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OCD UIC PROGRAM

Exempted Aquifer Documents

Aquifer Classification for the UIC Program:

Prototype Studies in New Mexico

Aquifer Classification for the UIC Program: Prototype Studies in New Mexico

by Lee Wilson[a] and Michael T. Holland[b]

ABSTRACT

Three case studies from New Mexico illustrate methods by which aquifers can be classified for purposes of the Federal Underground Injection Control program. The principal technique involves preparation of hydrogeologic maps or cross sections which display information on the permeability of rock units and the dissolved solids content of formation fluids. Because deep water wells are lacking in most areas, the analysis normally requires considerable interpretation of geological and geophysical logs collected by energy and mineral companies, plus use of a general model or concept about regional hydrogeology. Injection of waste fluids into aquifers containing water with less than 10,000 mg/l dissolved solids is not allowed unless an exemption is justified by economic, engineering and other factors. Based on the case studies, regulatory exemptions will be possible for aquifers which are hydrocarbon or mineral-producing, or which are important for brine disposal purposes.

INTRODUCTION

Subsurface injection of water and other fluids is regulated by the Federal Underground Injection Control program (UIC), which was established by the Safe Drinking Water Act of 1974 (Public Law 93-523). The primary goal of UIC is to protect from contamination those aquifers which are or may become a source of drinking water. Much of the injection in the U.S. occurs in Texas, Oklahoma, Louisiana, and New Mexico, within the jurisdiction of Region VI of the U.S. Environmental Protection Agency (EPA). Consequently, Region VI was the first to explore methods by which aquifers could be identified, mapped and classified as to the need for UIC protection. The work was performed in part through grants to agencies of the State of New Mexico in 1979-82. These agencies, the N.M. Oil Conservation Division and N.M. Environmental Improvement Division, funded a series of consultant studies which: established a system for classification of aquifers according to UIC criteria; demonstrated methodologies by which the classification can be performed; and provided specific aquifer classifications in all parts of the State where injection is active.

This article summarizes the New Mexico UIC studies which involved aquifer classification: Holland *et al.*, 1979; Holland *et al.*, 1980; and Wilson *et al.*, 1981. Not discussed here are those parts of the UIC studies concerned with salt-water extraction wells (Wilson, 1982) and geothermal injection (Wilson, 1983).

AQUIFER CLASSIFICATION

EPA's UIC regulations contain complex instructions as to the kinds of rock units into which injection may be allowed. An early step in the New Mexico work was to summarize the regulations in a flow chart which sets forth what may be termed "the UIC Aquifer Classification Process" (see Figure 1). The figure clarifies the concepts in the regulations and provides a unified terminology for classification purposes.

The classification process involves questions about rock units which can be answered by yes or

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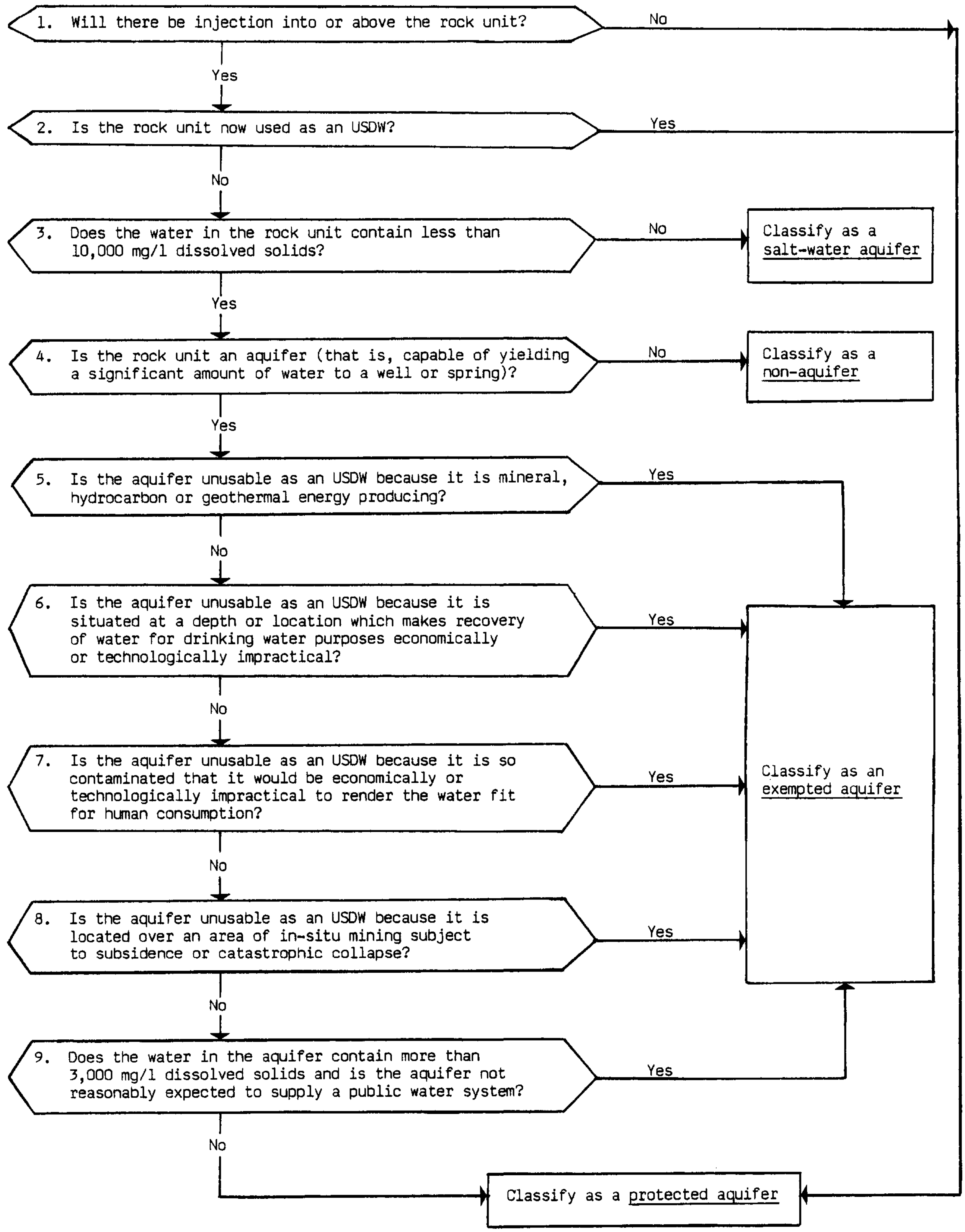

USDW = underground source of drinking water, defined as an aquifer or portion thereof which supplies any public water supply system or which supplies drinking water of less than 10,000 mg/l TDS for human consumption.

Source: Lee Wilson, based on reading of UIC regulations, principally 40 CFR 146.3 and 146.4.

Fig. 1. UIC Aquifer Classification Process.

no; depending on the answer, the rock unit will be classified or the evaluation process will move on to the next step. The UIC regulations contain no term for the geological units which must be studied during the classification process. The term rock unit was used for this purpose. A rock unit is a geological formation, or part thereof, which can be mapped and evaluated as to its general water-bearing and water-quality characteristics.

Under the UIC program, injection of waste waters such as oil field brines is not allowed above the base of the deepest *protected aquifer*. The regulations specify well construction and operation requirements to prevent casing leaks or other problems above the injection zone. As indicated by step 2 of Figure 1, a designation of protected aquifer applies to any rock unit which is a present source of drinking water. Rock units which are not now a source of drinking water are also protected aquifers unless they are explicitly classified into one of three categories for which UIC protection is not required: salt-water aquifer, nonaquifer, or exempted aquifer.

Salt-water aquifers are rock units which contain water having a total dissolved solids (TDS) content in excess of 10,000 mg/l; see step 3 of Figure 1. *Nonaquifers* are rock units which are not able to yield usable amounts of water to a well or spring (step 4). *Exempted aquifers* are rock units which are excluded as a potential source of drinking water for reasons of economics, technology, gross contamination, or relationship to subsidence or collapse zones (steps 5-9).

EPA's initial guidance regarding the aquifer evaluation process indicated that it should be relatively thorough and detailed (Ground-Water Program Guidance No. 4.2, 1978). The agency specifically suggested the use of techniques such as: maps and cross sections showing TDS isocons; maps showing depth to base of fresh water; maps of aquifer thickness, elevation, and saturated thickness; maps of water levels in different aquifers at different dates; and many others.

PROTOTYPE STUDY OF THE ARTESIA AREA

In order to provide a real-world test of the guidance, EPA and the New Mexico Oil Conservation Division funded an initial prototype project to gather and interpret data necessary for an aquifer classification in a lithologically complex area near Artesia, in southeastern New Mexico (Figure 2). Within this area, drinking water and hydrocarbons are produced from the same stratigraphic unit, the San Andres Formation of Permian age. Chloride-rich brines coproduced with the oil are disposed of by injection back into the oil reservoir, often for the purpose of enhanced recovery (waterflood). Under UIC regulations, such injection should not occur into or above a protected aquifer. If the entire San Andres were designated for protection, much of the waterflood activity in New Mexico would cease and brine disposal would become an expensive, perhaps impossible operation. Clearly, the San Andres poses a complex and economically important problem in UIC aquifer classification.

Methods

Geologic, hydrologic and energy-resource data for the Artesia area were gathered from published reports and from the files of Federal, State and local agencies concerned with water or energy resources. Tables were prepared to summarize aquifer properties, water well records, and records of oil, gas and injection wells. Although considerable information is available on that part of the San Andres now used for drinking water, there is a marked absence of conventional hydrologic data for oil-yielding zones. In these zones, information on salinity and porosity was determined primarily from geophysical logs. The dual laterolog and

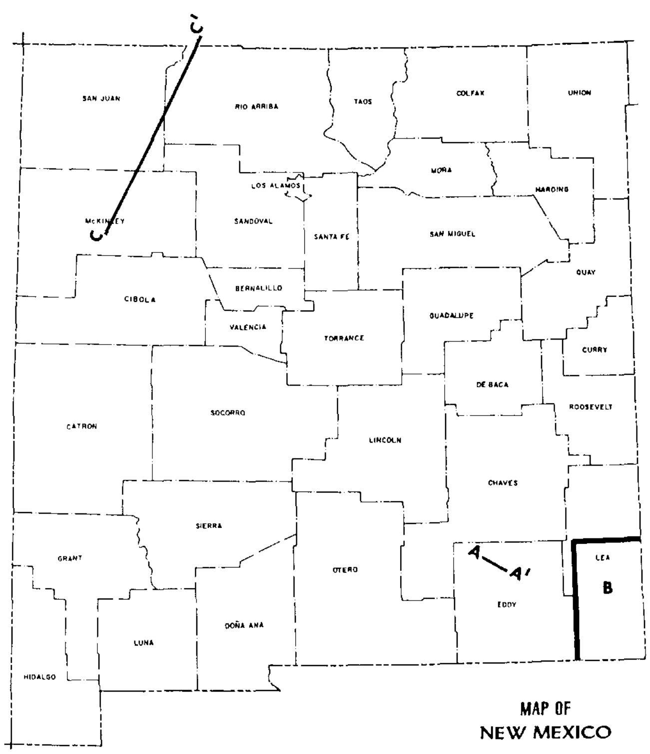

Fig. 2. Location of prototype study areas. Cross section A-A′ is in the Artesia area; see Figures 3 through 6. Area B is in southern Lea County; see Figure 7. Cross section C-C′ is in the San Juan Basin; see Figure 8.

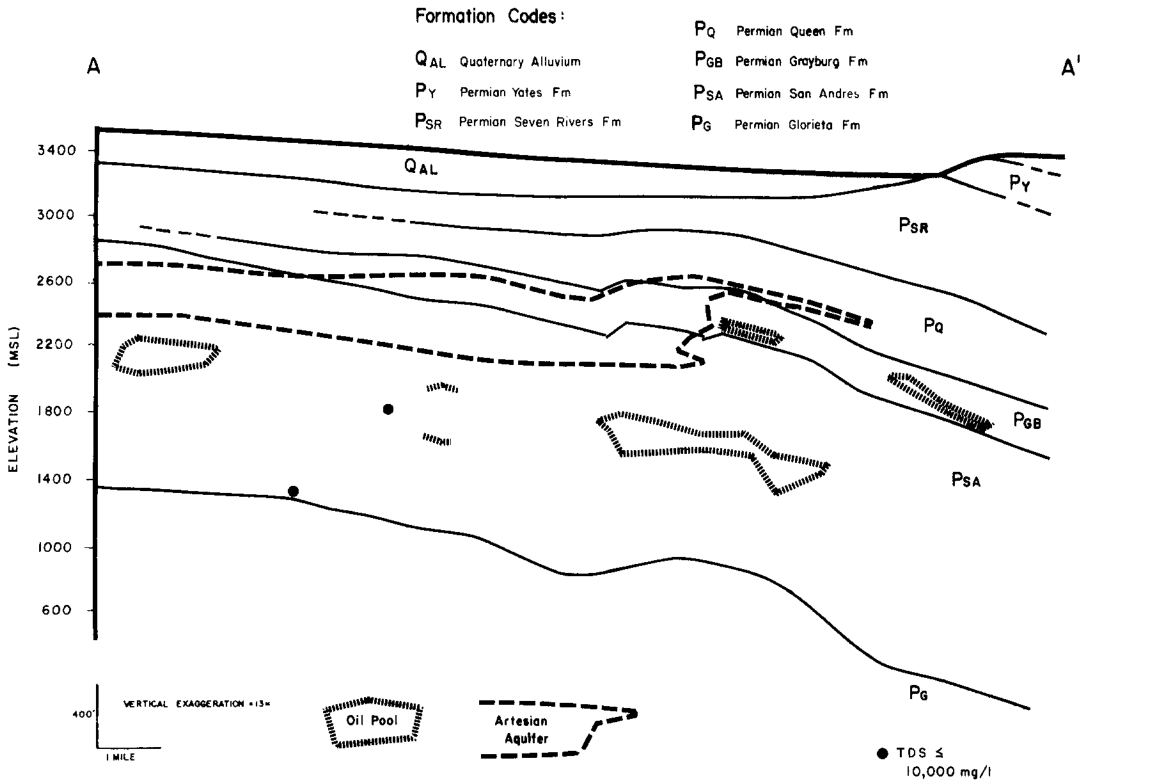

Fig. 3. Hydrogeologic cross section of the Artesia area, New Mexico. Primary oil-bearing zone is located 200-400 feet below the base of the artesian aquifer. The potentiometric surface of the artesian aquifer lies just beneath the land surface.

compensated neutron log have been run on most recent, deep gas wells and can be used to determine resistivity of formation fluids (hence salinity) and formation porosity; see Keys and MacCary (1973).

The tabulated data were interpreted to develop maps displaying structure contours, potentiometric surfaces, the location of shallow oil and gas pools, and the location of data wells. No one map contained all of the information important to the aquifer evaluation process, but the maps could be combined and interpreted to develop a single hydrogeologic cross section of the Artesia area showing all of the information which is important to an aquifer classification for UIC purposes. Figure 3 displays this cross section.

Hydrogeology

The Artesia area is in the shelf zone of the Permian Basin province. The Permian rocks are dominantly dolomitic, with limestone increasing in frequency southeastward toward the main Capitan Reef, and redbeds and evaporites increasing north and west. In general, the Permian units dip toward the southeast and thicken in the same direction.

Most of the region's drinking water comes from an artesian aquifer which occurs near the top of the San Andres Formation and which locally extends into the overlying Grayburg Formation (Figure 3). Water in the artesian aquifer generally contains less than 3,000 mg/l dissolved solids, but higher concentrations do occur, especially toward the east, where San Andres water is naturally saline.

The lower boundary of the artesian aquifer shown in Figure 3 represents the maximum depth of present fresh-water wells. In most locations, water containing 10,000 mg/l or less TDS is not found in wells which penetrate below this boundary. However, the resistivity data obtained from geophysical logs indicate that fresh water may extend to the base of the San Andres in some locations (see solid dots, Figure 3). In all such cases, the logs indicate that the fresh water occurs in rocks with low porosity (averaging less than 7 percent), suggesting that the pores contain irreducible connate water with little potential for cost-effective production. No fresh-water yield is obtained from any well which penetrates below the base of the artesian aquifer.

Hydrocarbon yields in the San Andres occur primarily from a dolomite zone with locally developed porosity; total dissolved solids in coproduced brine always exceed 10,000 mg/l. Subtle changes of strike and dip couple with variations in effective

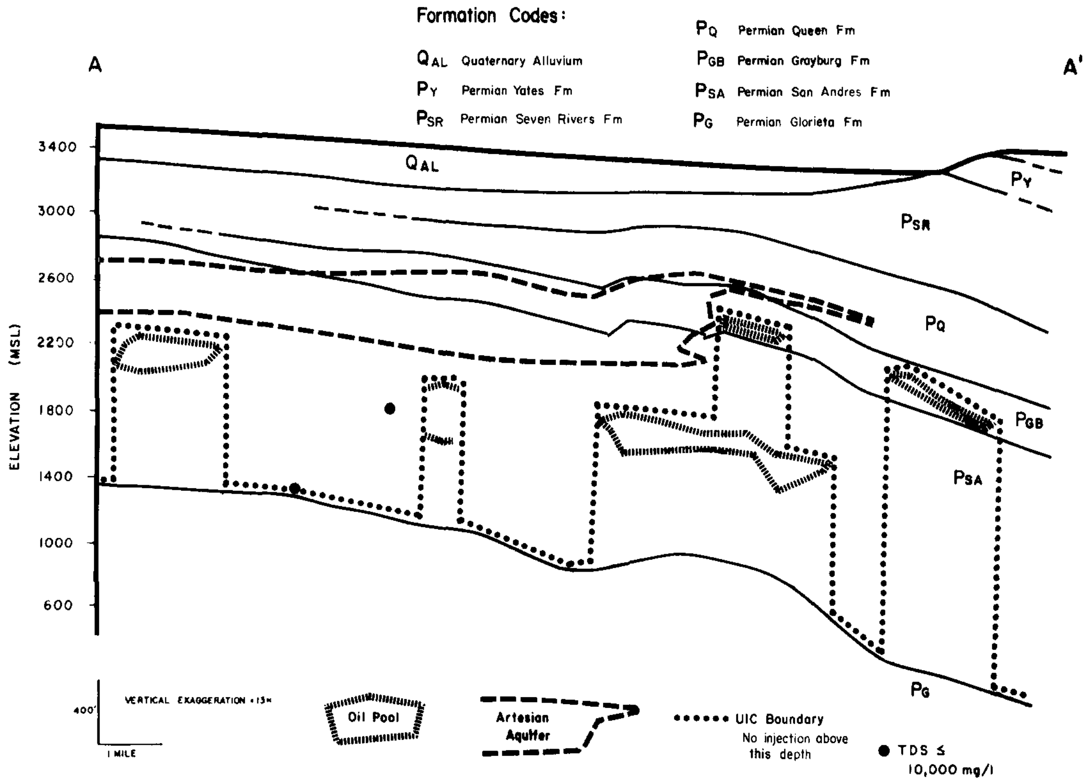

Fig. 4. Alternative UIC classification in which protection extends to base of San Andres Formation except for oil pools, which would be exempted per step 5 of Figure 1.

porosity to control regional pinchouts of hydrocarbon production. Rocks with low porosity and low vertical permeability act as barriers which separate the drinking water of the artesian aquifer from the oil and gas pools in the reservoir zone. If there were no vertical barriers, the oil pools could not exist; if horizontal barriers were absent, the oil pools would be merged.

Oil production in local porosity zones of the Grayburg results in hydrocarbon occurrence adjacent to, as well as beneath, the artesian aquifer (Figure 3). Again, a barrier must exist between the hydrocarbons and the fresh water, otherwise the low-density oil would readily migrate into the artesian aquifer. For additional details on area hydrogeology, refer to: Hantush (1955); Hood (1963); NMGS (1969); Gross *et al.* (1976); LeFebre (1977).

Aquifer Classification

The evaluation process shown in Figure 1 requires boundaries to be drawn around aquifers which are to be protected against injection. The base of the confining layer immediately below the deepest protected aquifer represents the shallowest interval at which injection of a nonpotable water would be allowed. In the prototype study, three alternative aquifer classifications were evaluated; these are illustrated in Figures 4 through 6.

Alternative 1. Designate the entire San Andres Formation as a protected aquifer, but use step 5 of the classification process to exempt all oil pools from protection (Figure 4). This would allow waterflooding to continue; as formation pressures from waterflood do not exceed the natural pressures which occurred when hydrocarbon production began, waterflood injection would not be expected to breach the barriers which now separate the oil pools from the drinking-water aquifer. Brine disposal into nonproducing zones would be prohibited, even where such zones contain saline water.

Alternative 2. Limit protection to the fresh-water part of the San Andres; that is, draw the aquifer boundary along the 10,000 mg/l TDS isocon (Figure 5). All existing waterflood and brine disposal wells inject below this line.

Alternative 3. Designate for protection only the artesian aquifer which now is used for drinking-water supplies (Figure 6). (In practice it would be appropriate to provide a margin of safety and draw the boundary at least 100 feet below the base of the artesian aquifer.) This approach is based on a hydrogeologic concept which recognizes that in

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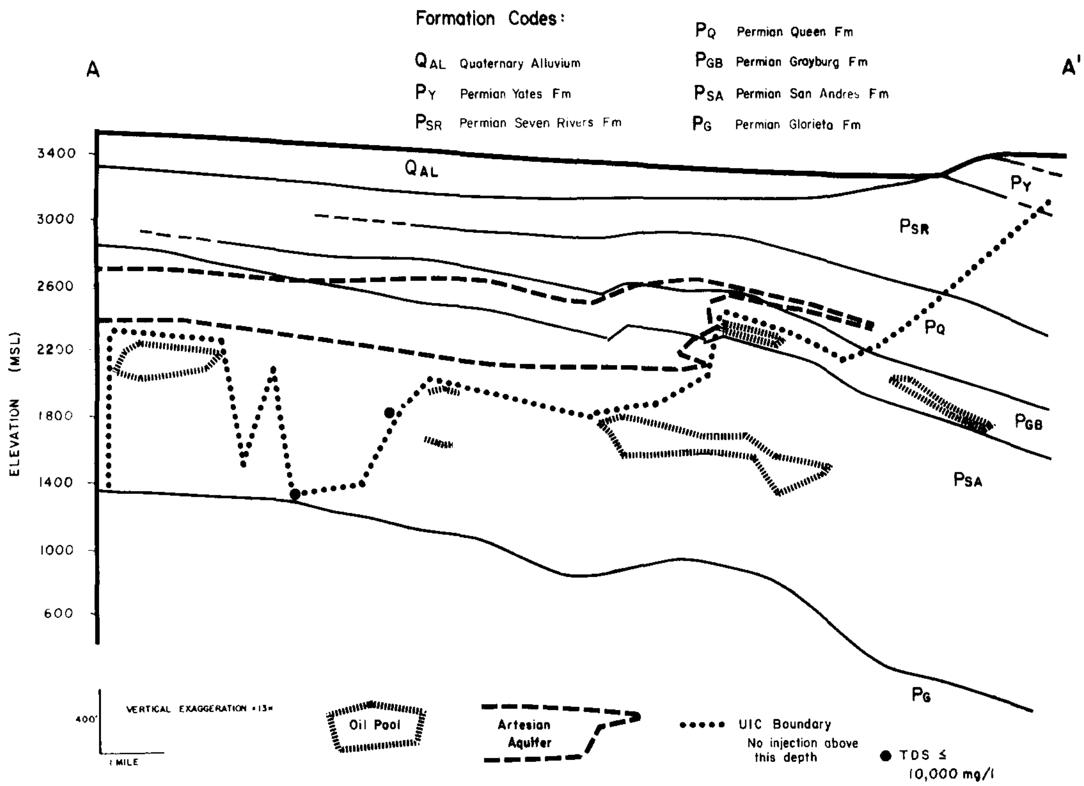

Fig. 5. Alternative UIC classification in which protection extends to base of water known to contain 10,000 mg/l total dissolved solids or less. Rock units below UIC boundary would be classified as nonaquifers.

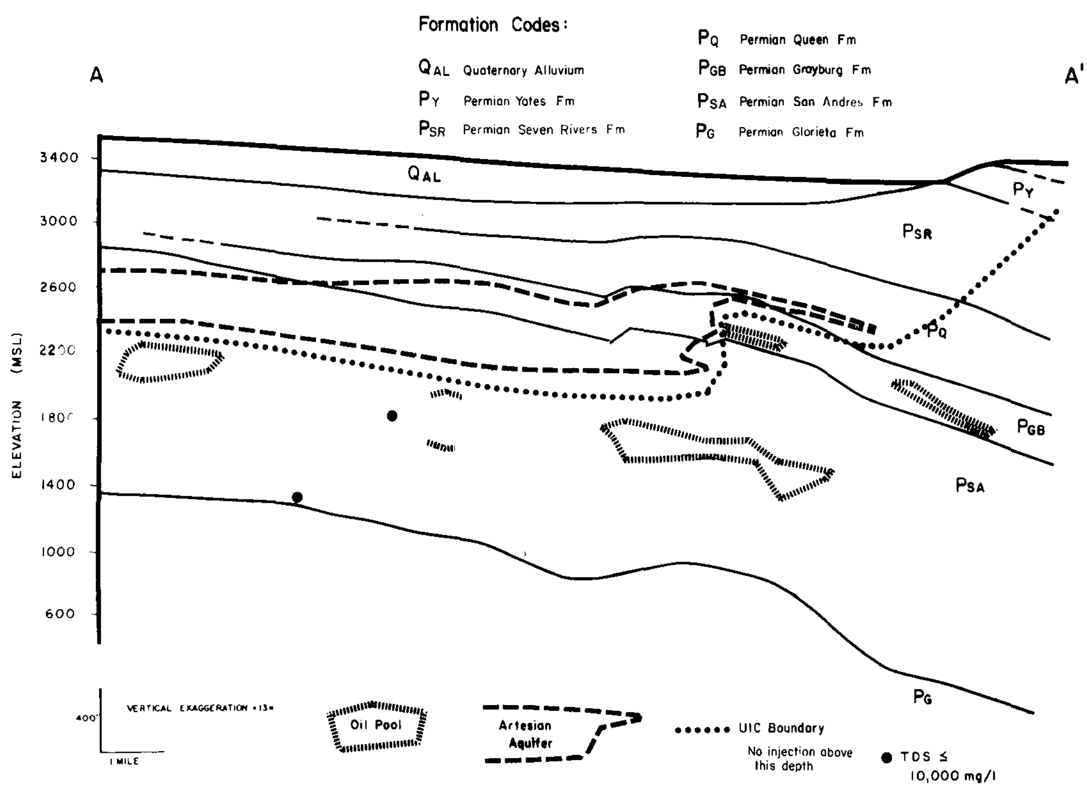

Fig. 6. Alternative UIC classification in which protection extends to base of formations known to be sufficiently permeable to yield significant amounts of water to wells and to contain water with 10,000 mg/l total dissolved solids or less. Rock units below UIC boundary would be classified as nonaquifers or salt-water aquifers.

the rocks beneath the artesian zone, permeability is so low that the unit can be considered as a nonaquifer, per step 4 of Figure 1.

Both alternatives 1 and 2 have significant drawbacks. Alternative 1 would disallow San Andres injection which is not into an oil pool; at least some existing brine disposal wells would be shut down. This would have important economic consequences, as will be shown by the Lea County case study discussed subsequently. Alternative 1 also poses an administrative problem: aquifer boundaries would need to be redrawn each time an oil pool is discovered or extended. Under EPA's UIC regulations, a lengthy public review and hearing process would be required for each new exemption. Alternative 2 is technically and economically feasible, but because water-quality data are scarce in the deeper parts of the San Andres, extension of the isocon boundary outside the prototype area would entail time-consuming, expensive interpretation of geophysical logs.

Alternative 3 is simple to implement because the base of the artesian aquifer has been mapped over a large region using data from extensive water well records. It provides full protection to all of the producible fresh water in the area. Alternative 3 (Figure 6) is the preferred classification because it: corresponds to UIC regulations; provides full protection of existing or potential sources of drinking water; and poses no unusual administrative problems. The concepts shown in the figure can be used by the regulatory agency to propose aquifer classifications for hearing and possible adoption.

LEA COUNTY

The Artesia study was followed by a second prototype project, involving aquifer evaluation in the portion of the Permian Basin which occurs in Lea County (Figure 1).

Level of Detail Needed in UIC Aquifer Evaluation

Preparation of detailed cross sections, based in large part on well log analysis, is a time-consuming process. To determine if less costly methods would be adequate for UIC purposes, the initial Lea County aquifer evaluation was based on a simple review of the technical literature on drinking-water resources of the area. The results were then checked using the more detailed techniques established in the Artesia area.

The literature search indicated that the San Andres and other Permian formations of Lea County are salt-water aquifers and that the base for UIC protection can be drawn at the base of overlying Triassic sediments; exceptions occur in a few locations where slightly saline water is known to occur in the reef limestones of the Permian Capitan Formation. The more detailed analysis reached a *different conclusion*, namely that actual measurements of water quality on file with the U.S. Geological Survey demonstrate that slightly-saline water containing less than 10,000 mg/l TDS does occur in the San Andres and many other Permian units over a sizeable part of the oil-producing area of Lea County. Moreover, in contrast to the Artesia region, this slightly-saline water commonly occurs in zones of good permeability and is capable of being produced by water wells.

The conclusions reached are: UIC evaluations require detailed analyses of logs and other types of data in order to ensure that areas of fresh water are adequately defined; in Lea County, such a detailed analysis indicates that UIC protection may be needed for a number of Permian rock units where injection is active.

Regional Hydrogeologic Model

The area potentially needing UIC protection was mapped based on the location of the 10,000 mg/l isocon as inferred from the regional hydrogeologic model of Hiss (1980). This model indicates that the relatively fresh water in the Permian formations of Lea County originated as recharge from the Glass Mountains in Texas, a source intercepted by Pleistocene incision of the Pecos River. The flow path was controlled by a number of lithologic features and is shown by the heavy black arrow in Figure 7. The remnant fresh water is found in the Capitan Reef and in a limestone sand facies deposited in a paleobathymetric area known as the Hobbs Channel. The facies interfingers with relatively impermeable sediments and cannot be separately mapped from available data. It is necessary to conclude that the entire Hobbs Channel and most of the Capitan Reef are potential sources of drinking water.

Consideration of an Aquifer Exemption

The San Andres and other Permian formations of Lea County are prolific oil producers and support many waterflood projects and salt-water disposal wells. Perhaps one-fifth to one-quarter of all brine injection in southeastern New Mexico occurs into zones which potentially require UIC protection. If injection to these aquifers were disallowed, then hundreds of injection wells would

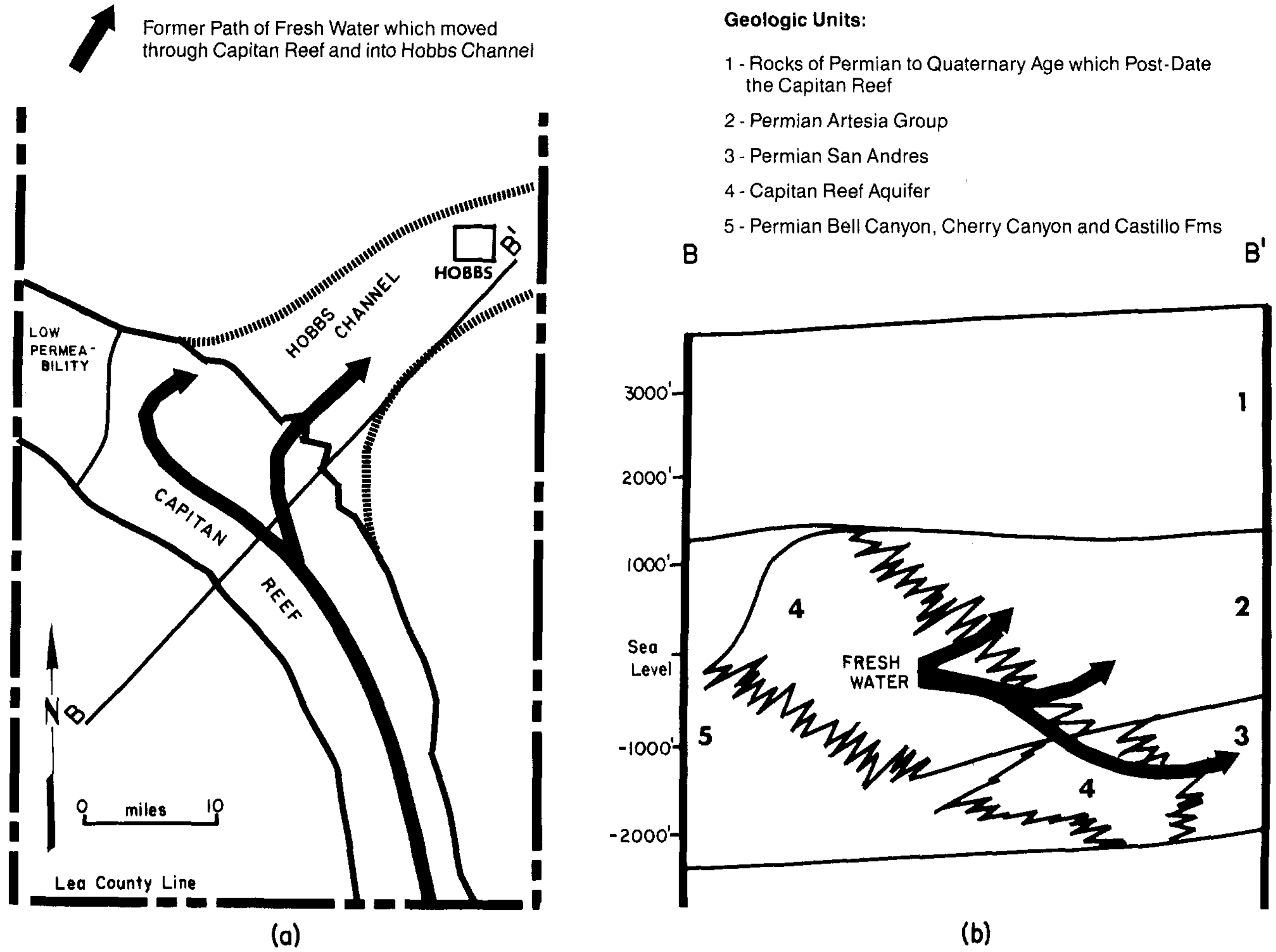

Fig. 7. Hydrologic features important to UIC classification in southern Lea County, New Mexico. The 10,000 mg/l TDS isocon inferred from the water-supply literature occurs in the upper part of unit 1, at about 3,000 feet elevation (msl).

have to be shut down. Waterflood operations would cease, and brine disposal would have to occur in the next deeper permeable zone containing saline water—which is Devonian strata at depths of up to 10,000 feet (versus 4,000-5,000 feet at present). Such a change in injection practices would have obvious economic consequences.

At the time the study was performed, EPA's UIC regulations did not include step 9. Application of steps 5 through 8 in the aquifer evaluation process (Figure 1) indicated that only step 6 fully resolved the apparent conflict between then-existing UIC rules and industry practices. Step 6 indicates that injection may be allowed in a fresh-water aquifer which is "unusable as a source of drinking water because it is situated at a depth or location which makes recovery of water for drinking-water purposes economically or technologically impractical." The criteria of "economic impracticality" suggests that exemption might be allowed if it made no economic sense to ever use a given aquifer as a drinking-water resource. Application of step 6 to the Permian aquifers of Lea County involved the following steps and findings.

1. The San Andres Formation contains the largest and freshest of the potential drinking-water resources in the Permian units of the Hobbs Channel; the City of Hobbs is the principal area where drinking water is needed. Therefore, the analysis assumed that the fresh water in the San Andres Formation was a potential source of drinking water for Hobbs.

2. The need for water in Hobbs was estimated for a 100-year period; the total requirement is 1.5 million acre-feet. Hobbs can obtain this supply from a nearby shallow source of ground water (the Tertiary Ogallala Formation) at a cost of $75 per acre-foot.

3. In contrast, the cost of San Andres water would exceed $900 per acre-foot. The high price primarily reflects the need to desalt the slightly

saline water in order to make it potable; pumping costs also are much greater than for the shallow ground water.

4. The cost to industry of developing new disposal wells into the Devonian would be about $1,000 per acre-foot of San Andres water which would be protected.

When all factors are considered, protection and use of the San Andres Formation for Hobbs drinking water would cost nearly $2,000 per acre-foot, or about 25 times more than the alternative of using Ogallala ground water. This cost differential demonstrates that production of San Andres water for drinking-water purposes is economically impractical and that a step 6 exemption is justified. The same conclusion would apply to the smaller amounts of fresh water in other Permian aquifers. This conclusion is specific to the area studied; economics might *not* support an exemption in an area where alternative supplies of drinking water are scarce. (Note: After the study was completed, New Mexico revised its regulations to allow a step 6 exemption only where TDS exceeds 5,000 mg/l; this does not affect the Lea County aquifers.)

SAN JUAN BASIN

A third study applied the lessons from hydrocarbon-producing areas of southeastern New Mexico to the uranium-producing San Juan Basin in the northwestern part of the State (Figure 1). Two new insights were gained in the San Juan study.

Classification Strategy

A different strategy toward UIC classification was used in the San Juan Basin because, at the time of the study, only one small, experimental injection project was active in this region. Based on step 1 of Figure 1, it is appropriate to provide UIC protection for all rock units in the Basin. Reclassifications or exemptions can be provided on a case-by-case basis as industry makes specific injection proposals.

The most likely exemptions would involve in-situ uranium mining, where a lixivant would be injected into water-bearing ore bodies (Wilson *et al.*, 1981). Such injection may be allowed per step 5 of Figure 1. The anisotropic nature of the ore-bearing formations makes it difficult to predict the fate of the injected lixivant. Also, the uranium ore is often in the least permeable part of the rock, which makes it difficult to prevent leachate excursions. Because of these problems it may be necessary to exempt aquifers over a much larger area than indicated by the idealized in-situ flow system and to limit the exemption to the time frame of the mining. Monitoring networks will need to be extensive, and aquifer restoration will be required to ensure that any remnant leachates do not migrate to areas outside the exempted zone. New Mexico's UIC regulations do in fact specify time limits to step 5 exemptions, and require aquifer restoration.

Regional Hydrogeologic Model

Modern geophysical logs are absent over much of the San Juan Basin. To develop a regional hydrogeologic model it was necessary to extrapolate limited information on water quality and lithology. The model was based primarily on three facts.

1. The San Juan Basin contains a thick sequence (up to 15,000 feet) of Cambrian to Holocene sedimentary rocks within a large, mildly deformed, asymmetric structural basin that is typical of the Colorado Plateau tectonic province. Based primarily on the literature (Berry, 1959; Shomaker, 1971; West, 1972; Lyford, 1979; BIA, 1980) and on water well data, it can be demonstrated that, in one location or another, every stratigraphic unit contains (or has the potential to contain) some permeable beds with water of less than 10,000 mg/l TDS. This supports the concept of classifying every rock unit as a protected aquifer, unless there is some basis for a determination to the contrary.

2. Textural facies changes in Permian rocks result in coarser sediments toward the north of the basin while Cretaceous rocks coarsen to the south. This pattern is modified by cement dissolution, which is greatest near recharge areas along the southern margin of the basin. The result is that, in general, transmissivity decreases towards the center of the basin.

3. Total dissolved solids vary laterally within individual aquifers. The freshest water is found close to recharge areas at the south basin margin. Salinity increases as the ground water migrates toward the basin center.

Figure 8 illustrates the net effect of the relationships described. The heavy dotted line is the approximate location of the 10,000 mg/l TDS isocon. Near the major recharge zone at the southwest basin margin, no base of fresh water has been identified. Near the basin center the base of fresh water occurs near the land surface. In between there are alternating zones of "fresh" (by

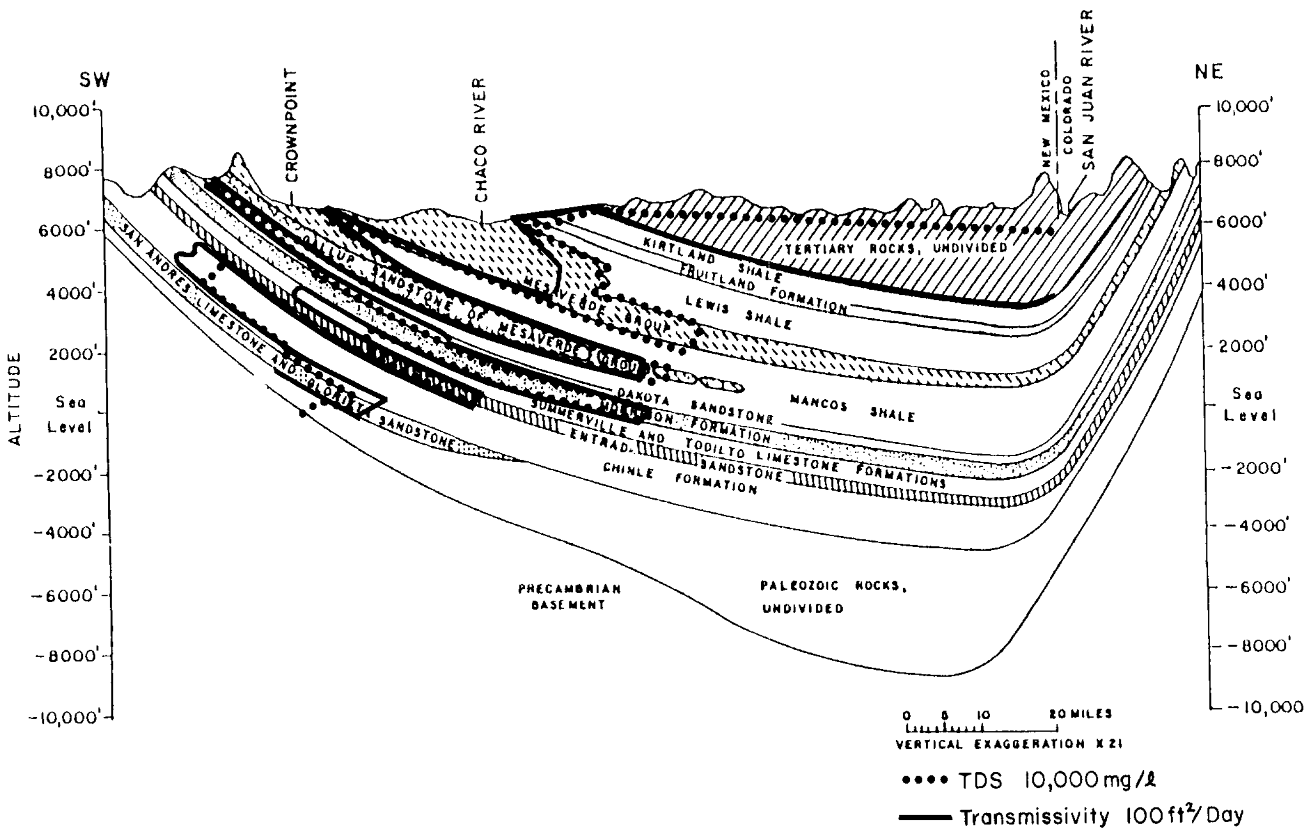

Fig. 8. Hydrogeologic cross section of the San Juan Basin, New Mexico. Water containing 10,000 mg/l or less total dissolved solids occurs above and to the west of heavy dotted line. Formations with a transmissivity of 100 ft^2/day or greater occur above and to the west of solid line. Section taken from Lyford (1979).

UIC standards) and saline water. The fresh water appears in cross section as fingers pointing toward the center of the basin; each finger is located along a relatively permeable unit such as the main Mesaverde Group, Gallup sandstone, Morrison Formation, Entrada sandstone, and San Andres limestone/Glorieta sandstone. Conversely, fingers of saline water point toward the southwest basin margin; each saline finger is associated with a relatively impermeable formation, most often a shale. The heavy line in Figure 8 shows that, in general, the fresh water occurs in rocks with a transmissivity greater than 100 feet squared per day.

If Figure 8 is supported by future studies, then injection will be feasible into the salt-water aquifers which occur at relatively shallow depths in the northern half of the basin, and into saline portions of the Chinle or older units to the south. At the southern margin of the basin, which is where much of the uranium activity is concentrated, injection will require a temporary aquifer exemption.

CONCLUSIONS

The three studies demonstrate that it is practical but not simple to implement the aquifer classification component of the UIC regulations. Aquifer classification involves the steps shown in Figure 1 and relies upon hydrogeologic cross sections which reflect understanding of regional hydrology and geology, and which utilize data obtained from well records and geophysical logs. Nongeologic considerations, such as economics, become important in areas where UIC classifications could conflict with existing or proposed industry practices.

Based on these prototype studies, the cost of a UIC aquifer classification should be in the range of \$0.50 to \$1.00 per square mile. The expense would be much higher, except that precise classifications are needed only in areas of active injection. Elsewhere, aquifers can be protected to the deepest plausible level unless and until a particular applicant provides site-specific data in support of an aquifer reclassification or exemption.

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