on this and earlier work, some observations regarding salt water hazards can be made.

- 1) In areas in which the lower portions of the unconsolidated aquifer are chronically plagued with salt water problems, the shallow fresh water is often underlain by a relatively thin, but extensive clay unit.
- 2) The salinity of the water near bedrock seems to be related to the quality of water found in the shallow, and usually weathered zone of the bedrock.
- 3) Occurrence of salt or fresh water in the shallow bedrock can often be related to the apparent local hydraulic gradient.
- 4) The occurrence of relatively low chloride water in the shallow zone of the bedrock does not preclude occurrence of higher chloride water at deeper horizons.

These points indicate the degree of risk attendant to any irrigation well installation in the eastern Great Bend Prairie. There are areas where current water quality indicates that drilling may apparently be carried to the top of the redbed, but there is no guarantee that salt water does not lie at greater

depth and is being kept under control by a downward gradient in the local hydraulic head (refer to Fig. 2). Local heavy pumping of such an installation can reverse that gradient to the extent that salt water may succeed in moving upward in the bedrock and out into the unconsolidated aquifer. The result of such an occurrence will of course depend upon the ability of the well construction and the local aquifer to dilute the salt water. If the amount of salt water reaching the well is small, or if the concentration is low, successful irrigation may continue. However, if the quantity of intruding fluid is great, or has a high concentration of dissolved solids, the mixing at the irrigation well may not be sufficient to render the water quality suitable for application to crops. The result may range from a reduction in crop yield to loss of the present crop and sufficient damage to the field to impair or prohibit future crops. Clearly, it is incumbent on the irrigator contemplating a well in this area to insure that the well be drilled only deep enough to give the required yield for the irrigation unit, and perhaps some buffer for dry years, but to avoid if at all possible placing the well near the redbeds. The well should be constructed so that it can be plugged back if required.

Depending upon special geological conditions, the precautions indicated above may not be sufficient to guarantee segregation of fresh and salt waters (refer to Fig. 2). Flaws such as improperly plugged holes or removal of part of the layer by local erosion after its deposition may provide routes for pollution which are not obvious or cannot be detected except by extensive reconnaissance. Placing wells in formations which are only locally degraded may actually serve to spread the area of degradation by causing lateral

movement of the low quality water. Such movements may or may not be dramatic and degradation may take place at such a slow pace as to go unnoticed for a time.

As irrigation facilities are put into place the danger of pollution by intrusion of low quality water from bedrock increases (see Fig. 13). As larger quantities of water are removed from the Great Bend Prairie aquifer, the degree and period of gradient change are enhanced, thus implying that the rate of leakage and period of leakage will probably be greater than during undeveloped conditions and that the total amount of low quality water introduced by direct leakage will likely increase. This leakage is never totally reversible since as leakage occurs, mixing also occurs, so that even if the same volume of water is forced back into the bedrock, there will be a net residual of dissolved salts in the unconsolidated aquifer. Similar arguments may be applied to aquifers underlain by leaky clay units or disturbed confining layers.

#### Equus Beds

The unconsolidated aquifer called the Equus Beds occurs in parts of Rice, Reno, Ellsworth, McPherson, Marion, Harvey and Sedgwick counties. The principal part of the Equus Beds aquifer is contained in GWMD#2 (see Fig. 1). This area includes the Wichita well field in addition to extensive irrigation installations. Saturated thicknesses may reach several hundred feet. To date, the most significant water quality problem is the Burrton Plume, a large slug of low quality water introduced into the unconsolidated aquifer from brine pits located in the oil fields around Burrton.

A potential, but as yet unrealized problem in the Equus Beds aquifer is the Wellington aquifer, or so-called lost circulation zone (see Fig. 14).

This feature is principally the result of solution of Permian evaporites, mainly the Hutchinson Salt which has resulted in the subsequent collapse of the overlying shale (see Fig. 15). The result has been a relatively long, but narrow network of solution and collapse features generally filled with highly concentrated brine. The ability of these features to take large volumes of fluid has resulted in the name "lost circulation zone," for drilling fluid circulation is frequently lost when this feature is encountered.

Historically, no pollution has resulted from natural circulation in the Wellington aquifer within the Equus Beds, for the steady state, and even post-development, heads appear to be higher than the head in the Wellington. Apparently the aquifer is recharged by downward leakage from the Equus Beds (Gogel, 1981). Natural salt water pollution does occur along the northern and southern thirds of the trace of the zone. These are especially prevalent in Saline County and in southern Sedgwick County. Saltwater leakage from springs degrades the Saline and Arkansas rivers, respectively.

Salt water pollution has in the past occurred in the Equus Beds when oil field brine was disposed into the Wellington aquifer. Local increases in head were able to drive salt water upward through leaky casing, unplugged holes and flaws in the semi-confining Permian shales. Disposal of saline water into the Wellington no longer occurs, but some concentrated brine is withdrawn and used for product displacement in the LPG underground storage industry (Leonard and Kleinschmidt, 1976).

There are two outstanding hazards existing today in the Equus Beds in regard to irrigation. The first is the problem of the movement of the Burrton plume in response to declines in water table produced by pumping (see Fig. 16). This problem has been recognized and is currently being investigated. Action is being considered to restrict further development of the aquifer in

areas most likely to be influenced by such a movement. The second potential threat is in areas where currently downward leakage of fresh water into the Wellington aquifer is occurring. Several authors (Leonard and Kleinschmidt, 1976; Gogel, 1981) have pointed out that the direction of flow could be reversed (i.e., salt water move upward) if the relative gradient were to be changed. Gogel does not think that this change need be extreme in order to produce some effect upon quality (see Fig. 17).

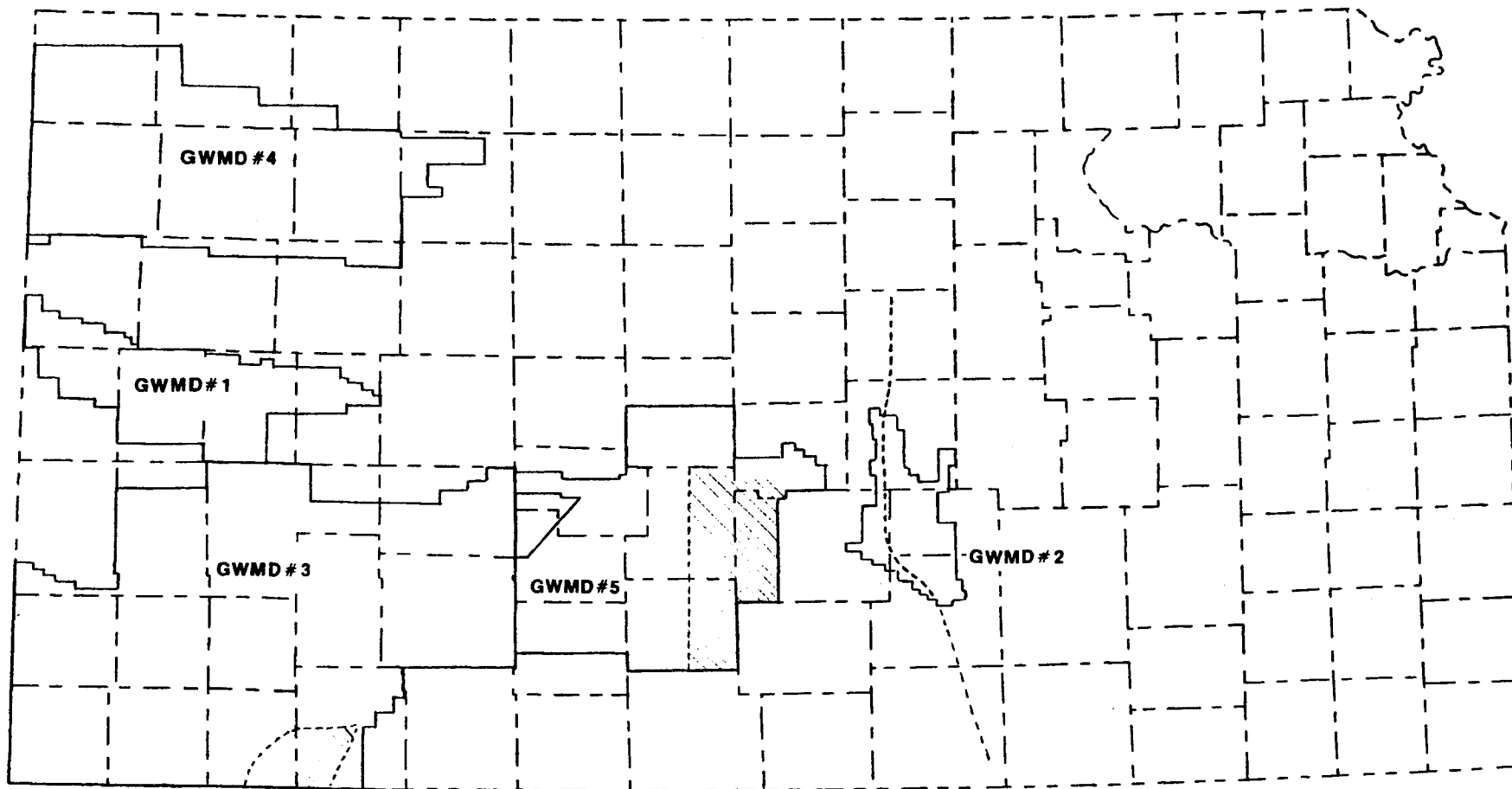
The clear strategy dictated by both of these problems is to achieve the maximum amount of groundwater use without producing excessive drawdowns. It is still a matter of opinion just what "excessive" means. It is an important matter to determine the ability of the Equus Beds to support as much irrigation as possible without degrading the net water quality.

#### Summary

The existence of salt water in Permian bedrock units which are in direct contact with major fresh water aquifers constitute a serious water management problem. Salt water - fresh water systems tend to be dynamic and respond to changes in the groundwater regime. Development of irrigation potential must be mitigated by the realization that water quality needs to be preserved. Only a responsibly developed and managed irrigation agriculture can prolong the good quality of an aquifer under this hazard.

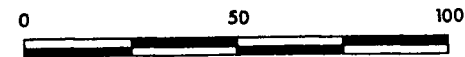
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- Leonard, R.B., and Kleinschmidt, M.K., 1976, Saline water in the Little Arkansas River basin area, south-central Kansas: Kansas Geological Survey Chemical Quality Series #3.
- Sophocleous, M.A., 1983, Water quality modeling of the Equus Beds aquifer in south-central Kansas: Kansas Geological Survey Open-File Report 83-1.
- Note:** The water quality values posted on Figures 9 through 12 are initial estimates. Total analyses for all sites indicated on the Figures should be available from the Kansas Geological Survey in late 1983.

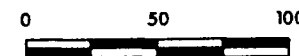


Area effected by Permian salt water

----- Trend of the Wellington Aquifer



Scale in miles



Scale in kilometers

Figure 1. Map showing location of Groundwater Management Districts in Kansas and the areas presently or potentially effected by salt water from Permian rocks.

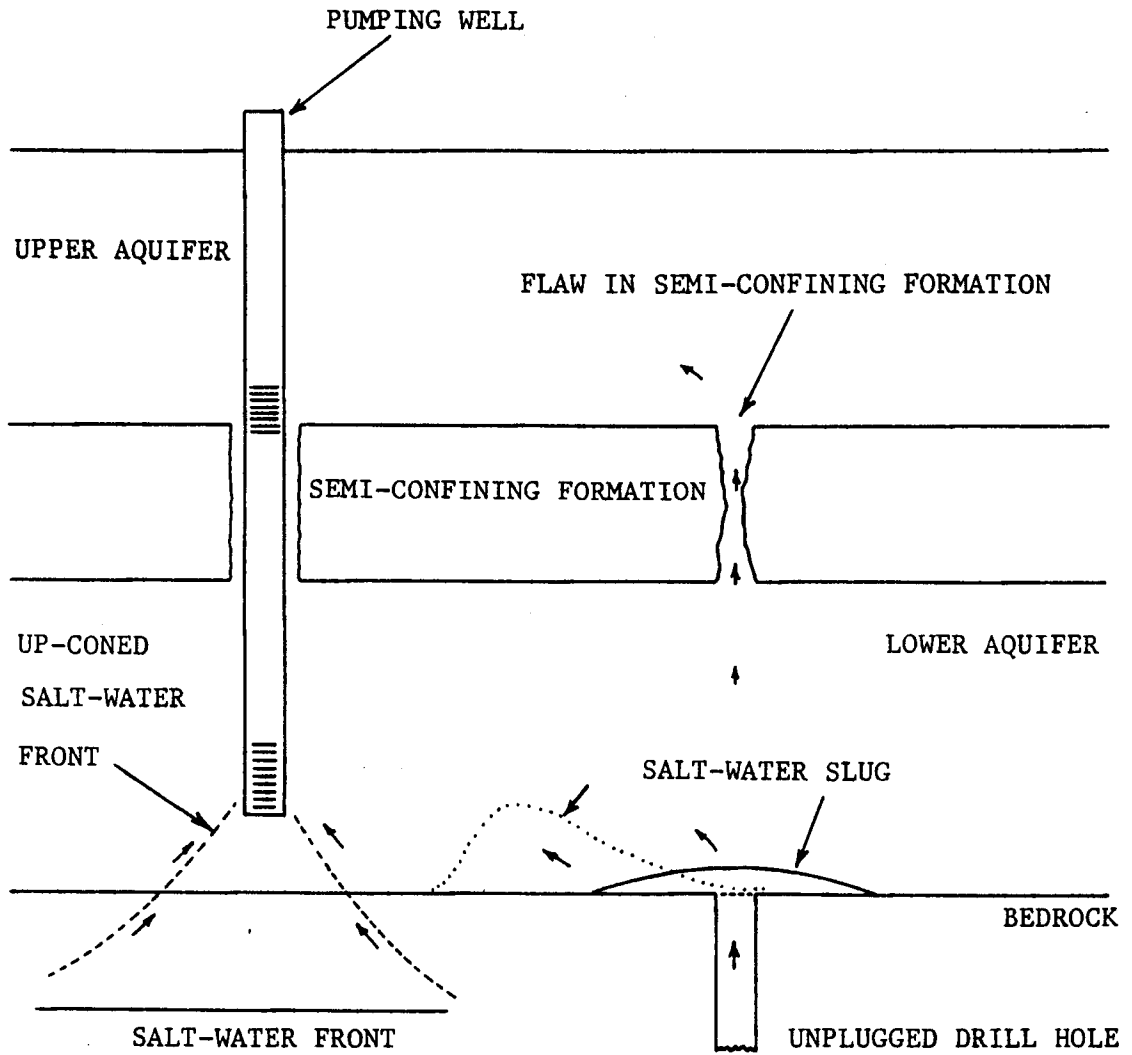


Figure 2. Schematic showing the typical configuration of the Great Bend Prairie aquifer, and also various possible scenarios for salt-water movement.

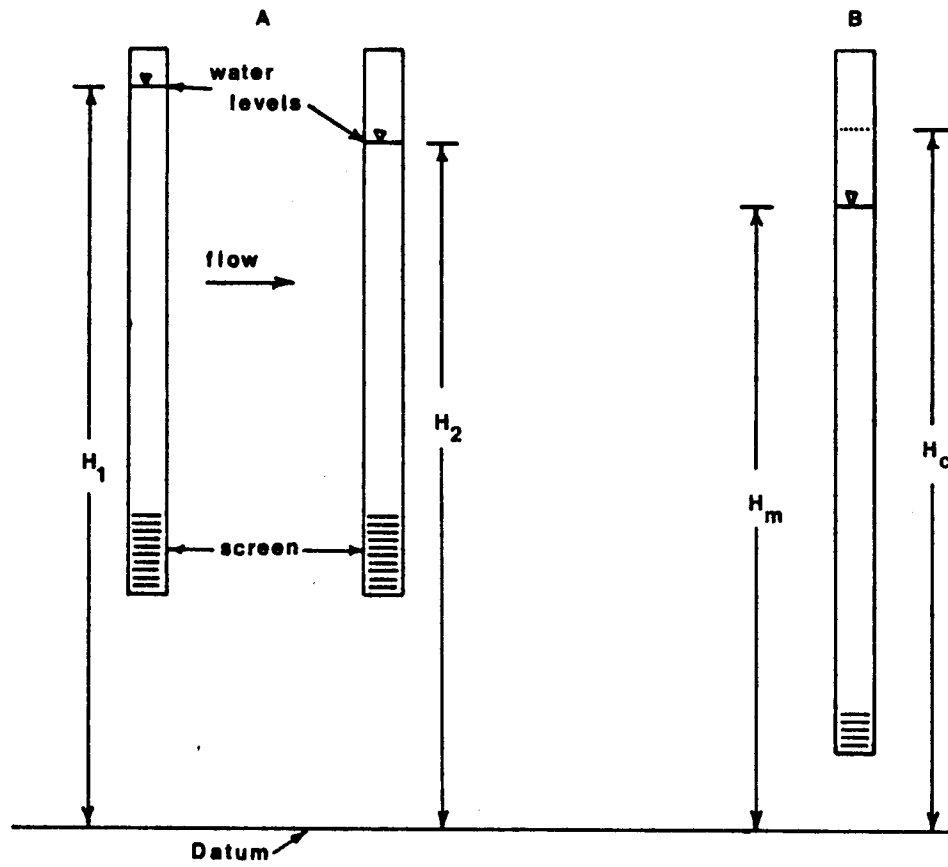
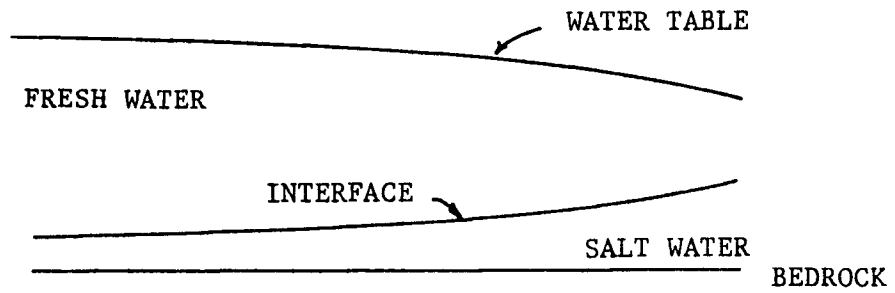
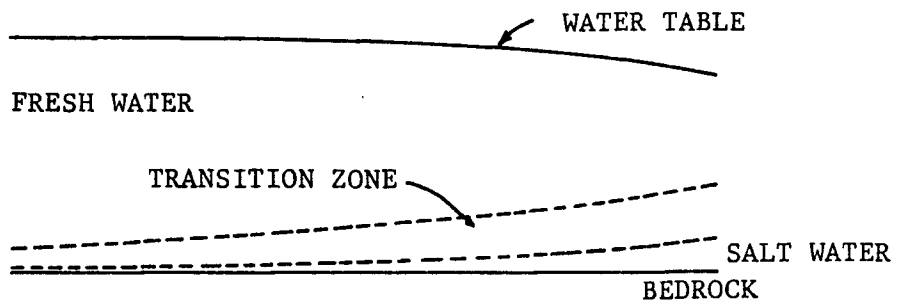


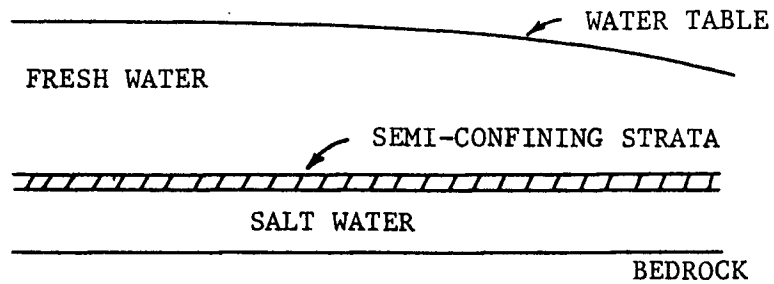
Figure 3. Schematic showing: A) the definition of hydraulic head and its relation to flow direction; and B) the effect of density corrections on measured hydraulic head.



A. SEPERATION BY AN INTERFACE



B. SEPERATION BY A TRANSITION ZONE



C. SEPERATION BY A SEMI-CONFINING STRATA

Figure 4. Possible configurations of fresh and salt water in natural systems.

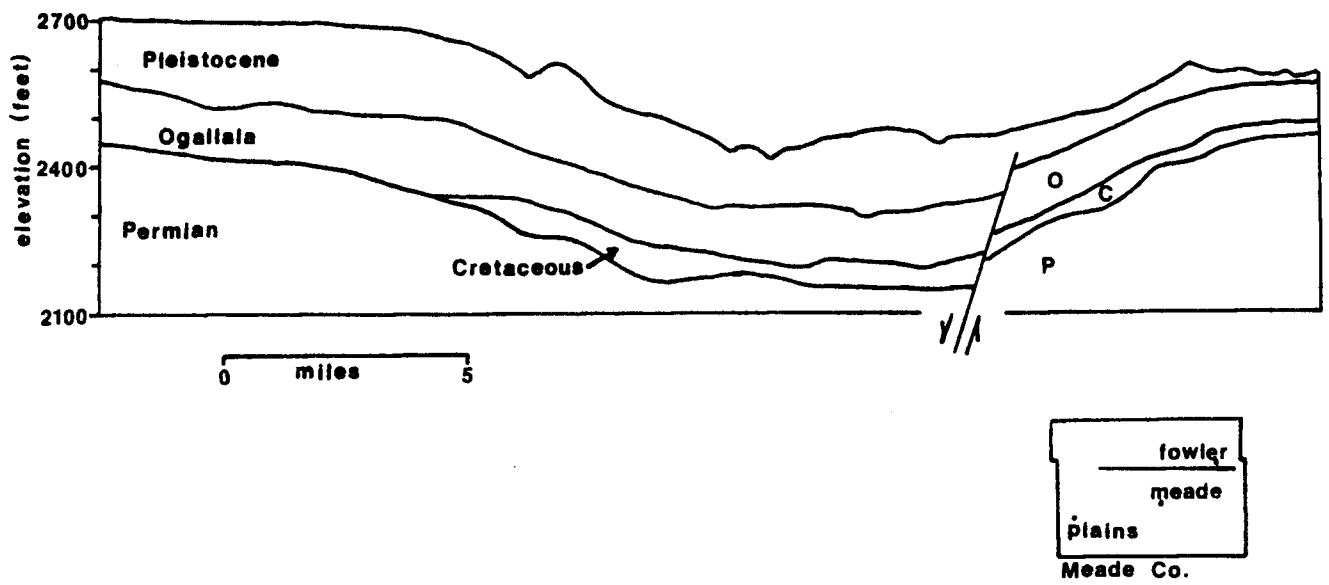


Figure 5. Geological cross-section of the Crooked Creek - Fowler Fault complex in Meade County (from Frye, 1940).

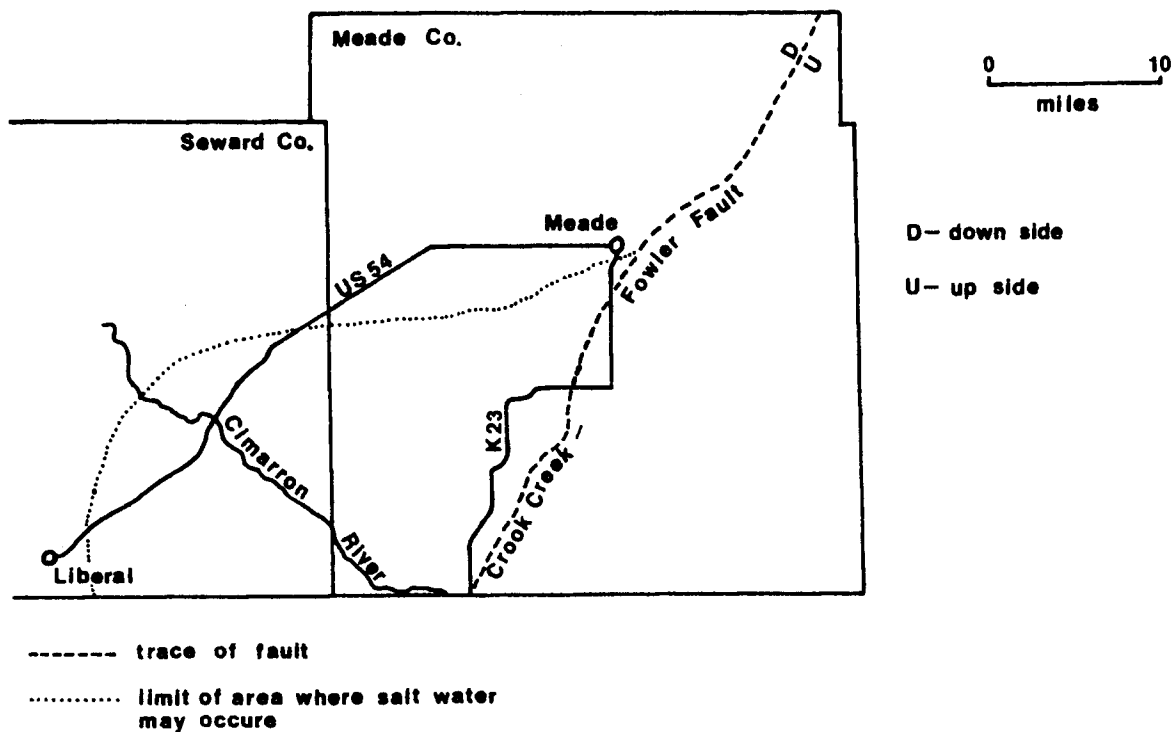


Figure 6. Map showing the trace of the Crooked Creek - Fowler Fault complex and the approximate limits of highly mineralized water in the unconsolidated aquifer (from Gutentag, et al., 1981).

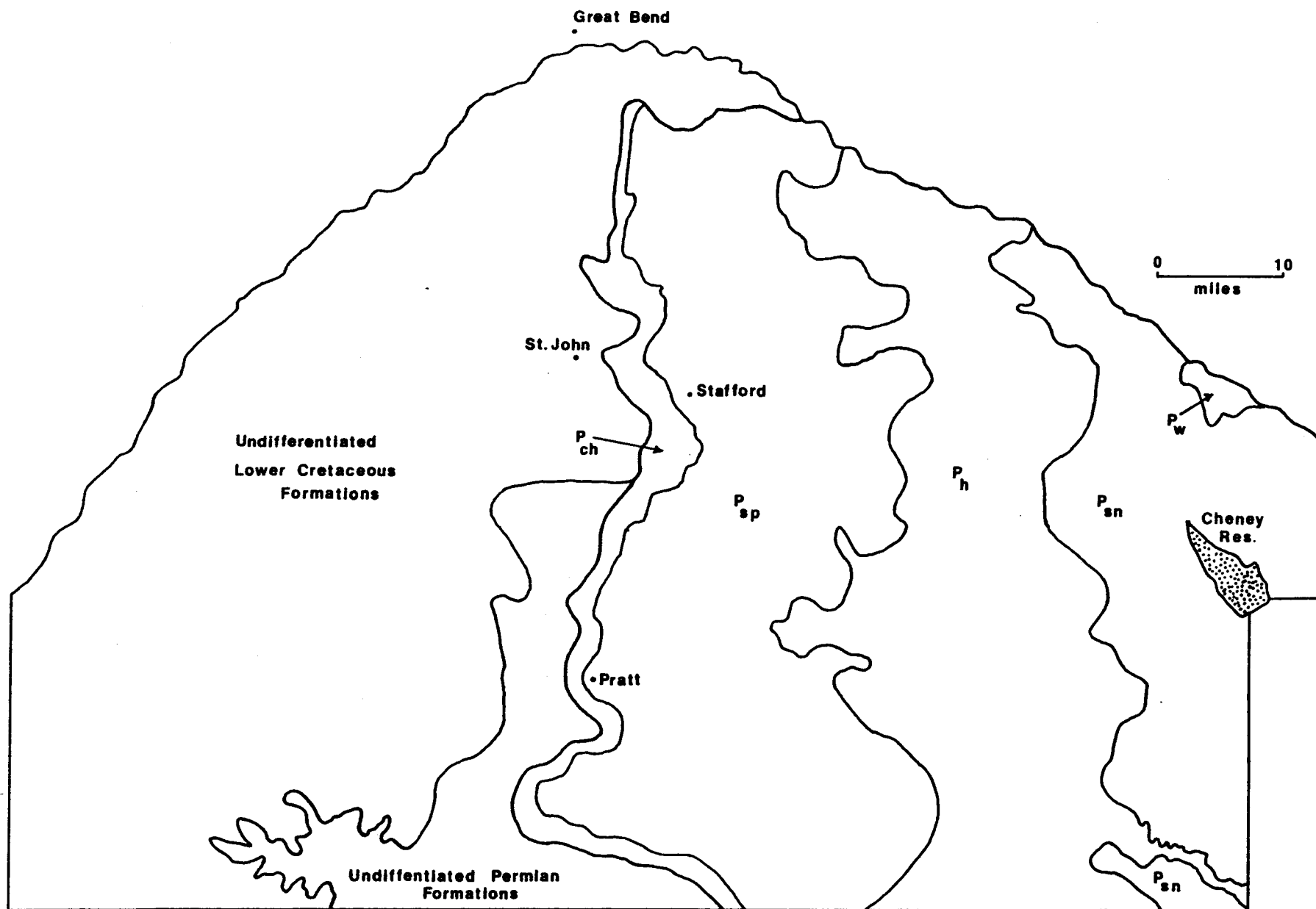


Figure 7. Map showing distribution of bedrock units in the Great Bend  
 Prairie (trace of US 281 is south from Great Bend through Pratt)

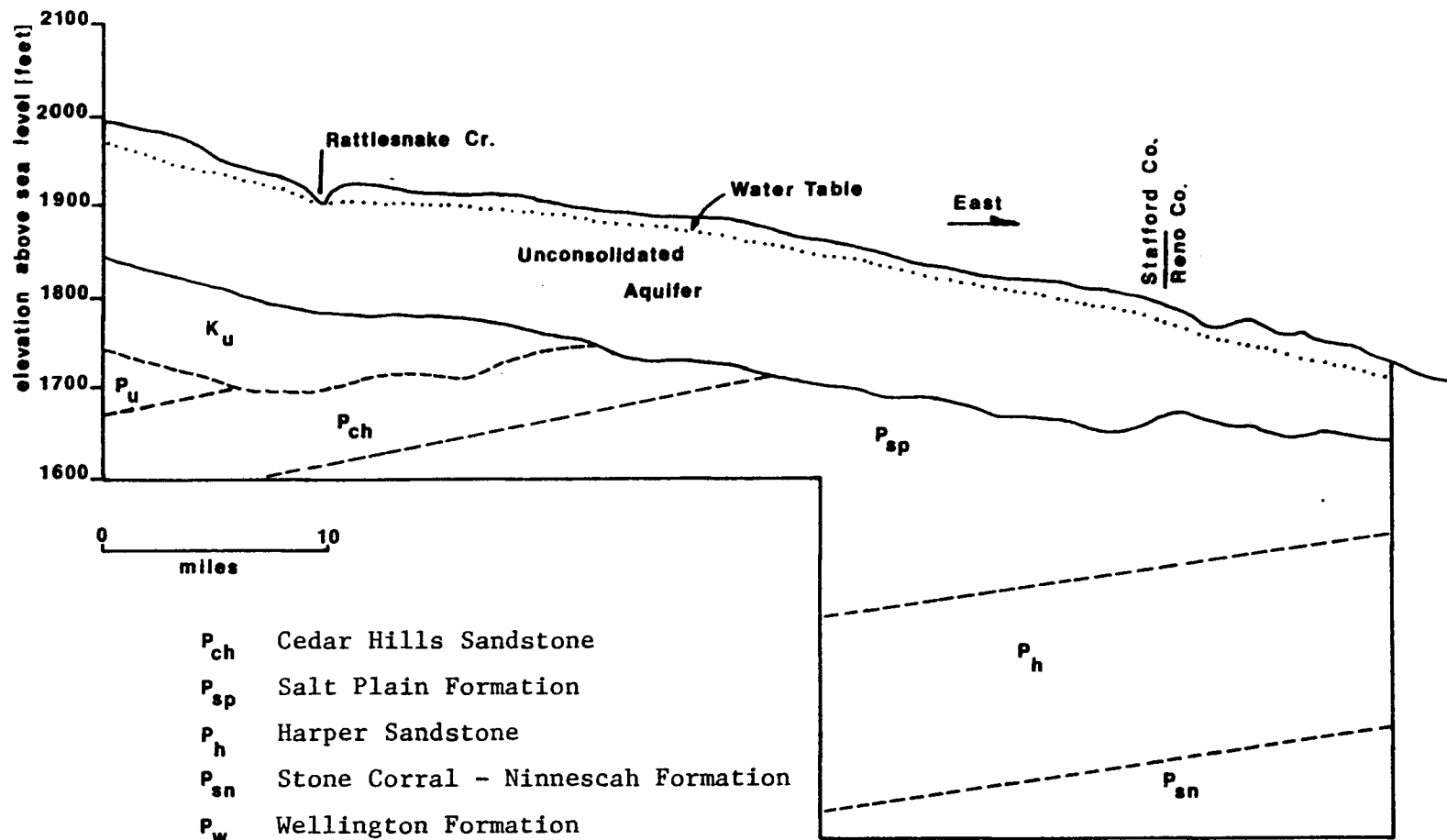


Figure 8. Relation of the unconsolidated aquifer to the bedrock stratigraphy (after Fader and Stullken, 1978).

● OBSERVATION WELL SITE  
 30 CHLORIDE CONCENTRATIONS (mg/l)

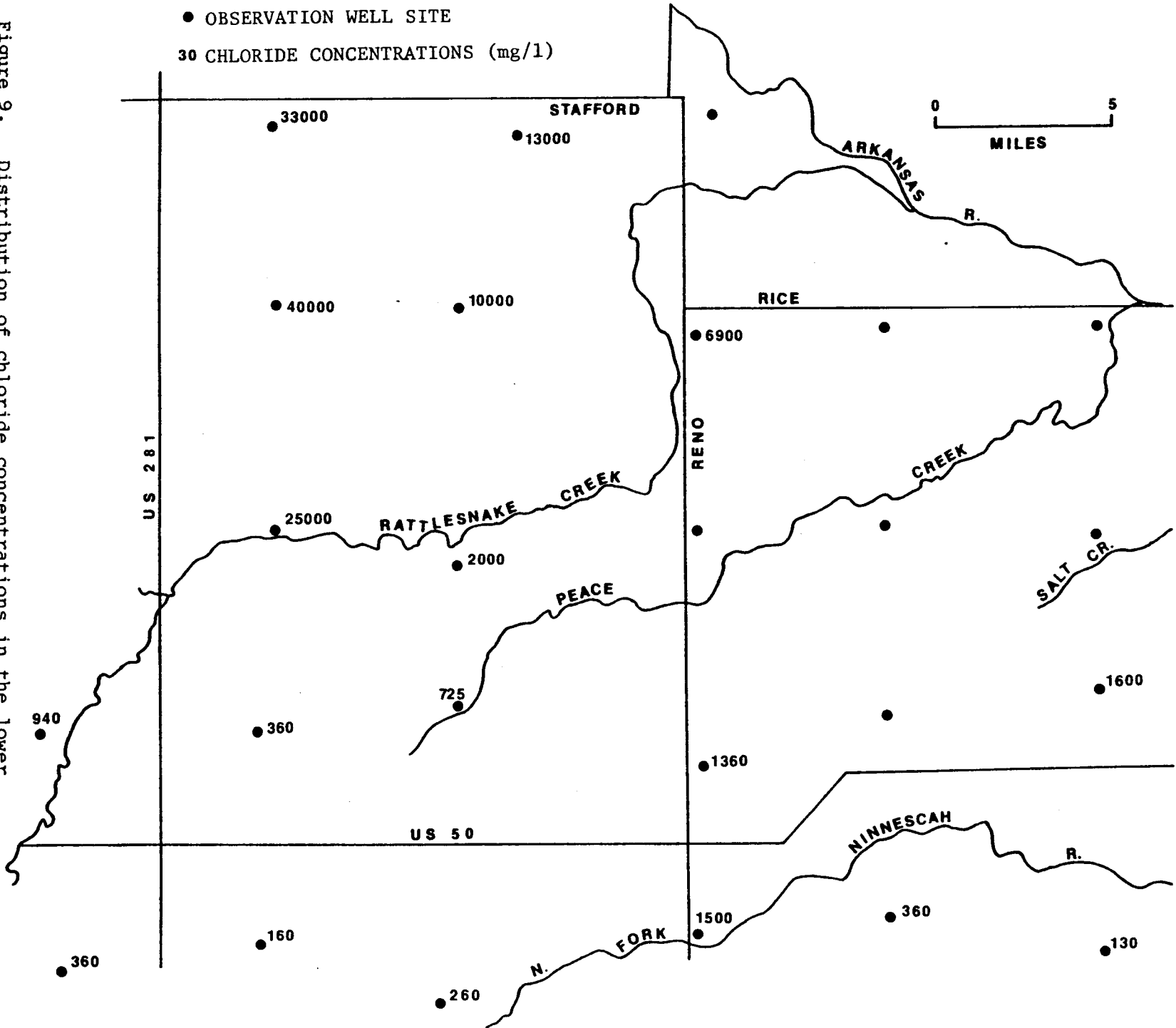
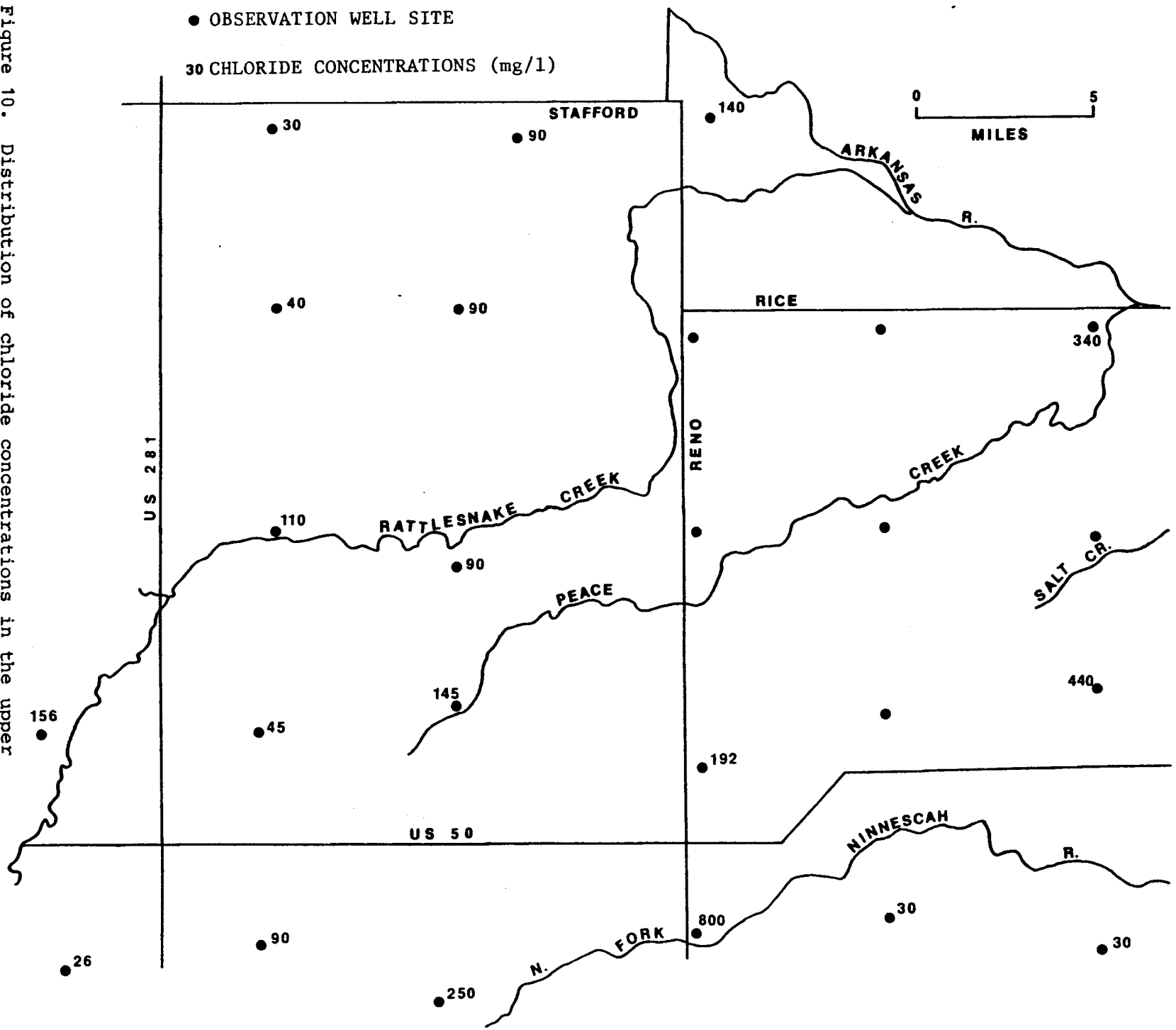


Figure 9. Distribution of chloride concentrations in the lower unconsolidated aquifer of the northeastern part of GWMD#5, February 1983.

Figure 10. Distribution of chloride concentrations in the upper unconsolidated aquifer of the northeastern part of GMD#5, February 1983.



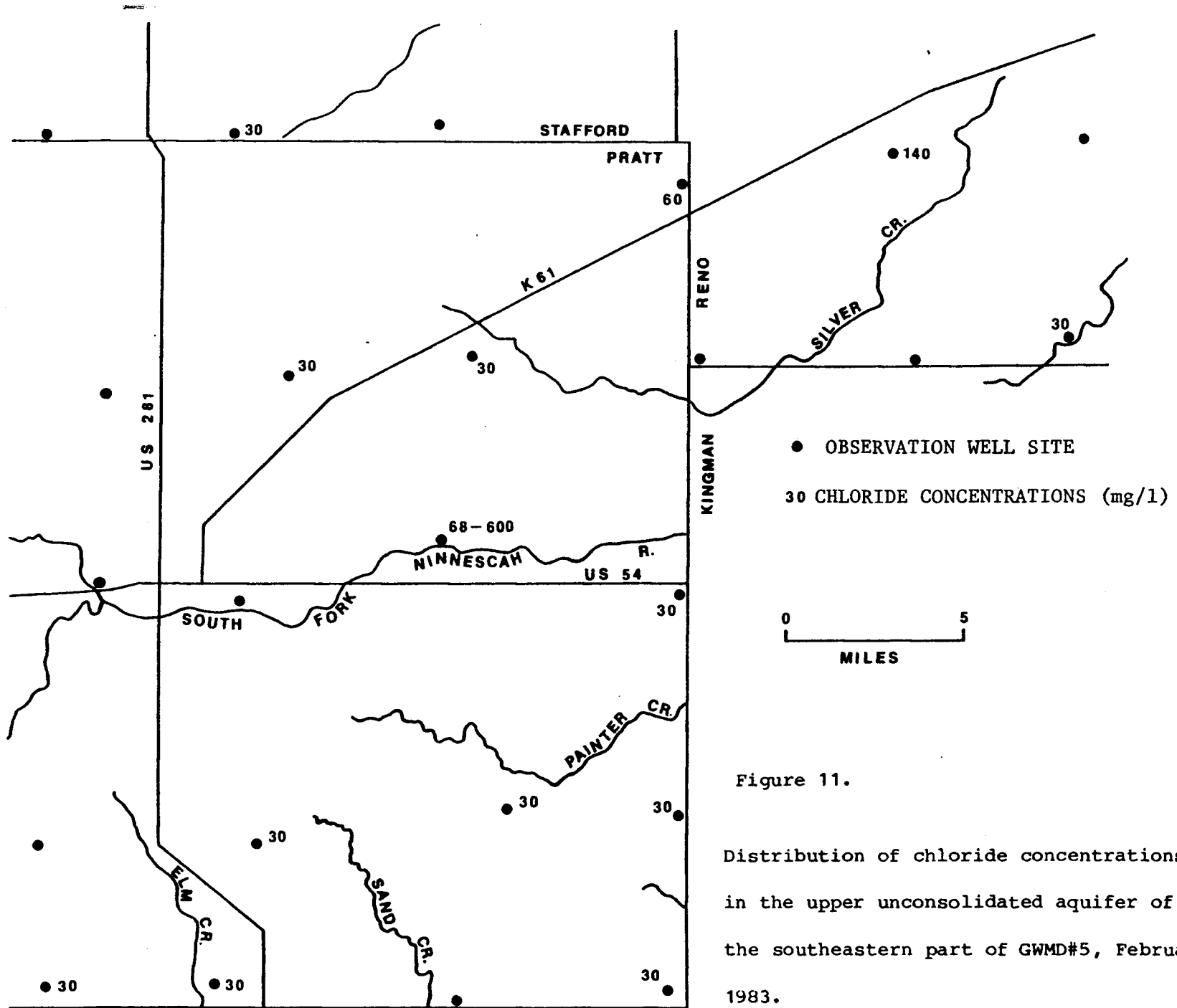


Figure 11.  
 Distribution of chloride concentrations  
 in the upper unconsolidated aquifer of  
 the southeastern part of GWMD#5, February  
 1983.

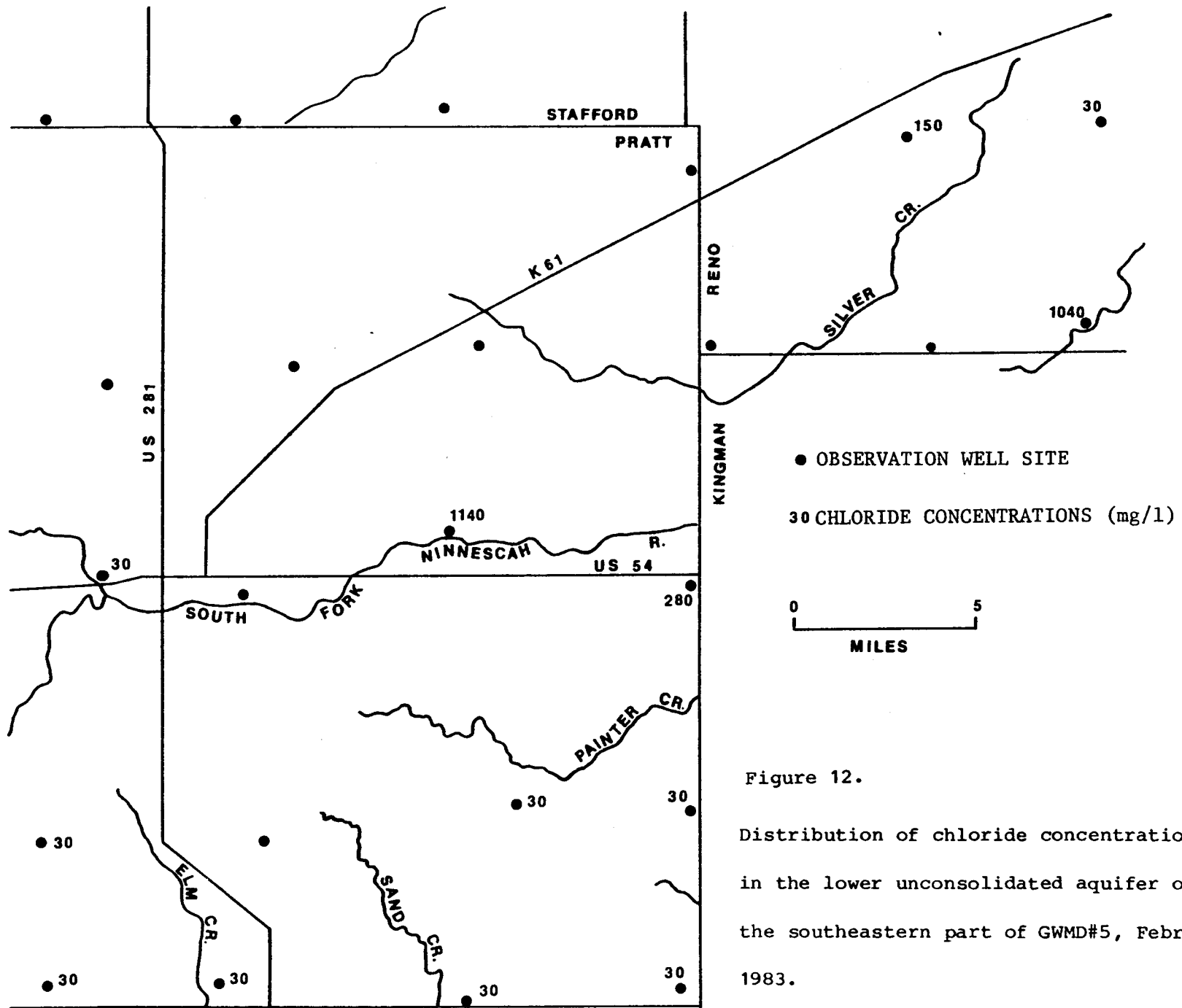


Figure 12.

Distribution of chloride concentrations  
 in the lower unconsolidated aquifer of  
 the southeastern part of GWMD#5, February  
 1983.

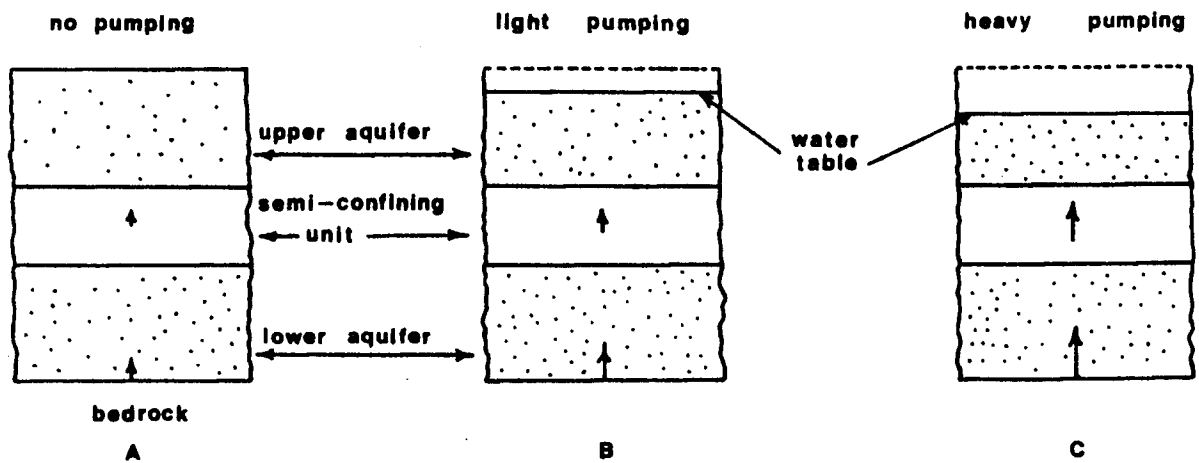


Figure 13. Schematic demonstrating the possible effects of increasing pumpage on the leaking of salt water from bedrock and the movement of fresh water across the semi-confining unit (lengths of arrows show only relative magnitudes, not absolute values).

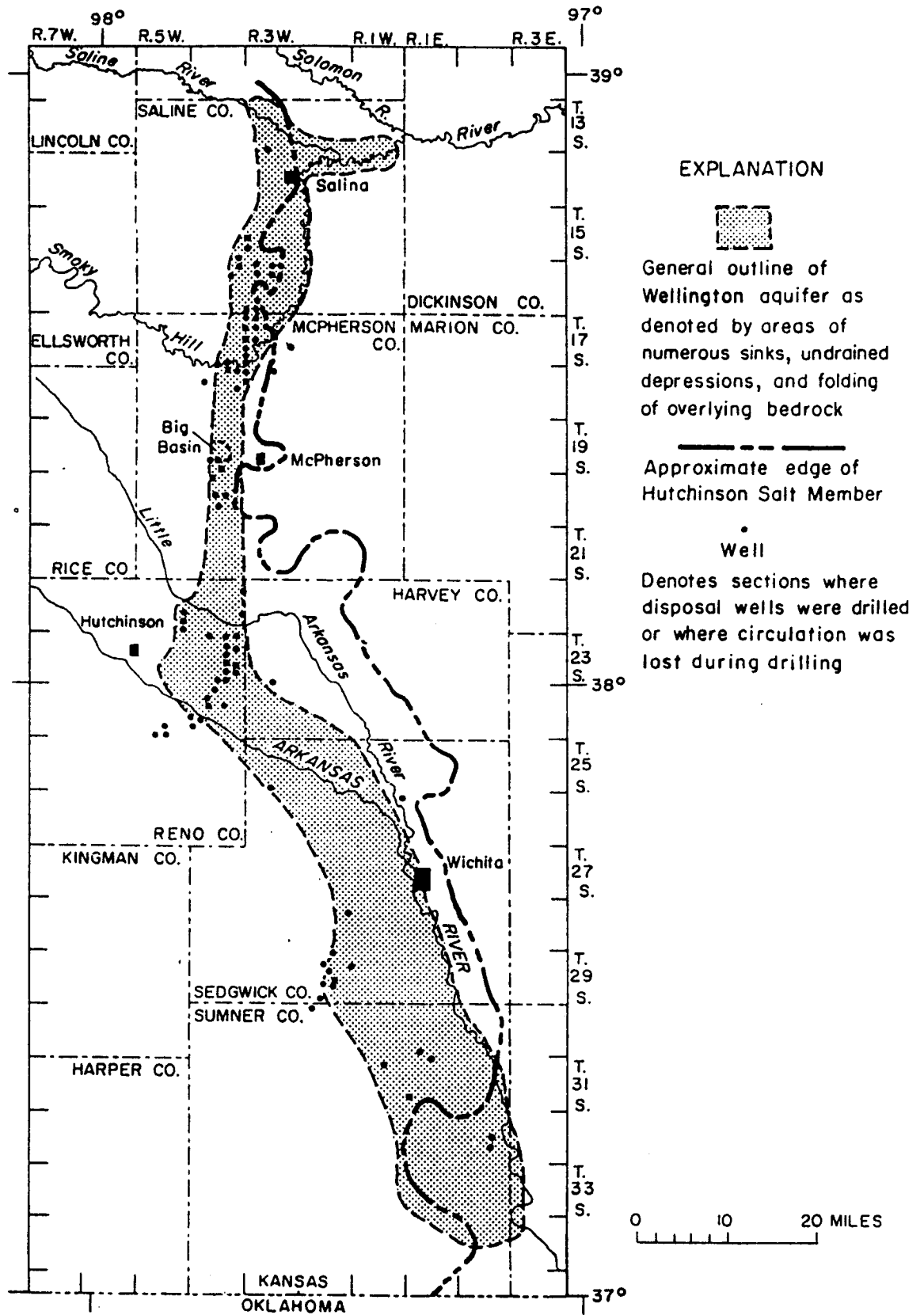


Figure 14. Areal configuration of the lost circulation zone (from Gogel, 1981).

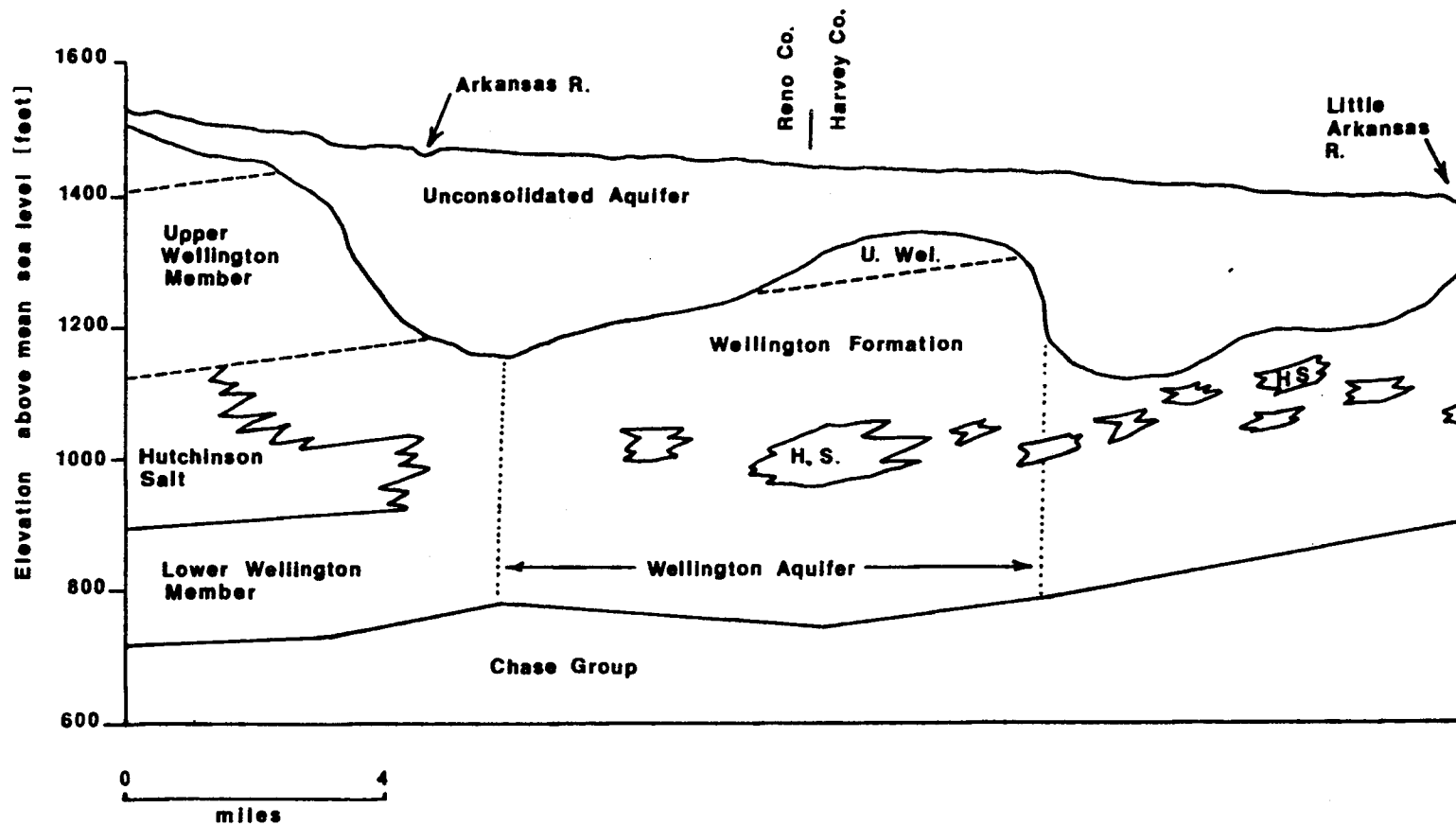


Figure 15. Typical cross-section of the Wellington Aquifer, the "lost circulation zone" showing the effects of removal of the Hutchinson Salt by fresh water (from Gogel, 1981).

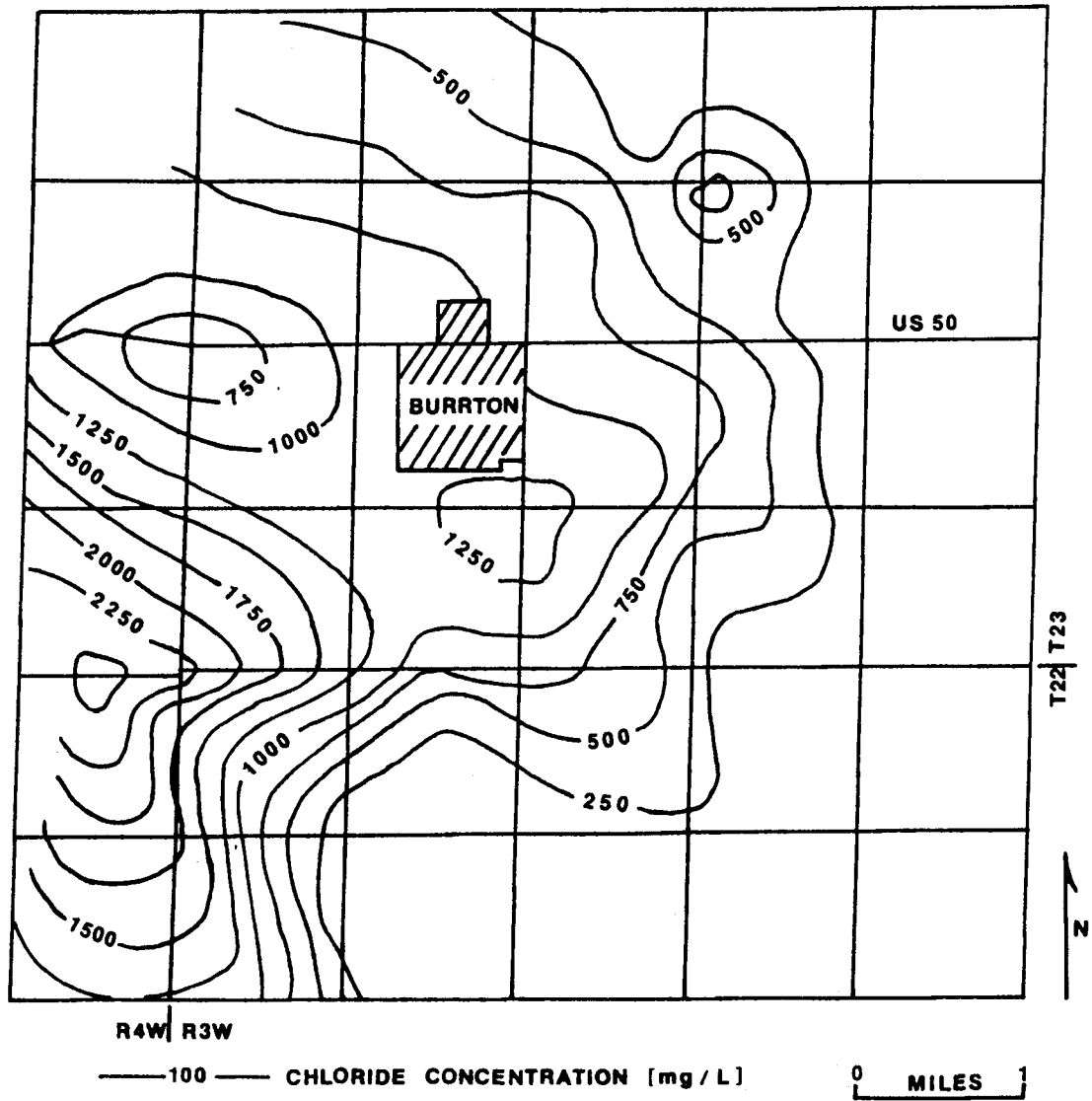
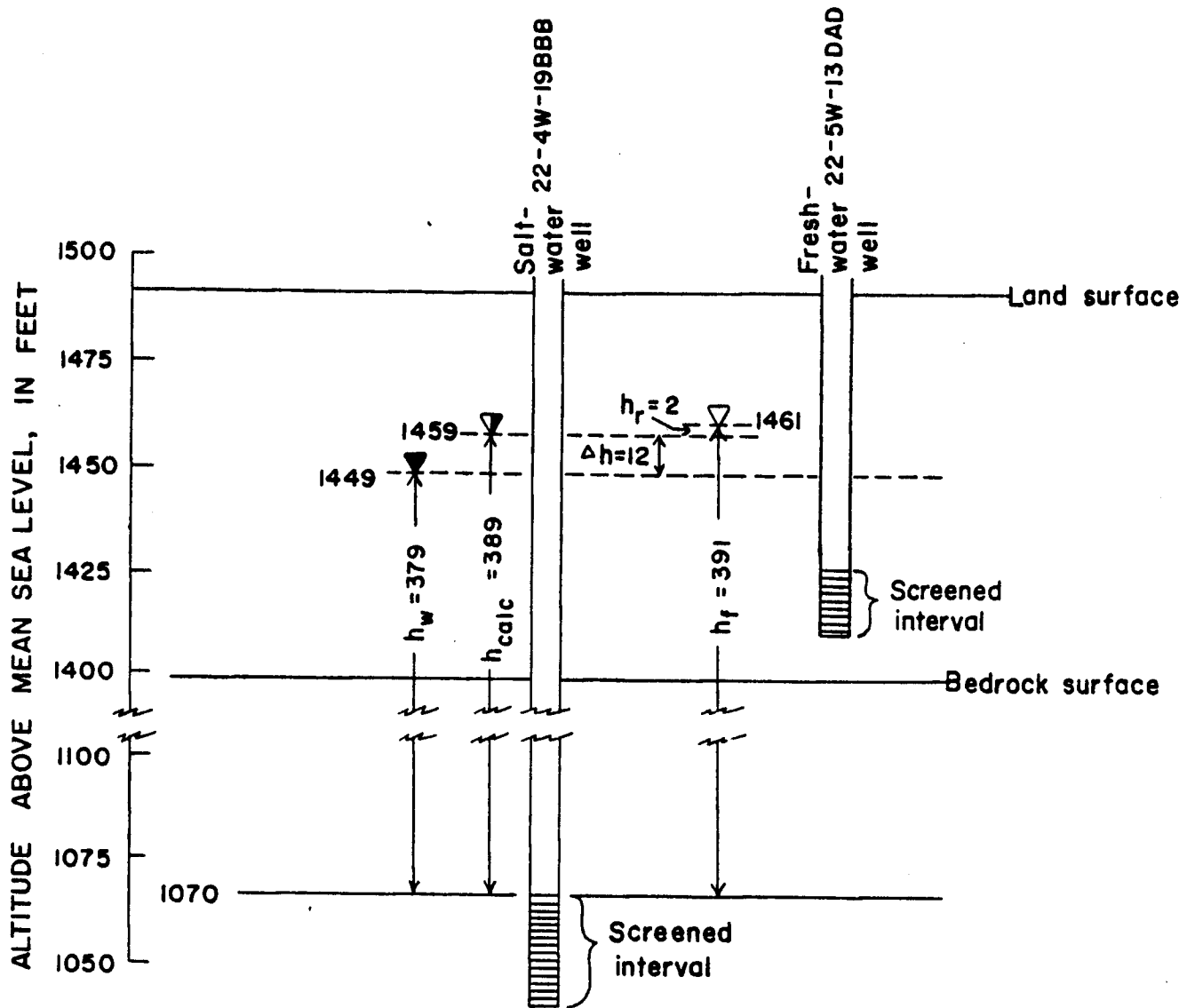


Figure 16. Map of the "Burrtion Plume" as determined in 1981 (after Sophocleous, 1983).



**EXPLANATION**

- ▽ Measured freshwater level, alluvial aquifer
- ▼ Measured brine level, Wellington aquifer
- ▽ Calculated equivalent freshwater level

Figure 17. Comparison of measured and calculated head in the Wellington as compared to the unconsolidated aquifer (after Gogel, 1981).