EEG-62

FLUID INJECTION FOR SALT WATER DISPOSAL AND ENHANCED OIL RECOVERY AS A POTENTIAL PROBLEM FOR THE WIPP: PROCEEDINGS OF A JUNE 1995 WORKSHOP AND ANALYSIS

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Environmental Evaluation Group
New Mexico

August 1996

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DOE/AL58309-62

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FOREWORD

The purpose of the New Mexico Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the Waste Isolation Pilot Plant (WIPP) Project to ensure the protection of the public health and safety and the environment. The WIPP Project, located in southeastern New Mexico, is being constructed as a repository for the disposal of transuranic (TRU) radioactive wastes generated by the national defense programs. The EEG was established in 1978 with funds provided by the U.S. Department of Energy (DOE) to the State of New Mexico. Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989, Section 1433, assigned EEG to the New Mexico Institute of Mining and Technology and continued the original contract DE-AC04-79AL10752 through DOE contract DE-ACO4-89AL58309. The National Defense Authorization Act for Fiscal Year 1994, Public Law 103-160, continues the authorization.

EEG performs independent technical analyses of the suitability of the proposed site; the design of the repository, its planned operation, and its long-term integrity; suitability and safety of the transportation systems; suitability of the Waste Acceptance Criteria and the generator sites' compliance with them; and related subjects. These analyses include assessments of reports issued by the DOE and its contractors, other federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP. Another important function of EEG is the independent environmental monitoring of background radioactivity in air, water, and soil, both on-site and off-site.

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EXECUTIVE SUMMARY

The Waste Isolation Pilot Plant (WIPP) is a facility of the U.S. Department of Energy (DOE), designed and constructed for the permanent disposal of transuranic (TRU) defense waste. The repository is sited in the New Mexico portion of the Delaware Basin, at a depth of 655 meters, in the salt beds of the Salado Formation. The WIPP is surrounded by reserves and production of potash, crude oil and natural gas.

In selecting a repository site, concerns about extensive oil field development eliminated the Mescalero Plains site in Chaves County (U.S. DOE 1980, 2-10) and concerns about future waterflooding in nearby oil fields helped eliminate the Alternate II site in Lea County (Griswold 1977, 13). Ultimately, the Los Medaños site in Eddy County was selected, relying in part on the conclusion that there were no oil reserves at the site (U.S. DOE 1980, 2-15).

For oil field operations, the problem of water migrating from the injection zone, through other formations such as the Salado, and onto adjacent property has long been recognized (Ramey 1976). In 1980, the DOE intended to prohibit secondary recovery by waterflooding in a one mile buffer surrounding the WIPP Site (U.S. DOE 1980, 8-4). However, the DOE relinquished the right to restrict waterflooding (McGough 1983) based on a natural resources report (Brausch et al. 1982, 30) which maintained that there was a minimal amount of crude oil likely to exist at the WIPP site, hence waterflooding adjacent to the WIPP would be unlikely.

In the early 1990s, the Delaware Basin experienced a drilling boom that included oil field discoveries surrounding and underlying the WIPP Site (Broadhead et al. 1995). Salt water disposal wells are now operating throughout the area (Silva 1994; Broadhead et al. 1995) and waterflooding is just beginning with new oil field pressure maintenance programs underway (Broadhead et al. 1995).

Beginning in 1988, sudden water level rises in the Culebra aquifer to the south of the WIPP site raised questions about the water injection activities of the oil and gas industry (Bailey 1990; LaVenue 1991). LaVenue (1991) cautioned the WIPP Performance Assessment (PA) team about the yet to be determined impact of these activities. However, the WIPP PA team did not include the impact of fluid injection in the calculations citing either "low consequence" arguments for human activities adjacent to the WIPP (SNL 1991, SNL 1992) or "consequences greater than that of exploratory drilling" in the case of human intrusion (SNL 1992). In 1993, the WIPP project was again cautioned about injected oil field water fracturing the Salado Formation and migrating into adjacent properties. An oil and gas producer in southeast New Mexico had suffered a major salt water blowout as a result of a waterflood operation two miles away (Hartman 1993).

The potential impact of brine injection on the long-term performance of the WIPP prompted the Environmental Evaluation Group (EEG) to organize a June 13, 1995, workshop on the issue. This report publishes the workshop presentations (Chapter 2) and presents the author's analysis of the workshop issues (Chapter 3) based on information from the scientific literature, public records, the draft compliance application submitted by the DOE to the U.S. Environmental Protection Agency (EPA), and the WIPP specific compliance Criteria promulgated by the EPA. The workshop included presentations describing the extent of oil and gas resources, the anomalous water level rises in the Culebra Aquifer, the documented effects of water flooding on the Salado Formation, the geology of waterflooded areas in southeast New Mexico, the current petroleum production practices, the treatment of water injection by the performance assessment effort, and the need for a water flooding scenario in the WIPP PA calculations. As was intended, a number of issues were deliberated. On many issues there was no consensus. Nonetheless, the workshop was an excellent example of cooperation and open exchange of information by various federal and state agencies, private industry, the university sector, and other interested parties.

In addition to exploring the potential impact of waterflooding and salt water disposal on the WIPP, Chapter 3 identifies a number of unresolved issues. Some unresolved topics are currently in litigation between oil and gas companies and the federal government for operations adjacent to the WIPP. The issues identified in Chapter 3 include questions about a) the productive life of an oil field in the Delaware Basin, b) the extent of oil and gas reserves in unexplored areas, c) the potential for waterflooding and other secondary recovery methods, d) the volumes of water to be injected, e) the availability of water for waterflooding, f) delays in oil and gas drilling due to the presence of potash g) the true extent of potash reserves, h) evidence of communication between formations above and below the WIPP through vertical pathways possibly created by the improper abandonment of wells, poorly cemented and cased wells, degraded well casings and cement in saline environments, and i) violation of existing regulations.

This report also raises questions about how much credit for protection from out-of-zone injection the WIPP project can justify, based on state regulations unique to the Known Potash Lease Area. The state regulations were never intended to address the needs of WIPP. Rather, the state regulations were promulgated to address the concerns of the potash and oil and gas industries (LeMay et al. 1988). In light of the information presented in this report, it would seem prudent for the WIPP project to analyze the historical effectiveness of the New Mexico regulations specifically intended to address fluid injection, Rule 701, 702, and 703.

The potash companies carefully monitor activities with a potential impact on the Salado Formation. For instance, the New Mexico Oil Conservation Division held a hearing on November 16, 1995, for a proposed oil field pressure maintenance well to be located one mile from the outer boundary of the WIPP and eight miles from IMC's existing potash mine workings. At the hearing IMC expressed concern that injected water could escape or otherwise migrate from the proposed injection interval into potash bearing formations. The DOE was notified of the hearing but did not attend (LeMay 1995b). The injection well was approved to operate at a pressure that exceeds the lithostatic pressure at the WIPP horizon.

The oil and gas industry is also concerned about the operation of injection wells in close proximity to its hydrocarbon reserves. When Yates Petroleum proposed converting an oil production well to salt water injection, another oil company objected. Mitchell Energy was concerned about excessive injection pressures and the loss of reserves as a result of injection into potential oil producing horizons (Stephenson 1991). An agreement was reached between the two oil companies (Kellahin 1991). The salt water disposal well was approved by the New Mexico Oil Conservation Division (LeMay 1991). The DOE appeared unaware that there was a salt water injection well operating within one mile of the WIPP Site Boundary and continued to list the well as an oil producing well (Arthur 1993a; Arthur 1993b; Silva 1994, 55-56; Kehrman 1995, 254, lines 18-20).

The DOE Draft Compliance Certification Application (DCCA), submitted to EPA in July 1995, did not include fluid injection in the performance assessment calculations. Citing Cranwell et al. (1990), fluid injection within the WIPP site was screened out on the basis of "regulatory guidance" (U.S. DOE 1995, 6-38), but this criterion is not found in Cranwell et al. (1990). Furthermore, DOE's expert elicitation exercise of 1990 identified industrial fluid injection as a potential human intrusion activity for the full 10,000 year regulatory period (Hora et al. 1991, Table IV-16). Fluid injection due to activities on adjacent properties was screened out on the basis of "low consequence" although the DOE draft application had no documentation to support that position (U.S. DOE 1995, SCR-72). With respect to fluid injection adjacent to the WIPP Site, the February 1996 EPA Criteria (40 CFR 194) require performance assessment to include the effects of any near future activities on lands surrounding the WIPP. A credible compliance application should include performance assessment calculations that fully consider the distinct activities of 1) fluid injection for resource recovery and 2) waste disposal activities within the site and adjacent to the site for the regulatory period of 10,000 years.

1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is intended to serve as a repository for the disposal of transuranic (TRU) waste generated by the defense activities of the United States Government. The WIPP is situated in the lower portion of the Salado Formation in a resource rich area in southeastern New Mexico. Natural resources in the immediate vicinity of the WIPP site include economically attractive reserves of potash, crude oil, and natural gas (Foster 1974; Keesey 1976, 1977, and 1979; Griswold 1977; Powers et al. 1978; U.S. DOE 1980; Brausch et al. 1982; Neill et al. 1983; Weart 1983; Silva 1994; Griswold 1995a; Broadhead et al. 1995; U.S. DOE 1995).

1.1 Natural Resources and Water Injection at Other Candidate Sites

The problem of natural resources and the use of water injection in the vicinity of a nuclear waste repository has long been recognized. In 1972, the Lyons, Kansas site for a proposed TRU waste repository was rejected because there were too many drill holes in the area that could not be positively located, and nearby solution mining was experiencing unexplained water losses (U.S. DOE 1980, 2-7; U.S. DOE 1993, 26). Of the three areas in New Mexico chosen for further study, the Mescalero Plains area in Chaves County was disqualified because of extensive oil field development (U.S. DOE 1980, 2-10). In the Carlsbad vicinity, two of eight sites survived the screening criteria, the current Los Medaños site and the Alternate II. However, Alternate II in Lea County was rejected for a variety of reasons including the observation that it lay adjacent to the Double X and Triple X oil fields where waterflooding for secondary recovery could occur (Griswold 1977, 13).

1.2 Oil Field Waterflooding and the Salado

Typical oil field operations include two types of water injection activities - salt water disposal and waterflooding. In a successful salt water disposal operation, the unwanted brine is injected through a disposal well into an approved zone or zones. The production of oil, particularly in the Delaware Basin, is often accompanied by the production of large volumes of reservoir brine.

Oil production by primary recovery relies on natural reservoir energy to drive oil towards the well bore. These sources of natural energy include fluid and rock expansion, solution gas drive, gravity drainage, and the influx of water from connected aquifers. As oil, gas, and reservoir brine are produced, the natural reservoir energy is expended. Waterflooding aims to enhance crude oil recovery by restoring or supplementing reservoir energy (Willhite 1986). A successful waterflood injects pressurized water through the well bore into the oil bearing zone to force additional oil to flow towards the producing well.

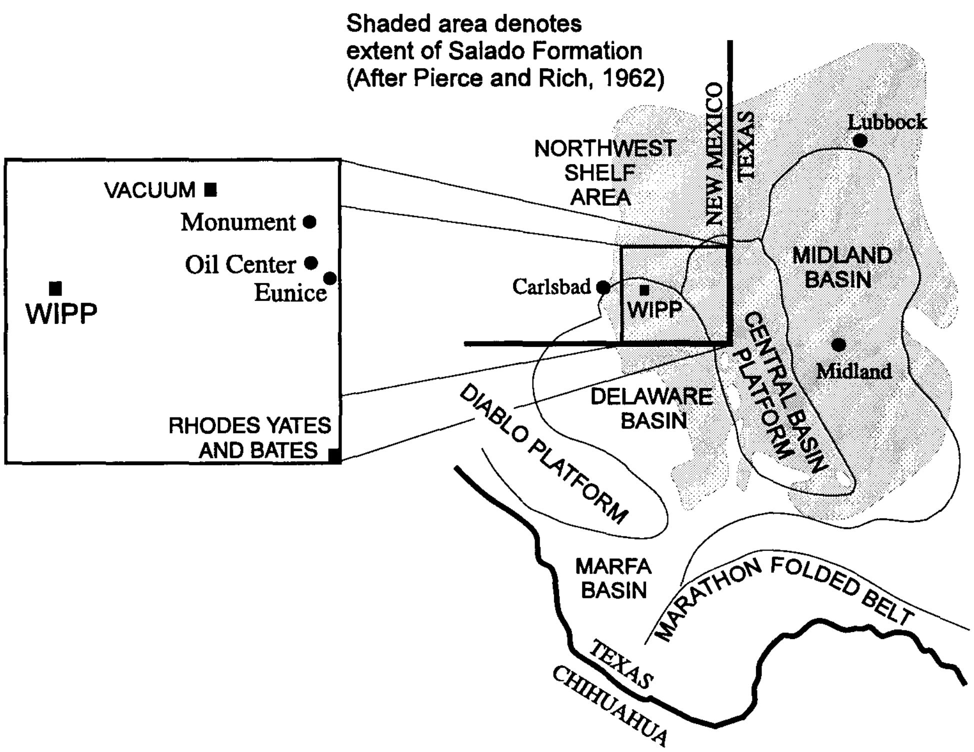

Figure 1-1. Physiographic provinces, extent of the Salado Formation, and oil field locations.

Figure 1-1 shows the locations of the physiographic zone and oil fields mentioned throughout the report. For oil fields underlying the Salado Formation, the problem of water escaping from the injection zone and migrating through the Salado Formation to adjacent properties has long been well known. For example, in a May 5, 1976, letter, Joe D. Ramey, Director of the Oil Conservation Division, advised the Secretary of the New Mexico Energy and Minerals Department (NMEMD), John F. O'Leary, of the situation:

> It has recently come to our attention that there are numerous salt water flows in and around waterfloods in Lea County... Basically the problem is that water injected at around 3600' is escaping from the injection interval, migrating upward to the base of the salt section and then moving horizontally through this section. Waterflows of 5000-6000 barrels per day and recorded surface pressures of 1600 pounds on wells outside waterflood areas are not uncommon. This had resulted in collapsed casing in several wells but the critical aspect in this is the threat of widespread contamination of fresh water.... (Ramey 1976)

In 1980, the U.S. Department of Energy (DOE) intended to prohibit secondary recovery by waterflooding (U.S. DOE 1980, 8-4) in former control zone IV - the area that now forms much of the one mile buffer outside the 4-mile by 4-mile WIPP Land Withdrawal Boundary.[1] The DOE natural resources report (Brausch et al. 1982) maintained there was a minimal amount of crude oil likely to exist at the WIPP site and did not evaluate the potential impact of waterflooding. The DOE subsequently relinquished the right to restrict waterflooding for hydrocarbon recovery in former control zone IV (McGough 1983b).

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[1]See Silva (1994) for a discussion of how previous control zone III was squared off to form the current WIPP site boundary.

FORMATION		DEPTH TO CONTACT AT WIPP (FEET)	PRINCIPAL LITHOLOGY
Surficial Sand		10	Blanket sand and dune sand, some alluvium included.
Mescalaro Caliche and Gatuna Fm.		40	Pale reddish-brown, fine-grained friable sandstone; capped by a 5-10 ft. hard, white crystalline caliche (limestone) crust
Santa Rosa Sandstone		50	Pale red to gray, cross-bedded, non-marine, medium to course-grained friable sandstone; pinches out accross site.
Dewey Lake Redbeds		540	Uniform dark red-brown marine mudstone and sitlestone with interbedded very fine-grained sandsonte; thins westward.
Rustler		850	Anhydrite with siltstone interbeds. Contains two dolomite marker beds: Magenta and Culebra. Thickens eastward due to increasing content of undissolved rock salt.
Salado	Upper member		Mainly rock salt (85-90%) with minor interbedded anhydrite (43 marker beds), polyhalite and clayey to silty clastics. Potash minerals in McNutt Zone.
	McNutt member		
	Lower member	← WIPP REPOSITORY	
		2825	
Castile	Anh. III-IV		Varved anhydrite-calcite units alternating with thick halite (rock salt).
	Hal. II		
	Anh. II		
	Hal. I		
	Anh. I	4075	
Delaware Mountain Group	Bell Canyon		Mostly fine-grained sandstone with shaly and limy intervals. Bell Canyon is used for salt water disposal. Cherry Canyon and Brushy Canyon contain oil producing zones.
	Cherry Canyon		
	Brushy Canyon	~8000	

Figure 1-2. Stratigraphic cross section at the WIPP Site.

In April 1988, anomalous water level rises in the Culebra Dolomite aquifer were measured in several observation wells to the south of the WIPP site (Beauheim 1990). LaVenue (1991) conducted an investigation that raised serious questions about oil field operations. Bailey (1990), a certified professional geologist and petroleum engineer with the New Mexico State Land Office, described waterflooding problems for the Vacuum Field (an oil field overlain by the Salado and Rustler Formations) in a letter to Marsh LaVenue and suggested that the anomalous water level rises in the WIPP wells may have similar origin:

> Although the Vacuum Field, located in Township 17-18 South, Ranges 34-35 East, is located some distance northeast of the monitor wells in question, I believe the hydrogeologic setting is analogous to the well field you are currently investigating. The Vacuum Field is also overlain with Dewey Lake Red Beds and the Rustler and Salado Formations. Numerous water flows in the Salado were creating oil field casing failures and drilling and cementing problems and many people were concerned that the situation could cause contamination of the Ogallala aquifer.
>
> Discussions at the Vacuum Field Salt Water Flow Committee meetings with the Oil Conservation Division in 1986-1987 indicated that the uppermost water flow occurred at the base of the Rustler and the lowest flow occurred at the top of the Tansill Formation. The most numerous flows were found near the crest of the anticline, but flows were encountered throughout the field. Spot checking of old oil well drilling records indicate water flow drilling problems and numerous casing leak repairs in the Dewey Lake Red Beds, Rustler and Salado formation for many years. These water flows are still occurring in the Vacuum Field although at a lesser rate than during the 1970's and 1980's.

These water flows are characterized as strong, intermittent and spotty. Not all wells have encountered flows, but when they did, the flows were estimated at 1,000 - 2,000 barrels [42,000 - 84,000 gallons] per day. The flows often would last 4-5 days before stopping by themselves. The Oil and Gas Conservation District was greatly concerned about the effects of these flows and the potential for dissolution, vertical fracturing and collapse of the upper beds, and the contamination of the Ogallala aquifer.

After years of study, thousands of pressure tests, installation of pressure monitoring wells, and chemical analyses, the Water Flow Committee, decided that no one knew the origin of the early flows, or specifically where the water was stored. However, individual flows were correlated throughout the field to distinct horizons within the Salado Formation where fluid flow is facilitated along bedding planes at clastic-evaporite interfaces. Chemical dissolution of bounding salts and mechanical fracturing enable large volumes of fluids to be transported over large areas.

Chemical and isotopic analyses of the waterflow brines indicated that the waters were not naturally occurring connate waters produced by the evaporation of Permian seawater. (18)Oxygen/(16)Oxygen ratios and (18)Oxygen/Magnesium ratios indicated injected produced water as a strong candidate as a source of at least some of the water flows in the Salado Formation. Because the Vacuum waterflood project injection zone is at an approximate depth of 4320'-4720', casing leaks through the salt section are the most logical pathways for introduction of fluids into the Salado Formation (Bailey 1990).

The problem of injected water migrating "out of zone" is widespread. Bailey (1990) noted that waterfloods in and around Eunice, Oil Center, and Monument (Fig. 1-1) resulted in water flow problems through the Salado Formation. Nor is this strictly a problem of the past. Water migrating out of zone continues to plague other oil fields underlying the Salado.

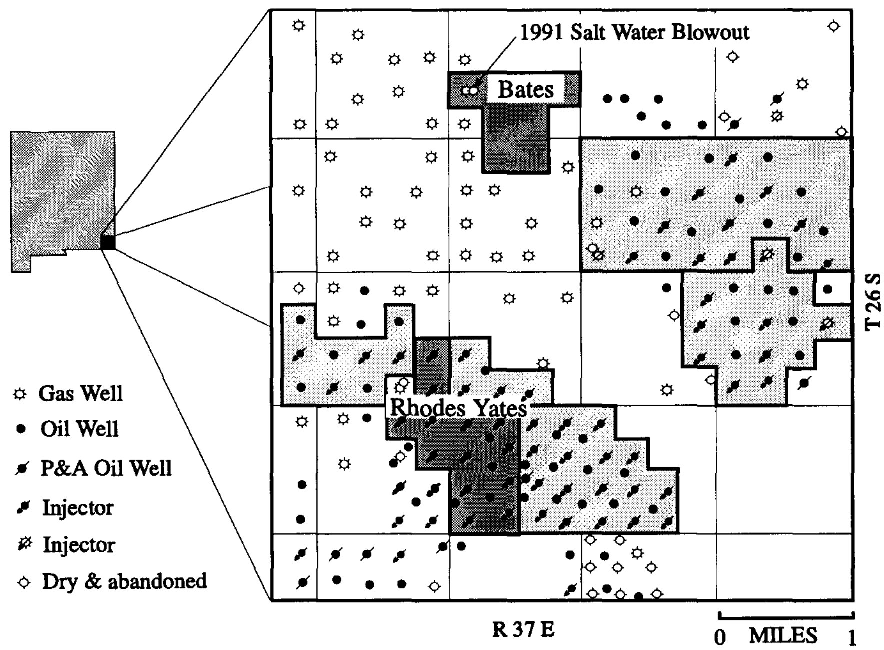

Figure 1-3. Bates Lease (Hartman), Rhodes Yates Waterflood (Texaco) and other nearby leases with injection wells.

1.2.1 Hartman vs. Texaco

On November 22, 1993, Mr. Doyle Hartman (1993) sent Sandia National Laboratories a copy of his November 17, 1993, Complaint (CIV93 1349M) filed in the Federal Court for the District of New Mexico. He stated that he furnished a copy of the complaint to familiarize Sandia "with the Lea County situation so that the proper safety measures will always be taken to preclude the occurrence of such a potentially disastrous event in the close vicinity of the WIPP site in Eddy County, New Mexico." Mr. Hartman claimed that a neighboring waterflood, Texaco's Rhodes Yates, allowed large quantities of injected water to escape out of the approved injection zone, part and dissolve the Salado Formation, and migrate to Hartman's Bates Lease (Hartman 1993, 13).

On January 15, 1991, while drilling through the Salado Formation, Hartman experienced a salt water blowout, which flowed uncontrolled for five days. The suspected waterflood operation was approximately two miles away. On December 12, 1994, after two weeks of hearing testimony and viewing exhibits, the jury found in favor of Hartman's claim for damages. On January 20, 1995, the court ordered the defendant, Texaco, to compensate Hartman for 5.6 million dollars for damages and for value of the property injured and destroyed due to defendants' trespass (Herrera 1995).[2]

Observations of waterflows during drilling and production in waterflood areas appear to be fairly widespread in time and location. Part of the evidence gathered by Hartman's engineers included a listing of 189 waterflows reported throughout various oil and gas fields in District One[3] of southeast New Mexico for the time period from 1978 to 1993. These may not represent all the water flows encountered in this district because not every waterflow encountered during drilling is reported to the New Mexico Oil Conservation Division (NMOCD) (Lanphere and Sullivan 1994a).

1.2.2 Bass vs. United States of America

The potential impact of water flooding and fluid injection on the WIPP has been cited in the recent denial of a valid lease to directionally drill oil wells under the WIPP site from a surface location immediately adjacent to the WIPP site. In April 1993, Bass Enterprises submitted applications to directionally drill eight

[2]The Environmental Evaluation Group understands that portions of this judgment may be in the appeal process. The Environmental Evaluation Group has no direct nor implied opinion about the case.

[3]District One of the New Mexico Oil Conservation District consists of Lea, Roosevelt, Curry, and part of Chavez County.

additional oil wells beneath the WIPP Land Withdrawal Area for the production of crude oil from the 320 acre lease (NM 02953C) in the southern half of Section 31, T22S, R31E. Drilling would have initiated on the surface outside the WIPP site Boundary, proceeded downward 6,000 feet, then deviated into the WIPP site Boundary. On August 22, 1994, the BLM denied approval to drill the eight proposed wells "due to the uncertainty of when a final determination will be made, ***and the unknown impacts from injection wells and water flooding***"[4] (Calkins 1994). On January 23, 1995, Bass Enterprises et al. (1995) filed suit against the federal government for a taking.[5]

1.3 Oil Field Salt Water Disposal

Waterflooding to promote oil recovery is not the only oil field water injection practice of concern. In a memo to LaVenue, Bailey (1990) suggested that a salt water disposal well may be the source of the water level rises south of the WIPP site:

> Because a water injection well or salt water disposal well is the most logical source of a long term or continuous increases in fluids in the monitor well (H-9), I investigated locations of such wells in the area, concentrating on any wells located north-northeast. Spot checking of production wells in the section adjacent to the monitor well had not shown a logical production well as the source of a large fluid pressure increase.... In my opinion, the most likely source of increased fluid pressure is the Devon Energy Corp. Todd 26 Federal Well #3 salt water disposal (SWD) well located northeast and upgradient of the monitor well... Since 1971,

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[4]Emphasis added.

[5]The Environmental Evaluation Group understands that this case may be in litigation. The Environmental Evaluation Group has no direct nor implied opinion with respect to this case.

2,962,402 barrels of produced water have been injected at a current average pressure of 795 psi. No records of any casing repairs are found in the OCD well files.

This observation invites the following questions. Is there evidence to indicate that the Todd 26 Federal #3 well is the source of the water level rises? How was this well completed? What is the status of this well? If the casing, tubing, and cement of this well are intact, are there other available pathways in the area providing communication? Most importantly, over the next 10,000 years, to what extent will there be salt water disposal in the vicinity of the repository?

The first four questions are explored in the EEG workshop presentations and analysis. As to the last question, salt water disposal in the vicinity of the WIPP is already taking place. As noted by Matthew Silva, Ron Broadhead, and Dan Stoelzel, in their respective presentations (Chapter 2), the Delaware wells surrounding the WIPP site produce a very high fraction of water (water cut), on the order of 50% to 70% by volume, as reflected in production records and tabulated by Broadhead et al. (1995, Table 8). Silva (1994, Figure 13) showed four salt water disposal wells within two miles of the WIPP site Boundary as of 1993. Broadhead et al. (1995, Table 7) tabulates ten salt water disposal wells and two pressure maintenance wells within the nine township area surrounding the WIPP as of 1994.

1.4 Oil Field Brine Disposal and the Potash Industry

The issue of salt water disposal in the Delaware Basin appears to be of concern to members of the potash mining industry, which also operate in the Salado Formation. On November 19, 1993, representatives from Bass Enterprises Production Company, an oil company, met with representatives from Western Ag-Minerals Company, a potash mining company, to discuss the Bass proposal to operate a brine injection well two miles west of the WIPP site. Western Ag was concerned about its substantial potash reserves surrounding the well location.

Rather than rely solely on state regulations to protect their portion of the Salado Formation, Western Ag outlined twelve additional operating provisions that would satisfy their concerns (Heinen 1994). The twelve provisions included notification of any request to increase injection pressure above 765 psi, immediate notification of tubing, casing, or packing failure and cessation of injection until the problem is corrected, an annual chemical analysis of injected brine, an annual test to determine migration of brine into other formations, and specifications for well abandonment.

1.5 Well Abandonment

Concerns about improper abandonment of wells appear to be justified. As discussed by Silva (1994), inadequate practices on U.S. Bureau of Land Management (BLM) properties are documented (U.S. DOI 1989, 1990; Baier 1990). A 1989 evaluation (U.S. DOI 1989) by the Inspector General for the U.S. Department of Interior identified considerable problems on the BLM properties resulting largely from "violations of existing regulations" (U.S. DOI 1989, 4). The report cited problems with wells in BLM's Carlsbad Area (U.S. DOI 1989, 6-7)

In arguing a difference between exploratory and development wells[6], the DOE has also brought the problem of improperly abandoned oil and gas wells to the attention of the EPA. As the DOE Carlsbad Area Office noted:

> Development wells are generally abandoned only after many years of production. Many development wells change ownership several times during their operational lifespan, and may not produce continuously. They may ultimately be abandoned improperly (Dials 1994, Supplemental Information to Options 2, 4 and 3, 12).

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[6]For other views on well definitions see Neill 1995; Vaughn 1995; Carroll and Bogle 1996; also Gorenflo vs Texaco, 566 F. Supp. 722 (1983); Sun vs. Jackson, 715 S.W. 2D 199 (1986) and 783 S.W. 2d 202 (1989).

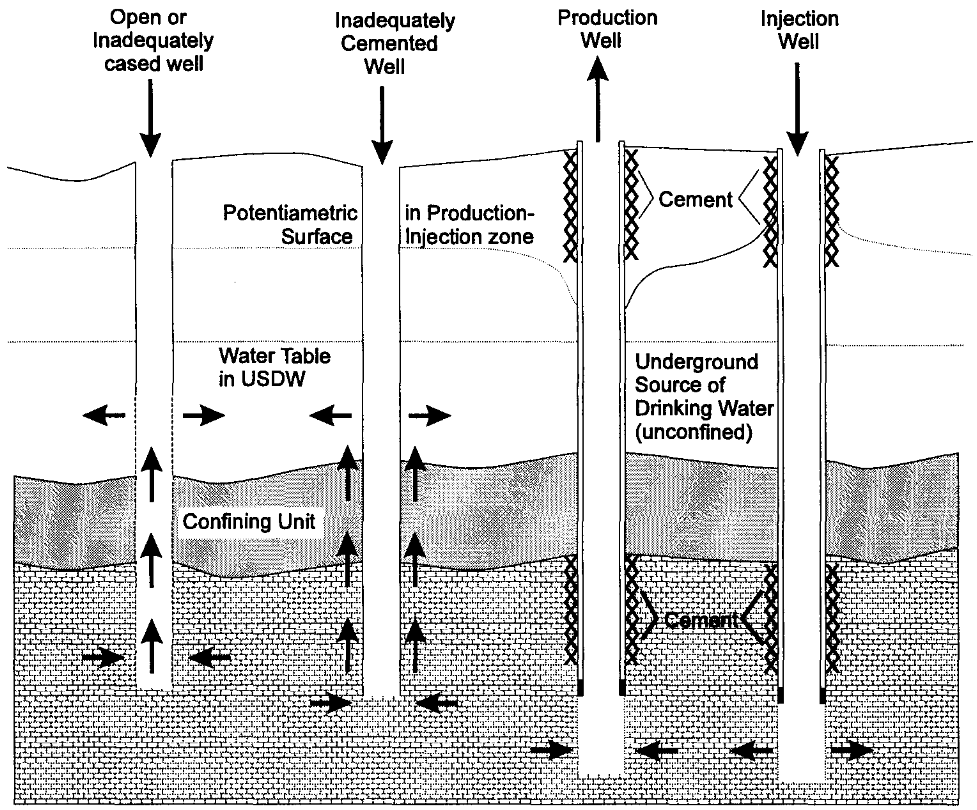

Figure 1-4. Upward flow from underlying hydrocarbon-producing zone to an underground source of drinking water through inadequately plugged wells. After Kreitler et al., 1994.

Improperly abandoned wells, in the vicinity of oil field injection wells, can serve as a pathway for contamination of underground sources of drinking water. The Texas Bureau of Economic Geology, with funding from the American Petroleum Institute, designed a method for use by regulators and operators to identify such areas (Kreitler et al. 1994).

In developing the method, Kreitler et al. (1994 pp. 64, 77) plotted the estimated density and distribution of oil field brine injection wells, as shown in Figure 1-5, and abandoned wells, as shown in Figure 1-6, throughout the greater Permian Basin, which includes the Delaware Basin.

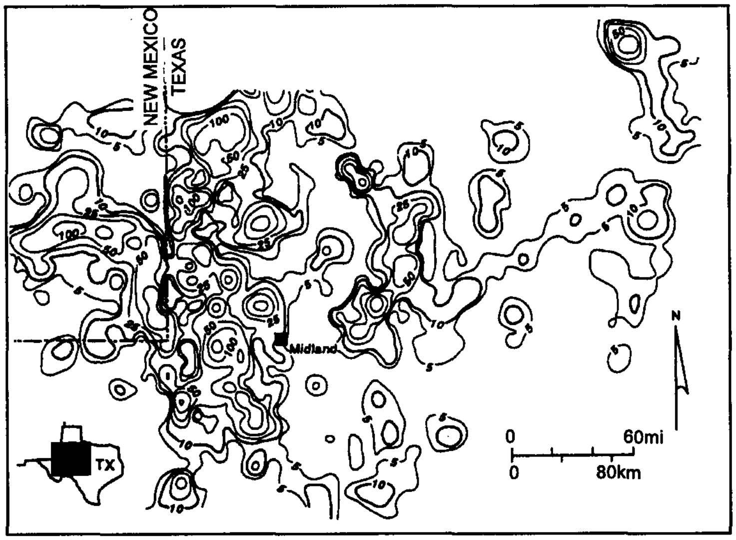

Figure 1-5. Density of Class II injection wells at 0.1°× 0.1° scale. After Kreitler et al. 1994.

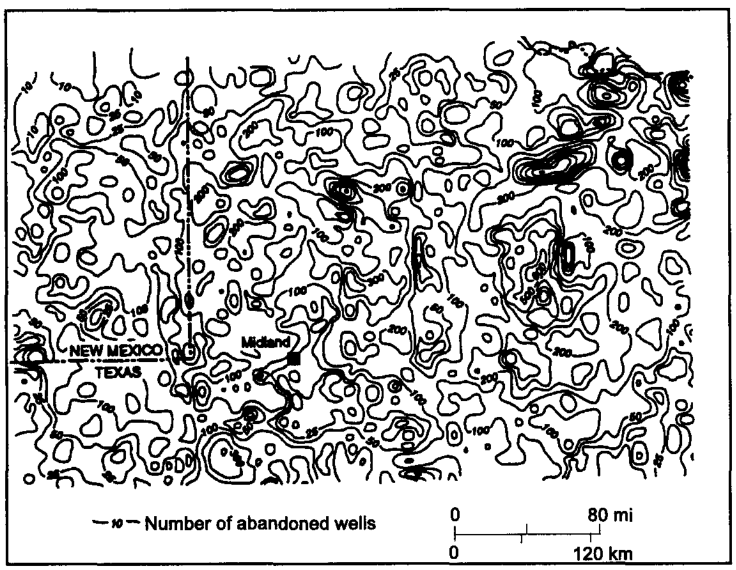

Figure 1-6. Estimated distribution of abandoned wells at 0.1°× 0.1° scale. After Kreitler et al. 1994.

They found that the most extensive area of upward hydraulic gradients occurs in the eastern Delaware Basin, Central Basin Platform, and western Midland Basin. Residual mapping indicates upward gradients with hydraulic head differentials as large as 6,000 ft (1,800 m) (Kreitler, et al. 1994, 73-74).

As part of their study, Kreitler et al. (1994) also offered insight into the problem of abandoned wells completed through salt formations. They note that in addition to less stringent construction and abandonment standards in past decades, the mechanical degradation of older wells may also reflect lengthy periods of exposure to corrosive brines. In the Permian Basin, wells that pass through a larger number of saline units are of particular concern (Kreitler et al. 1994, 76). LaVenue also commented on 20 to 30 years of exposure to the corrosive saline environment promoting a leak in the casing and/or degrading the grout holding the casing in place (LaVenue 1991, 2). This is consistent with the DOE position that the highly saline environment of some units can promote rapid corrosion of well casings and may result in fluid loss from wellbores (U.S. DOE 1995, SCR-73). All well casings to be abandoned in the WIPP vicinity will be exposed to more than two thousand feet of salt, not only in the Salado Formation, but also in the Castile Formation, a formation unique to the Delaware Basin. It seems prudent to assume saline environments promote rapid corrosion of well casing (Kreitler et al. 1994, 76; LaVenue 1991, 2; U.S. DOE 1995, SCR-73), existing regulations are violated (U.S. DOI 1989), and wells are improperly abandoned (U.S. DOI 1989; Dials 1994). Given these observations, do the existing and yet to be drilled wells in the vicinity of the WIPP represent viable vertical pathways for the upward migration of injected fluids either into the interbeds of the Salado Formation or into overlying aquifers such as the Culebra, the Magenta, and the Dewey Lake Redbeds?

1.6 WIPP and Performance Assessment

To proceed with TRU waste disposal, the WIPP Land Withdrawal Act requires the DOE to receive certification from the EPA that the facility is in compliance with the EPA radioactive waste disposal regulations (U.S. EPA 1985; 1993, 40 CFR 191) including containment and assurance requirements. This requires analyses that the probability and amount of radionuclides released to the accessible environment over the next 10,000 years will not exceed limits specified in the EPA Standards. The performance assessment (PA) calculations published to date have identified future drilling for oil and gas reserves as an event that could disrupt the repository and release radionuclides in excess of the standards (SNL 1992, 4.1.2). The calculations have not addressed the impact on WIPP's performance of the oil and gas industry practices of salt water disposal and waterflooding for enhanced oil recovery - two expanding activities now underway in the vicinity of the WIPP.

The 1991 DOE PA stated that such fluid injection could be eliminated from consideration in performance assessment on the basis of low consequence:

> The effects of injection wells on groundwater flow in units shallower than the Salado Formation is likely to be negligible. Units selected for injection will be thousands of feet deeper than the Rustler Formation, which is the most likely path for the groundwater transport of radionuclides to the accessible environment. The low permeability Bell Canyon, Castile, and Salado Formations are approximately 4,000 feet (1,220 meters) thick at the WIPP (Powers et al. 1978), and these low-permeability units will isolate flow in the Rustler Formation from the pressure increases in the much deeper units caused by the injection of fluids (SNL 1991, 1:4-36).

This explanation appears to be inconsistent with salt water disposal practices in the Delaware Basin, the observed water level rises in the Culebra, LaVenue's analyses (1991), and Bailey's comments (1990).[7] Records indicate that every salt water disposal well within the nine township area surrounding the WIPP injects into the Bell Canyon Formation (see Broadhead et al. 1995, Table 7). Hence, the Bell Canyon is not serving as an impermeable layer. Further, LaVenue's (1991) analyses indicated that the Bell Canyon Formation, which is below the WIPP horizon, is already in communication with the Rustler Formation, which is above the WIPP horizon. Hence, thousands of feet of vertical separation by

[7]Despite a January 28, 1991, distribution to the WIPP PA Department, the memos of LaVenue (1991), Bailey (1990), and Ramey (1976) are not referenced in either the December 1991 PA publication or in the December 1992 PA publication.

impermeable layers of salt do not appear to be isolating the Rustler from the fluid injected into the deeper units.

The 1992 PA also did not calculate the effect of adjacent fluid injection on performance assessment, maintaining that injection wells that do not penetrate the repository can be screened out on the basis of low consequence despite the 1976 Ramey memo, 1990 Bailey memo, and the 1991 LaVenue memo, and public records on fluid injection practices in the Delaware Basin.

With respect to any human related activity within the site, including fluid injection, the 1992 PA introduced a new criteria not found in Cranwell et al. (1990) for screening events and processes (SNL 1992, 2:4-3 to 4-4). The 1992 PA stated that the EPA regulations did not require the impact of fluid injection to be evaluated. The WIPP PA Department's interpretation (SNL 1992, 2:4-3) of the non-binding guidance for the disposal of transuranic waste (SNL 1992, 2:4-4) advances the argument that disruptive human activities, such as fluid injection, need not be considered because the consequences are greater than that of exploratory drilling (SNL 1992, 2:4-4). The impact of a future disposal well was limited to drilling and the consequences were assumed to be identical to drilling an exploratory well (SNL 1992, 2:4-4).

1.7 Issue

WIPP is surrounded by new oil producing wells. Many more are planned but have been delayed due to the presence of potash (Woodard 1992; Burski 1994). Oil production is accompanied by salt water injection either for salt water disposal or waterflooding. Forcing large volumes of such brine into the designated formation requires energy in the form of fluid pressure (force per unit area). Brine migration, with energy in the form of pressure, is the same mechanism by which radionuclides can be carried out of the repository and away from the WIPP site.

The potential impact of brine injection on the long-term performance of the WIPP prompted the Environmental Evaluation Group to organize a June 13, 1995, workshop on the issue. The workshop included presentations describing the extent of oil and gas resources, the anomalous water level rises in the Culebra Aquifer, the documented effects of water flooding on the Salado Formation, the geology of waterflooded areas in southeast New Mexico, the current petroleum production practices, the treatment of water injection by the performance assessment effort, and the need for a water flooding scenario in the WIPP PA calculations. As was intended, a number of issues were deliberated. On many issues there was no consensus. The workshop did not address the impact of solution mining of potash surrounding the WIPP or the disposal of potash brine.

2. WORKSHOP PRESENTATIONS

The presentations made at the June 13, 1995, workshop are contained in this chapter. A synopsis of each presentation, distributed by the authors at the workshop, is followed by their presentations. As with any verbal dialogue, some paraphrasing of the presentations was necessary. Nonetheless, every effort was made to preserve the message of the presenters and the thrust of the questions and answers. Also, some figures, most of which were provided by the authors on diskette, required modification from their overhead format into a report format. The cooperation, patience, and understanding of the presenters and participants in addressing these difficult, but important issues, is appreciated.

2.1 R.H. Neill - Opening Statement

All of us are extremely pleased to see this large turnout for this technical workshop. I think it is a good example of the cooperation between the various federal and state authorities with representation from the Department of Energy, the Environmental Protection Agency, the Bureau of Land Management, the National Academy of Sciences, the New Mexico Environment Department, the New Mexico Oil Conservation Division, the New Mexico Bureau of Mines and Mineral Resources, Sandia National Laboratories, Oklahoma University and, of course, the Environmental Evaluation Group.

It is interesting to step back a moment to evaluate our efforts in performance assessment in predicting the behavior of the repository. The focus has been on existing fluids, whether it is the interstitial brine within the Salado or the large brine reservoirs associated with the Castile Formation or the two dolomitic aquifers above the repository horizon and in the perched water aquifer in the Dewey Lake Redbeds. We are now looking at the impact of fluid injection into nearby formations on the long-term behavior of the repository — perhaps from three different standpoints, although we will only be looking at two today. The first is to enhance the recovery of oil. The second is on salt water disposal, which would be another reason for injecting fluids. The third might well be, in the future, to look at solution mining for potash, although we are not going to address that issue here today.

It might be helpful to mention a few things that we are not going to do today - to put everyone at ease. We are not going to address the legal issues associated with any court cases that have occurred, are pending, or will occur. Specifically, I'm referring to the Hartman vs. Texaco case. There is some very interesting, relevant, technical information associated with that case, but in no way should this workshop be construed as reopening the legal issues associated with that case. I want to make that quite clear.

We also are not going to be able today to determine the consequences of the impact of some of these actions. And although we can get some insights, perhaps, on the probability of events, one is not going to be able to determine the impact.

We look forward to each of us speaking as individuals — no one is being quoted on behalf of their agency. And also none of us have come here with a preconceived position on these issues.

I thought it might be important to those who are familiar with the performance assessment approach to acknowledge the uniqueness of the WIPP in the context that it is the only repository under consideration where there are substantial natural resources - oil, gas, and potash. And for those of you who are not in the business of performance assessment, in order to bring waste to WIPP it is necessary to be able to predict the behavior of these transuranic wastes over 10,000 years and convince EPA of the validity of those calculations and analyses. The way this is done is to come up with scenarios on how this could occur, design a model and then write the equations governing that, whether it is conservation of momentum or mass, conservation of radioactivity, the driving force, solve the equations, and then estimate the amount that arrives at the accessible environment in 10,000 years. You then look up the release limit table of the EPA standard. If the postulated releases are greater than the limits, you have problems. If they are less, you are home free.

On the current schedule, DOE expects to complete all this work by January 1997. We note that the deadline for the models is as early as September 1995, the end of this summer.

If we consider the 4-mile by 4-mile area of the WIPP site, the question comes up regarding the injection of fluids at depths greater than 4,000 feet outside the WIPP site. If by some mechanism, there is vertical movement of the brines or the fluids outside the repository, can this induce hydrofracturing in the Salado for a distance of 2 miles laterally to the repository, which may in turn flood the repository? And the question is, could this have a role in moving radionuclides laterally to the accessible environment, and exceed the EPA limits?

In terms of the location, the injection, and the timing, one can look at it in perhaps four different ways. The first is on the operational consideration of the time period from minus 20 years to t equals zero, and outside of the 4 mile x 4 mile area where this could have some potential effect on the hydrogeological real estate associated with the repository. The second is a period from T=0 to T=100 years where institutional control would prevent anyone from injecting fluids within the 4 mile x 4 mile area. The third might be a period from 100 years to several hundred years; that is not specified in the EPA criteria but it is presumed that one could take steps during that time period to prevent the injection of fluids. And the fourth is when knowledge of the repository is lost at some future date, and one could have brine injection occurring in the 4 mile x 4 mile site. We are not going to focus that much on the fourth one today, because we have some people that are able to contribute in a major way on the first three.

2.2 Evaluation of Oil and Gas Resources at the WIPP Site

Ronald F. Broadhead[1], Fang Luo[1], and Stephen W. Speer[2]
[1]New Mexico Bureau of Mines and Mineral Resources
[2]Independent Geologist, Roswell, New Mexico

2.2.1 Synopsis

Rigorous, quantitative estimates were made of oil, natural gas, and natural gas condensate resources that exist beneath the 16 mi^2 area of the WIPP land withdrawal area and an additional one-mile wide study area around the WIPP site. Calculations were made for resources that are extensions of known, currently producible oil and gas resources thought to extend underneath the WIPP land withdrawal area with reasonable certainty (probable resources). Qualitative estimates were also made of oil and gas that may be present in undiscovered pools and fields beneath the WIPP land withdrawal area (possible resources). Possible resources were not quantified.

Probable resources consist mostly of oil and associated gas in Permian strata and nonassociated gas and gas condensate in Pennsylvanian strata. Currently, most oil and associated gas production in the vicinity of the WIPP site has been obtained from sandstone reservoirs in the Delaware Mountain Group (Permian) at depths of 7,000 to 8,000 ft. Sandstones and carbonates in the Bone Spring Formation (Permian) at depths of 8,000 to 11,000 ft and carbonates in the Wolfcamp Group (Permian) at a depth of approximately 12,000 ft are secondary oil reservoirs. Carbonates in the Strawn Group (Pennsylvanian) at a depth of approximately 13,000 ft are secondary, but important, reservoirs of gas and light oil or condensate. Most nonassociated gas and condensate production in the vicinity of the WIPP site has been obtained from sandstone reservoirs in the Atoka and Morrow Groups (Pennsylvanian) at depths of 13,000 to 14,000 ft.

Probable oil and condensate resources within the boundaries of the WIPP land withdrawal area are 12.3 million bbls of oil and gas condensate recoverable by primary production methods and an additional 6.4 million bbls of oil potentially recoverable by secondary recovery with waterfloods (Table 1). Probable resources within the one-mile wide additional study area surrounding the WIPP land withdrawal area are 22.9 million bbls oil and gas condensate recoverable by primary production methods and an additional 13.8 million bbls of oil potentially recoverable through waterflooding.

Probable gas resources within the boundaries of the WIPP land withdrawal area are 186 BCF gas (Table 1); 89% of this gas is nonassociated and will be produced from the deep Atoka and Morrow reservoirs. The remainder is associated gas, most of which will be produced from relatively shallow reservoirs in the Delaware Mountain Group. Probable gas resources underneath the one-mile wide additional study area surrounding the WIPP land withdrawal area are 168 BCF gas; 79% of this gas is nonassociated and will be produced from the deep Strawn, Atoka, and Morrow reservoirs.

In addition to probable resources, there are significant possible resources of oil, gas, and gas condensate beneath the WIPP land withdrawal area and the additional study area.

These will be oil and associated gas in untapped sandstones of the Delaware Mountain Group in largely unexplored and unevaluated sandstones and carbonates of the Bone Spring Formation, and in carbonate reservoirs in the Wolfcamp and Strawn Group. Possible resources of nonassociated gas and gas condensate will occur in sandstone reservoirs in the Atoka and Morrow Groups and in the pre-Pennsylvanian section (Siluro-Devonian and Ordovician strata). The elusive nature of possible resources makes their quantification difficult or impossible for an area of limited extent such as WIPP.

2.2.2 Presentation by Ron Broadhead

The New Mexico Bureau of Mines and Mineral Resources (NMBM&MR) contracted to evaluate the resources under the WIPP Site and an adjacent area extending one mile beyond the WIPP Land Withdrawal Area. The evaluation included oil, gas, and other mineral resources.

One purpose of the work was to estimate the total of proven and probable oil and gas resources that could be obtained by primary and secondary recovery. With respect to oil and gas, the WIPP area remains essentially undrilled. Estimating resources is a geological task.

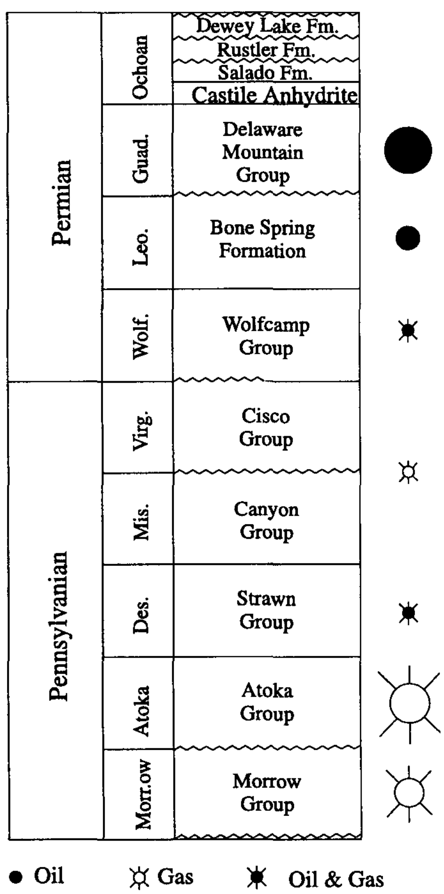

Figure 2.2-1. Productive oil and gas formations in the vicinity of the WIPP Site. Adapted from Broadhead et al. 1995.

The DOE needed a scientific, unbiased, third party estimate of the oil and gas resources. The principal data sources were well records on file at the New Mexico Bureau of Mines and Mineral Resources: Petroleum Information, Midland Oil Scouts Association, the Bureau's Niell Wills Collection, Bureau data gathered through the years, official state data from the New Mexico Oil Conservation Division, data from the U.S. Bureau of Land Management and the U.S. Geological Survey, an extensive collection of electrical logs, and the official production data reported to the State.

2.2.2.1 WIPP Area Description

Figure 2.2-1 shows the principal oil and gas producing formations within the WIPP

Site Area and surrounding areas. The principal oil production is shown by the solid circles and the principle gas production is shown by the open circles with the spikes. The major oil producing group in the area is the Delaware Mountain Group followed by the Bone Spring. There is a some production from the Wolfcamp, Cisco, and Canyon Group. Most of the gas production comes from the Atoka and Morrow Groups.

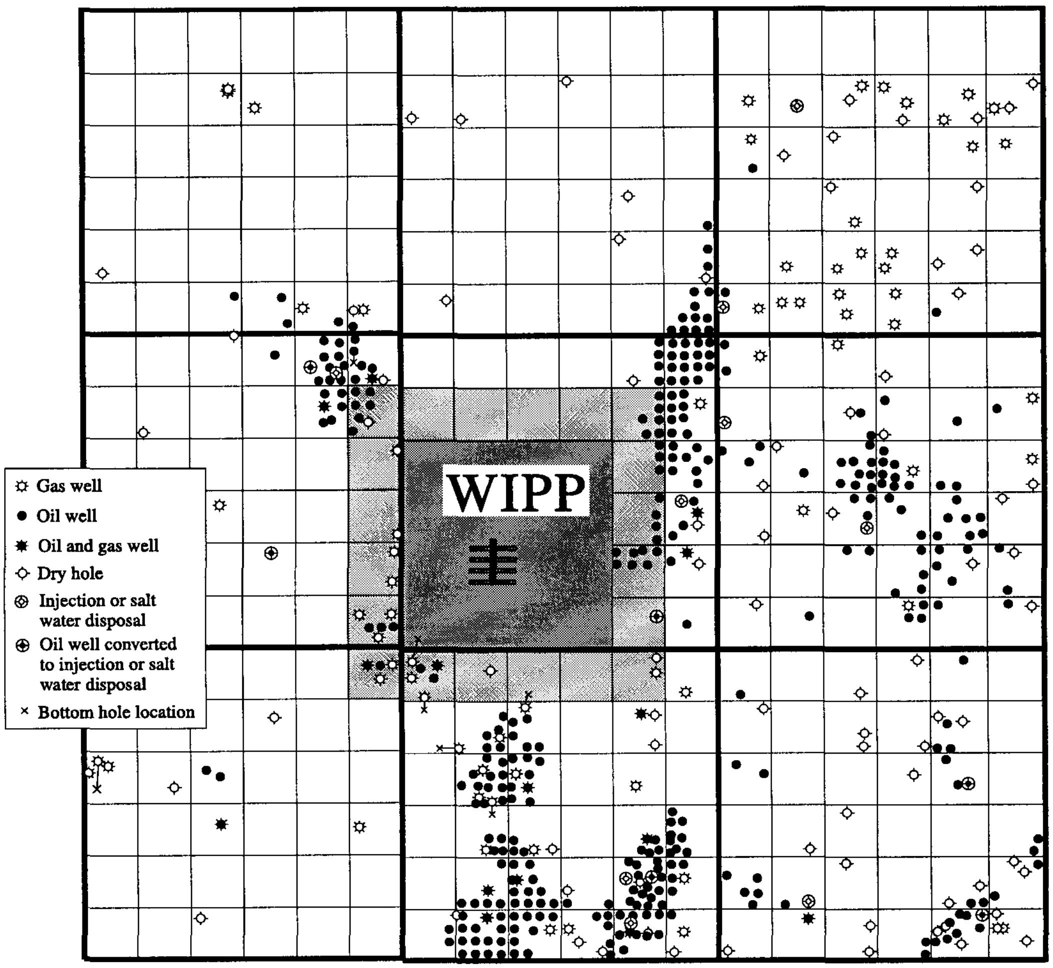

Figure 2.2-2. Oil, gas, and injection wells at WIPP Site, one-mile additional study area, and nine-township project study area.

Figure 2.2-2 shows the four mile by four mile land withdrawal area, the additional one mile wide study area, and the total nine township study area. Solid circles represent productive oil wells at the close of 1993, or early 1994. The open circles with the eight spikes are productive gas wells. The open circles with (four) spikes are non-productive. There is only one well that produces from under the WIPP Land Withdrawal Area. That is the Bass well in the southwestern part of section 31. That deviated well was directionally drilled under the Land Withdrawal Area. Most of the oil wells produce from the Delaware Mountain Group and most of the gas wells produce from the Atoka and Morrow Groups. A couple of the wells along the western edge of the WIPP produce from the Strawn Group.

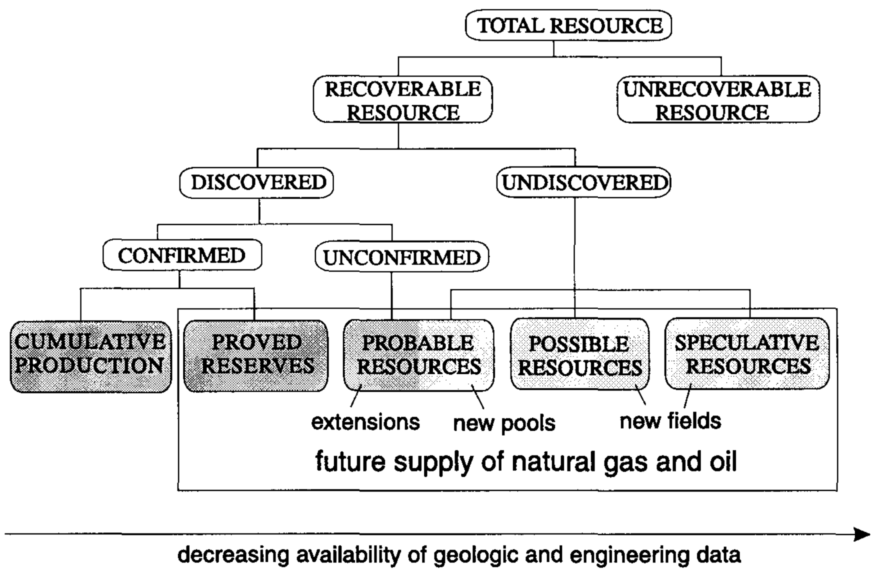

Figure 2.2-3. Oil and natural gas resource categories. From Potential Gas Committee (1993).

2.2.2.2 Method of Assessing Resource Potential

What was estimated and what was not estimated? Figure 2.2-3 illustrates the classification scheme of the Potential Gas Committee of the Potential Gas Agency. This classification can be applied to oil as well as gas. The total resource can be divided into recoverable and unrecoverable resources. The unrecoverable resource represents that which can not be taken from the rock. The recoverable resource includes the discovered and undiscovered. The numerical estimates are based on that which is discovered. Discovered can be divided between confirmed and unconfirmed. Confirmed is divided between cumulative production and proved reserves. Cumulative production is obviously that which has been produced. Proved reserves are those reserves in known identified traps and accumulations that can be recovered by existing wells. Note there is only one well which produces from within the WIPP Land Withdrawal Area. Hence, there are very little actual proved reserves under the WIPP itself. In the additional study area there are several producing wells.

Most of the estimates included probable reserves. Probable reserves are extensions of known petroleum accumulations that have been discovered. Those are reserves on the flanks of the existing, known accumulations.

Some qualitative assessment of possible reserves was made, but a quantitative assessment of possible reserves was not made. Possible reserves are untested traps, deeper or intermediate pools that have not been drilled, and have not been proven to be productive.

2.2.2.3 History of Drilling

As to the drilling history in this area, Figure 2.2-4 shows that through the 1920s, 30s, 40s, and 50s, drilling bumped along at no wells per year or maybe one well per year. Shallow wells were drilled down to 4,000, 5,000, or 6,000 feet and the wells proved to be non-productive. From the 1960s through the 1980s, there were little spurts of drilling within the nine township area surrounding the WIPP. There were some discoveries of oil but most were discoveries of gas. Around 1990, there was a big increase in drilling - *the Delaware Play*. Delaware Pools were discovered at Livingston Ridge, East Livingston Ridge, Los Medaños, Cabin Lake and a number of other smaller Delaware fields. This occurred throughout the Delaware Basin, not only around the WIPP Site, but throughout southeast New Mexico.

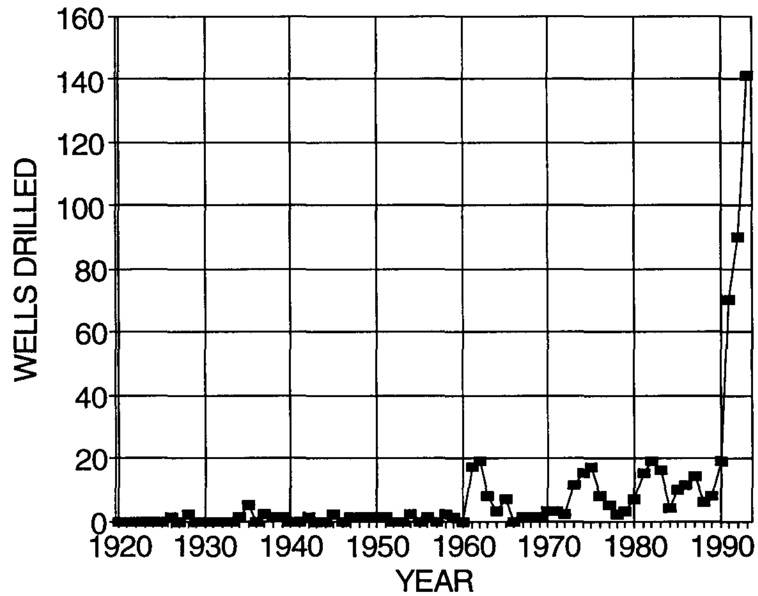

Figure 2.2-4. Annual number of oil and gas wells completed in the nine-township area centered on the WIPP Site.

People had been drilling through the Delaware Mountain Group for decades without realizing that oil could be produced economically. Log analyses and formation testing showed high amounts of water. Operators thought that these formations would produce mostly water and very little oil. With the advent of modern electric log analyses, it became apparent that oil could be economically produced. Oil discoveries were made, mostly in abandoned deep gas wells. As discoveries were made, a flurry of activity followed as the pools were developed.

The following example shows the methodology for estimating the per well resources. Production is obtained from the Brushy Canyon, the lowest formation in the Delaware Mountain Group. The sandstone is primarily interbedded with shales. The production is from stratigraphic traps. The production in the Delaware is oil and associated gas. Reservoir depths near the WIPP are 7,000 to 8,200 feet. Spacing is on forty acres, in other words, one well per forty acres. Production is from deep basin clastics and submarine fans. In order to project production away from where it presently exists and in order to project into the undrilled areas, we need a geologic model.

The depositional models for the Delaware sands are deep marine sandstones deposited on submarine fans. Closest to the shelf area, in the northern most parts of the Delaware Basin, the sands were deposited in channels. So they are channel like environments. As you get into more distal areas, the sands become unchannelized and become more laterally continuous.

The Livingston Ridge Pool and Lost Tank Pool are administratively separated. But for geologic and engineering purposes, they form the same pool. Figure 2.2-5 shows an isopach map of the main pay at the Livingston Ridge/Lost Tank Pools. The main pay forms a nice channel going from zero feet to a maximum of eighty feet or so in the middle of the channel. The east west cross section of the main pay shows that in the center the pool is fairly thick. It pinches out on the eastern edge. A north-south cross section shows almost constant thickness throughout the pool in that direction. Hence, the variation is

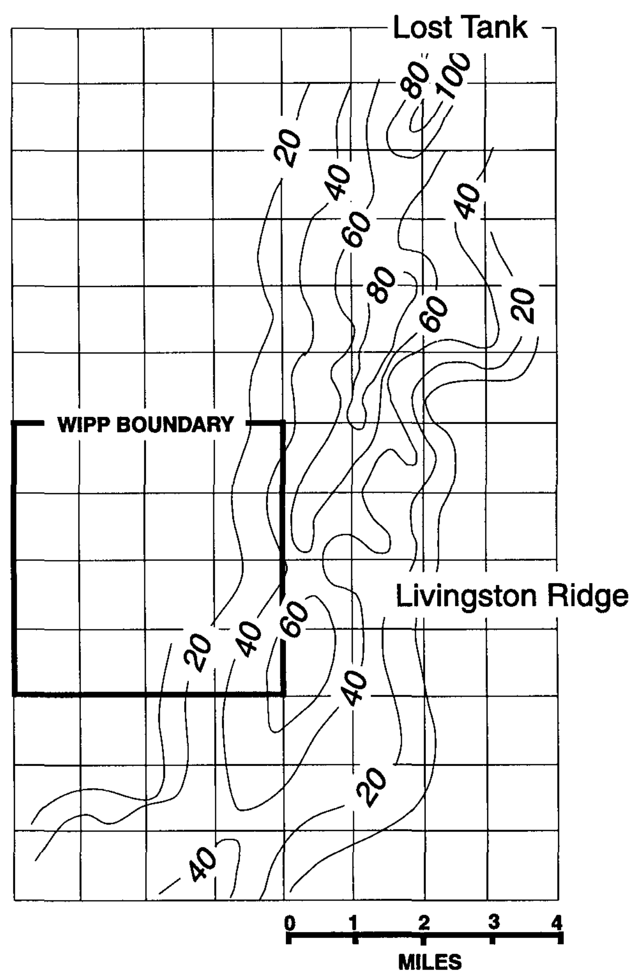

Figure 2.2-5. Isopach of gross channel thickness of Livingston Ridge main pay zone.

in the east-west direction. Economic production takes place where there is forty feet or more of main pay. From this, one can project into undrilled areas[1].

The question then is, are these pools entirely stratigraphic? Most of them seem to be primarily controlled by stratigraphy. The structure map shows that the dip is from the southeast (see Figure 25 of Broadhead et al. 1995). Projecting this channel shows that the WIPP Land Withdrawal Area is either at equal elevation or updip from the present production. Basically, the isopach map and the structural map can be superimposed to determine the areas of probable resources from the projections of known pools.

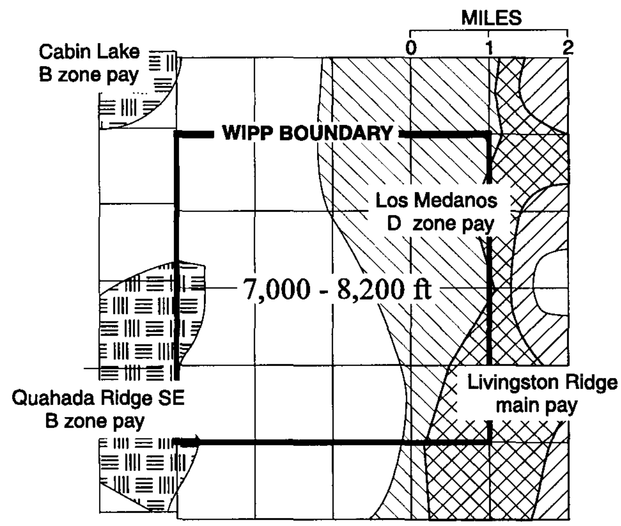

Figure 2.2-6. Areas of known and probable oil and gas resources for Delaware pools.

In Figure 2.2-6, the shaded area along the eastern edge of the WIPP Site shows the projection of the Livingston Ridge Pool. Also shown are other productive pools within the Delaware Mountain Group.

How much oil is each of these forty acre drilling or spacing units going to produce? In the case of the Lost Tank Delaware, a plot of production shows a production decline from roughly 3,500 barrels per month, down after thirty six

[1]Not shown in this report are the control wells and cross sectional diagrams as presented by Broadhead. See Figures 19, 20, and 24 of Broadhead et al., 1995 for the location of the control wells and the cross sectional diagrams.

months, to roughly 1,000 barrels per month. For an exponential curve, there is a high correlation coefficient of 0.87 for this particular well (see Figure 5 of Broadhead et al. 1995).

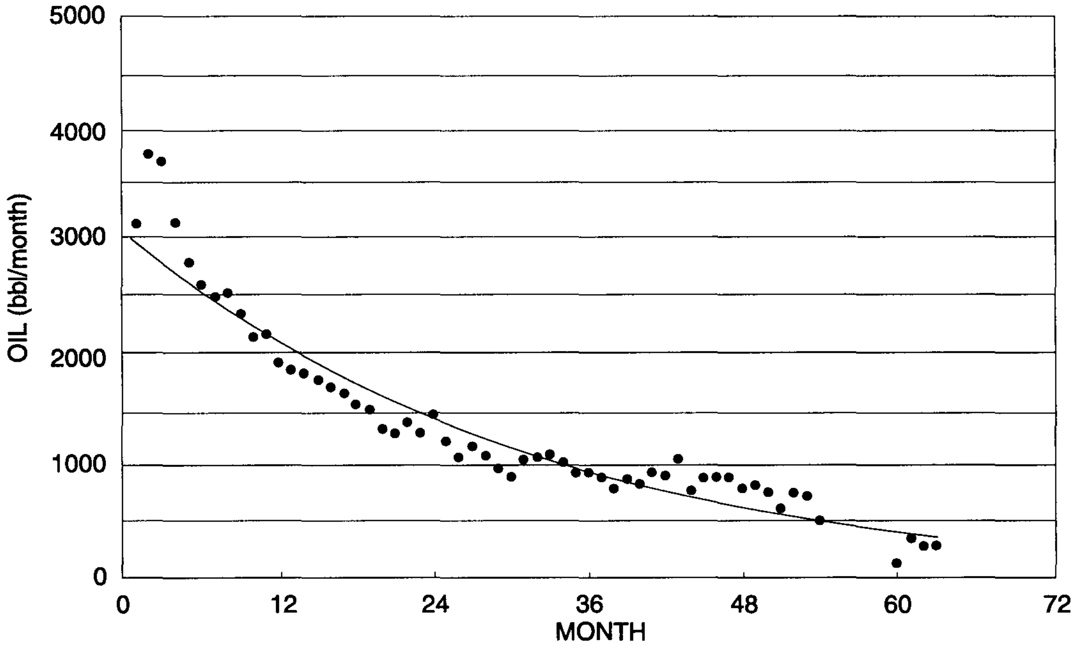

Figure 2.2-7. Average oil production decline curve for Livingston Ridge - Lost Tank Delaware pools, main pay.

As shown in Figure 2.2-7, an average production decline curve was constructed for the Livingston Ridge - Lost Tank pool. Integration of the area underneath that curve yields the resources for an average individual well. In the case of Livingston Ridge, for an assumed economic cutoff of 150 barrels per month, the average well will produce about 89,000 barrels of oil and about 116 million cubic feet of gas. The potentially productive area (calculated in spacing units) is multiplied by the resources for the average well to get an estimate of production for that pool. This was done for each of the Delaware Pools and each of the deeper pools in the area.

Figure 2.2-8 shows an isopach of one of the deep Livingston Ridge zones, the D zone, which produces to the south and the west. The isopach map shows a difference from the Livingston Ridge pay zone and an absence of discrete channels. The result is a blanket type deposit with unchannelized flows containing local thicks and thins and maximums of up to 120 to 140 feet of sand. It never pinches out to zero within the map area.

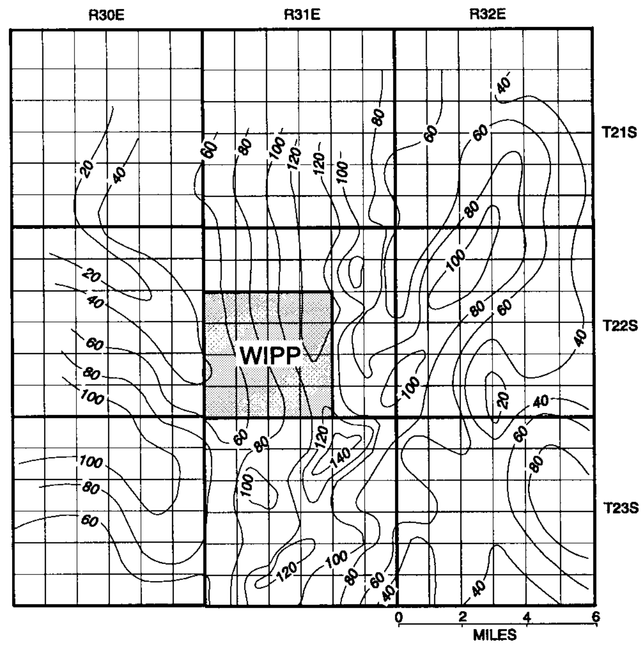

Figure 2.2-8. Isopach of Lower Brushy Canyon Formation zone D.

The deeper sandstones of the 3rd Bone Spring sand produce from stratigraphic or combination traps of deep basin turbidite reservoirs just outside the southwestern boundary of the WIPP Site. Production is oil and associated gas from about 11,000 feet. There are four forty-acre units for probable resources within the WIPP.

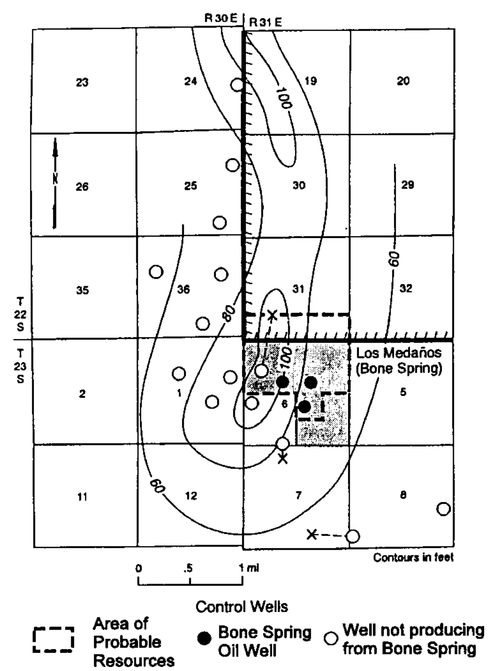

Figure 2.2-9. Isopach of Los Medanos Bone Spring Pool.

For the deeper Strawn Group, production is from limestones interbedded with shales. The reservoirs are bioherms developed on paleogeographic highs. Traps are stratigraphic. Production is gas and liquid condensate at the surface. Reservoir depths are 12,100 to 13,600 feet near the WIPP Site. Spacing is on 320 acres. There are two wells per section. Known and probable resources lie in the northwestern area of the WIPP Land Withdrawal Area.

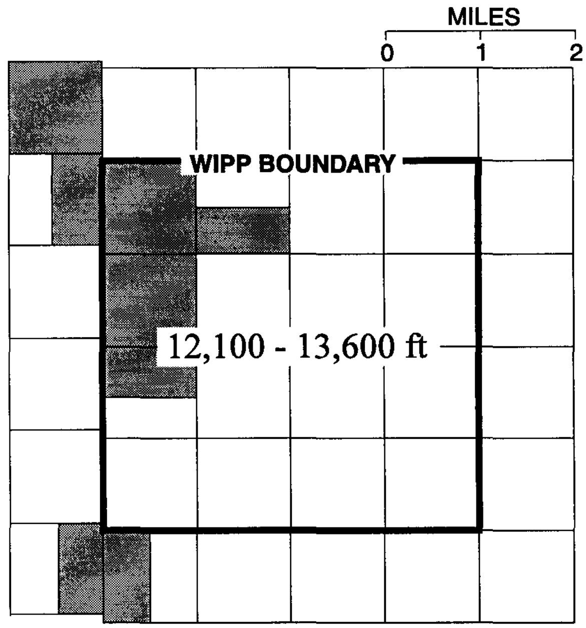

Figure 2.2-10. Areas of known and probable oil and gas resources for Strawn pools projected to extend under WIPP site.

Production of gas and condensate from the Atoka is from sandstones interbedded with shales and limestones. Production is from sandstone channels and a stratigraphic trap near the WIPP. Reservoir depths range from 12,400 to 13,800 feet near WIPP. Well spacing is 320 acres. There are two channels of probable resources that are extensions of existing known discovered traps

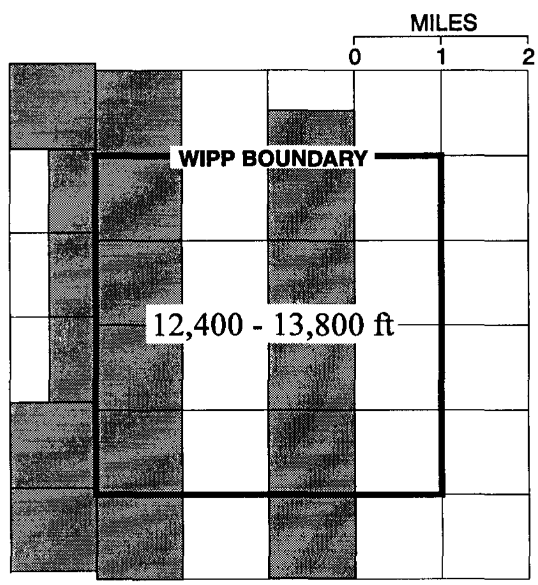

Figure 2.2-11. Areas of known and probable oil and gas resources for Atoka pools projected to extend under the WIPP site.

or pools. There are many sands in the Atoka that are untapped. At this stage of development, it is uncertain whether they are going to be productive or not. The Atoka is the main gas producing zone near WIPP.

The Morrow Group provides the deepest production in the area. Production is from the sandstones of the lower Morrow, interbedded with shales. A whole complex of different geologic models was used to predict production. It produces from stratigraphic, structural, and diagenetic traps. Production is gas and gas condensate. Reservoir depths are 14,300 to 14,800 feet near WIPP. As with the other producing gas zones such as the Atoka and the Strawn, spacing is on 320 acres. Shown are the areas of known and probable oil and gas resources. There is some established production to the south of the WIPP Site. There is no established Morrow production under the Land Withdrawal Area.

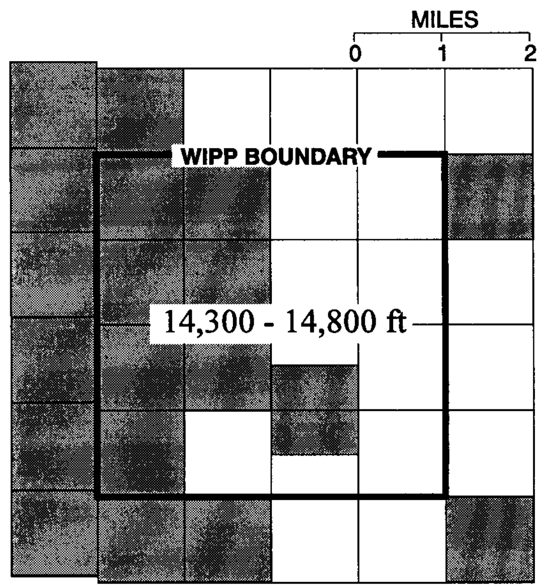

Figure 2.2-12. Areas of known and probable oil and gas resources for Morrow pools projected to extend under the WIPP site.

Table 2.2-1. Probable Resources.

	WIPP LWA	Additional Study Area
Oil and Condensate Primary Recovery (million bbls)	12.3	22.9
Oil Waterflood Recovery (million bbls)	6.4	13.8
Natural Gas (billion ft^3)	186	168

Table 2.2-1 summarizes the probable resources within the WIPP Land Withdrawal Area and the probable resources in the additional one mile wide study area. Under the WIPP Land Withdrawal Area, resources recoverable by primary production are 12.3 million barrels of oil and 186 billion cubic feet of gas. Within the additional one-mile wide study area, resources recoverable by primary production are 22.9 million barrels of oil and 168 billion cubic feet of natural gas.

2.2.2.4 Secondary Recovery Potential

If people decide to waterflood, what could they get if anything? Is it technically possible to waterflood the oil reservoirs, which would be primarily the Delaware under the WIPP Site?

First we looked at the feasibility of waterflooding. Is waterflooding the Delaware technically feasible? Yes, it does appear to be technically feasible although the pools that are under WIPP have not yet been waterflooded. Yes, water has been injected into eight Delaware Pools in southeast New Mexico for secondary recovery. Waterfloods have recently begun in the Avalon and Parkway Pools in the Delaware. One of those is in the Brushy Canyon. If we take a look at the Cabin Lake Pool which produces from the Delaware near the northwestern boundary of the WIPP, there has been some water injection for pressure maintenance purposes and it has showed some good response. There seems to be a chance for technical feasibility for waterflooding.

Feasibility also depends on economics. Obviously, revenues must exceed expenditures. Profits must meet or exceed expected profits from other possible ventures that a company could get into including waterflooding other fields and pools and drilling for primary recovery elsewhere. So even if something is technically feasible, it may not be economically feasible. Our studies show that waterflooding probably is economically feasible. But even if it is economically feasible, it may not be done because there could be a better return on an investment elsewhere.

Within the limited time available, we analyzed two mature waterfloods within the Delaware Mountain Group in southeast New Mexico. We used historical production data to estimate ultimate recovery from each of those mature waterfloods.

One of the mature floods examined was the Paduca Delaware Field. Primary production started in 1961. Projection of the exponential decline curves showed an estimated recovery of 8-1/2 million barrels of oil by primary production and 5-1/4 million barrels by secondary recovery. In the case of Paduca, there was a 61% increase in production by waterflooding the reservoir. Projecting primary and secondary recovery for the Indian Draw (Delaware) Field yields an 81% increase in production by waterflooding. Worthington made an industry estimate of a 100% increase in recovery from Brushy Canyon by waterflooding the East Shugart Delaware field, which has not been waterflooded at this time.

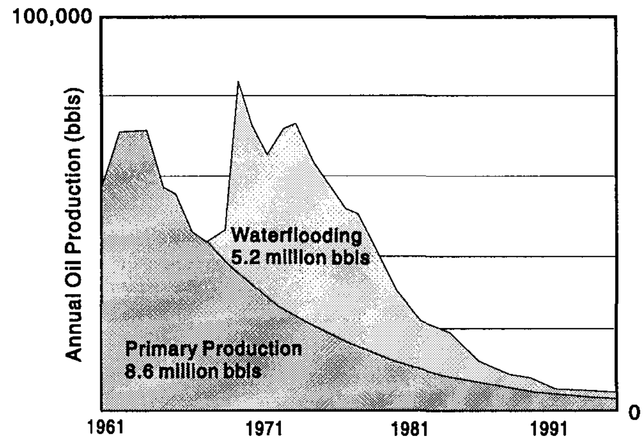

Figure 2.2-13. Production from Paduca Field.

None of the reservoirs under the WIPP Site have been waterflooded yet. Given the three estimates of 61%, 81%, and 100% additional oil recovery by waterflooding, the Bureau used a conservative estimate of 60% additional recovery by waterflooding to project recovery by waterflooding reservoirs in the vicinity of the WIPP Site. Further, there was proprietary information from the oil companies operating in the area indicating that they anticipated 70% to 80% increase in production by waterflooding the Brushy Canyon Formation. To accommodate the uncertainty, the Bureau used a very conservative estimate.

Production from the Cabin Lake Delaware Pool, just outside the northwestern corner of the WIPP Site, was used to provide technical information on the feasibility of waterflooding. Phillips Petroleum is the primary operator of this pool. Figure 2.2-14 shows the initial production at about 4,000 barrels per month for this well and a gradual production decline. The operator completed two wells nearby for pressure maintenance, which is a very early-stage form of waterflooding. The immediate response to water injection is clearly shown. The Delaware sands in the vicinity of the WIPP seem to be amenable to waterflooding. It doesn't mean someone is going to waterflood, it just means that the fields are amenable to waterflooding.

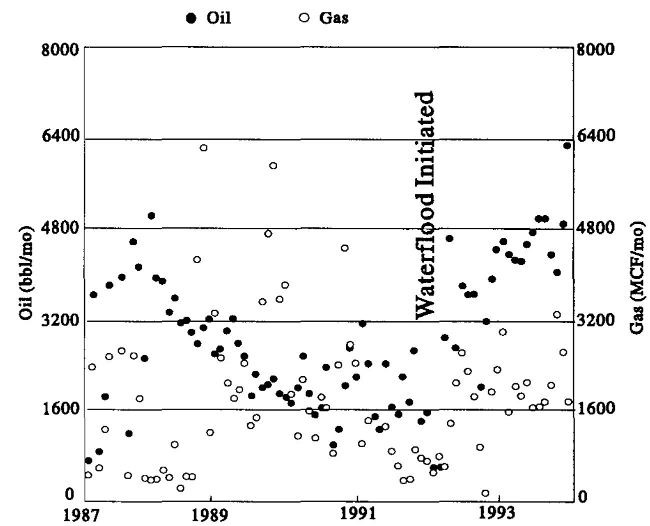

Figure 2.2-14. Monthly production of oil and gas, Phillips Petroleum Company No. 2 James A well, Cabin Lake Delaware pool.

2.2.2.5 Summary

In the Delaware Mountain Group, there is approximately 10 million barrels of oil recoverable by primary production and another 7 million barrels recoverable by secondary recovery. A very conservative estimate shows a little oil recoverable from the Bone Springs Formation and some condensates recoverable from the Strawn, Atoka, and Morrow Formations.

As to gas resources within the WIPP Land Withdrawal Area, approximately 125 billion cubic feet of gas is recoverable from the Atoka Formation, about 30 bcf non-associated gas from the Morrow Formation, and about 20 bcf associated gas from the Delaware Mountain Group. The Strawn Formation and the Bone Spring Formation would also produce gas.

The above estimates are limited to probable resources. There are probably undiscovered resources under the WIPP Site. But the area has not been drilled. Until then, there is no way of knowing for certain the extent of such resources. For years, operators drilled through the Delaware without knowing of the presence of economically recoverable oil in those formations.

2.2.2.6 Questions:

Wendell Weart: I was wondering if you could provide an average number for the lifetime of a well in this area of the basin, and an average pool lifetime.

Ron Broadhead: Lifetime of the wells. Even though there are some differences from well to well and pool to pool, we can use the average well from the Livingston Ridge to give some idea of a well lifetime. From initial production until about 150 barrels per month, this well is going to produce about 92 months of primary recovery. It is less than ten years for an average Delaware well. Probably production in Delaware pools is going to be in the ten year range, maybe less, because these pools tend to be drilled out and developed very quickly.

Chuck Byrum: What if you add secondary recovery to that? How much would that extend the field life?

Ron Broadhead: Secondary recovery will extend the field life. Secondary recovery will have to start while the primary well is producing. If you wait until the wells are plugged out, secondary recovery is not going to be economically feasible. Secondary recovery is going to have to start when production is around fifty percent, maybe as low as thirty percent of the peak primary production. There are ten years, at the most of secondary recovery, probably less.

Peter Swift: You described the pay zones as about forty feet thick for each pool. Is that all oil saturated or is that just the sand thickness you need in order to have a productive oil zone?

Ron Broadhead: For economic production from Livingston Ridge at present, you need at least forty feet.

Peter Swift: Forty feet of oil or forty feet of sand?

Ron Broadhead: Forty feet of pay, of channel. There is actually less sand. If you get less than forty feet you are going to require a multiple completion. There are a few wells that are completed in multiple zones.

Peter Swift: Is there an oil water contact in that forty feet?

Ron Broadhead: No, there is not.

Chuck Byrum: How much water is being produced during primary recovery per well on average and how much during secondary recovery? Is there a difference?

Ron Broadhead: I don't have an exact number. I can't recall exactly what the water production is from primary. But these wells in the Delaware produce a very high water cut.

Chuck Byrum: Some of the numbers that I have seen, it is like a four to one ratio.

Ron Broadhead: Yes, the water cut is very high. These are fairly unconventional sands. They are pretty fine grained. There is a high water saturation. There is a lot of moveable oil and moveable water. It is not being driven by an oil-water contact. It is water in the actual pore space with the moveable oil.

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2.3 Observations of Water Level Rises in the Culebra Aquifer

2.3.1 Presentation by Rick Beauheim (no synopsis)

The purpose of the presentation was to summarize the observed water level rises since 1988 and offer thoughts on explaining the water level rises, starting with the wells to the south and working northward. The plots start at 1988 because it was in 1988 that water level rises were first noticed in well H-9.

Shown at right are the locations of the Culebra Dolomite Wells in the vicinity of the WIPP Site. Well H-9 is approximately six miles to the south of the WIPP Site. In 1988, a rise in the water levels was first noticed at well H-9. The water level rise propagated north to other wells.

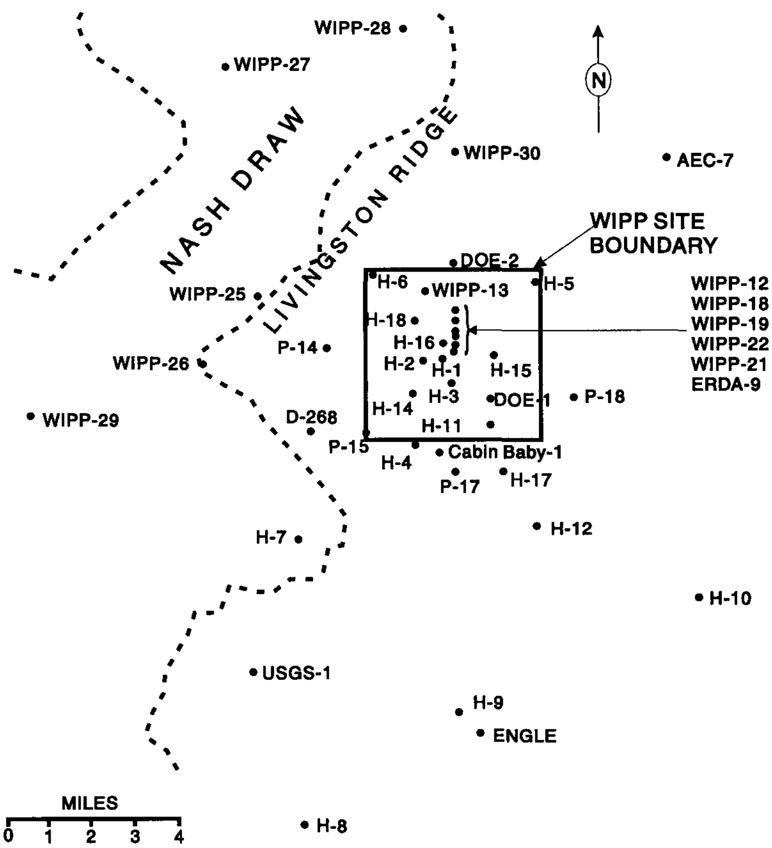


Figure 2.3-1. Locations of Culebra Dolomite Wells in the vicinity of the WIPP Site.

Since that time there have been other Culebra water rises related to other phenomena. To explain the other phenomena, the presentation was divided into three regions around the WIPP Site, starting with each well to the south, covering each well about the center, and finishing with the wells to the north.

2.3.1.1 Southern Region of the WIPP Site

For at least five years prior to 1988, the water level at H-9 was very stable at 431 to 432 feet below the surface. Between March and April of 1988, the water level took an abrupt turn and kept on climbing. In a natural system, that is a system undisturbed by man, you do not expect to see a steady water system and then in the space of one month, the whole thing turn. That is not a natural kind of phenomena. It screams that some event has occurred. Some human induced event has occurred. The rise generally continued from 1988 until about 1993. In 1993, the water level fell off rather abruptly, has been fluctuating, and is now on another rise. The events at H-9 are the result of some phenomena, most likely some well effect.

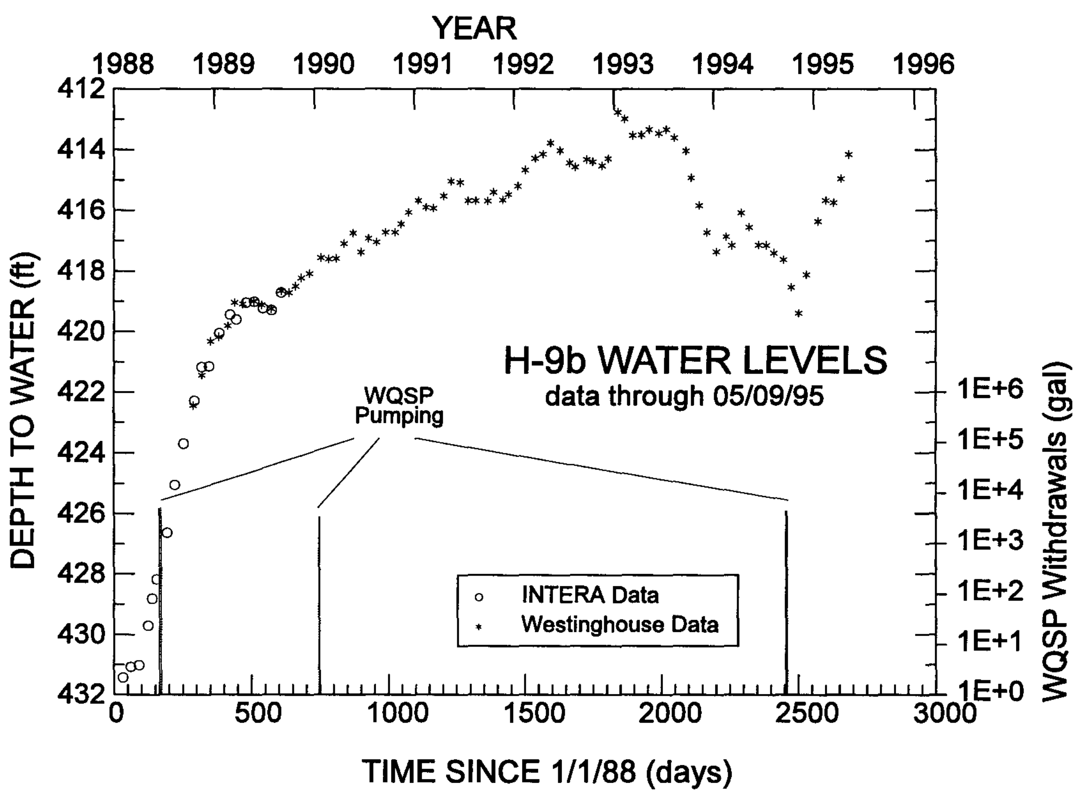


Figure 2.3-2. Well H-9b water levels.

The first well to the north of H-9 is H-12. At the time water levels at H-9 began rising, the water levels at H-12 were controlled by other events. One of those events was the H-11 multipad test. But after the conclusion of the pumping test, the water level was going to clearly recover past the point prior to the pumping test. A water quality sampling test brought the water level down, but at the end of the sampling test the water level continued climbing steadily. The total water level rise at H-12 was on the order of nine feet.

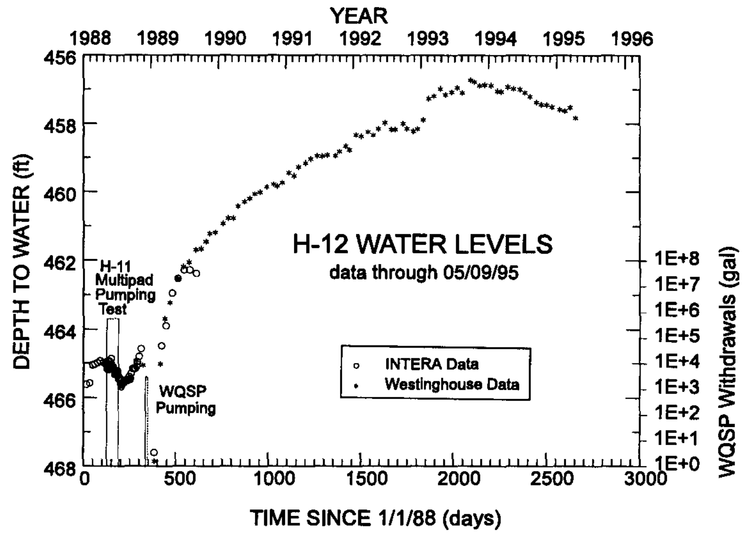


Figure 2.3-3. Well H-12 water levels.

Well H-17 lies a little further to the north of well H-12. Again, after the response to the H-11 multiwell drawdown test, the recovery continued to climb. The water level has fairly well stabilized at the upper end. From 1993, there is not the same kind of detail that is seen in some of the other wells.

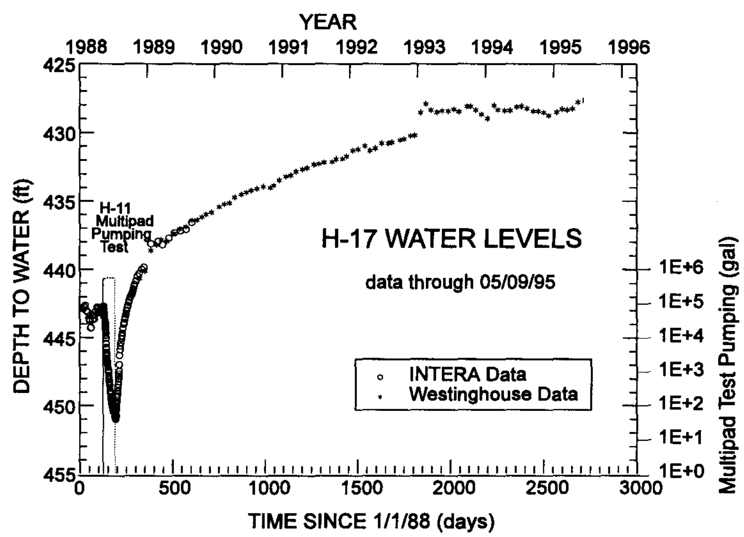


Figure 2.3-4. Well H-17 water levels.

Well P-17, which is due west of H-17, shows the same kind of behavior but it does seem to be a little more in touch with the other fluctuations that have occurred since 1993. There was, again, on the order of nine feet of water level rise.

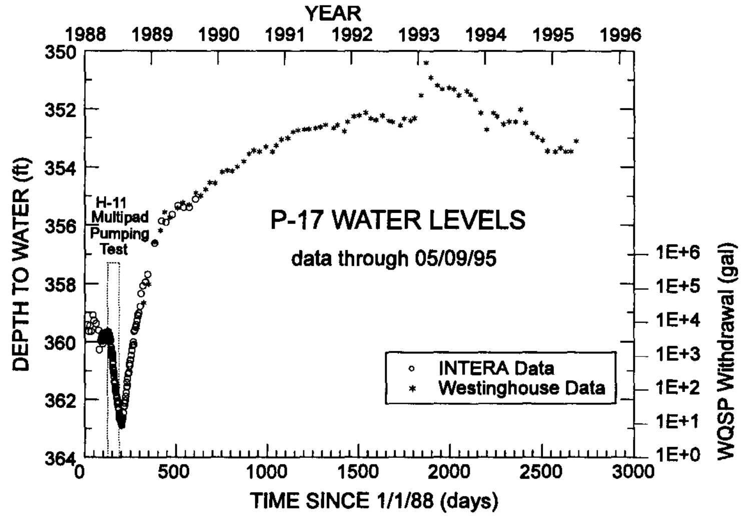


Figure 2.3-5. Well P-17 water levels.

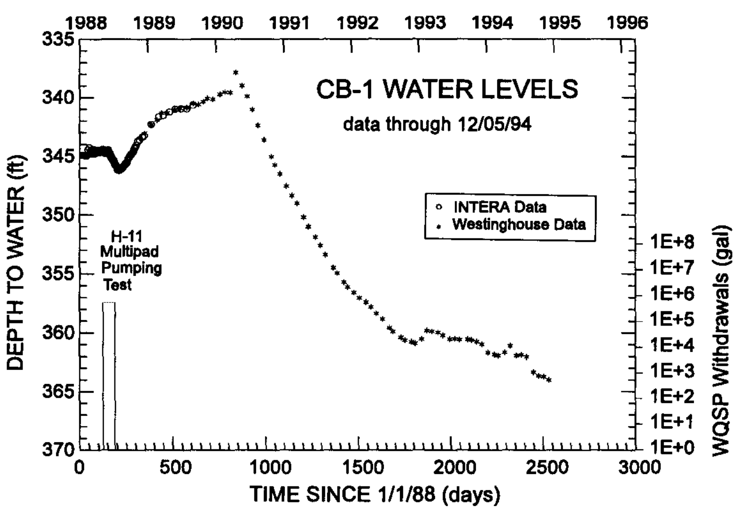


Figure 2.3-6. Well CB-1 water levels.

Cabin Baby [CB-1], which is just to the northwest of P-17, saw the H-11 multipad test response. The water level was continuing to rise and then the packers and bridge plug failed. That drawdown response (after early 1991) has nothing to do with the Culebra. At that time, the Culebra and everything else in that well were interconnected. Late last year we replaced the packers in that well and put in a new bridge at the base of the casing. Westinghouse may not be aware of that and needs to go back to measuring the water levels.

Well H-4b is the next well slightly to the northwest of Cabin Baby, and again you see the same response to the H-11 well and then this rise. Westinghouse takes water samples from time to time resulting in an occasional drawdown, but the well does recover. But they also went into H-4b and a number of other wells. Some of these older wells were caving in and were not providing full access to the Culebra Formation. Some of these wells were cleaned out. The cleaning required Culebra water, but Culebra water was not available from well H-4b. Water from well H-3 was used for all of these 1992 cleaning exercises. The water from H-3 has a different density from the density of the water in the wells that were cleaned out. As a result, upon completion of the cleaning exercise the water level had declined. The foreign water was pumped out and the water level rose sharply as a result of density change more than anything else. The water level has continued to decline. The decline in the H-4b well may reflect the decline in the Cabin Baby well because H-4b and Cabin Baby are very close to each other. The Culebra saw a pressure decline in the Cabin Baby well, which would create the drawdown in well H-4.

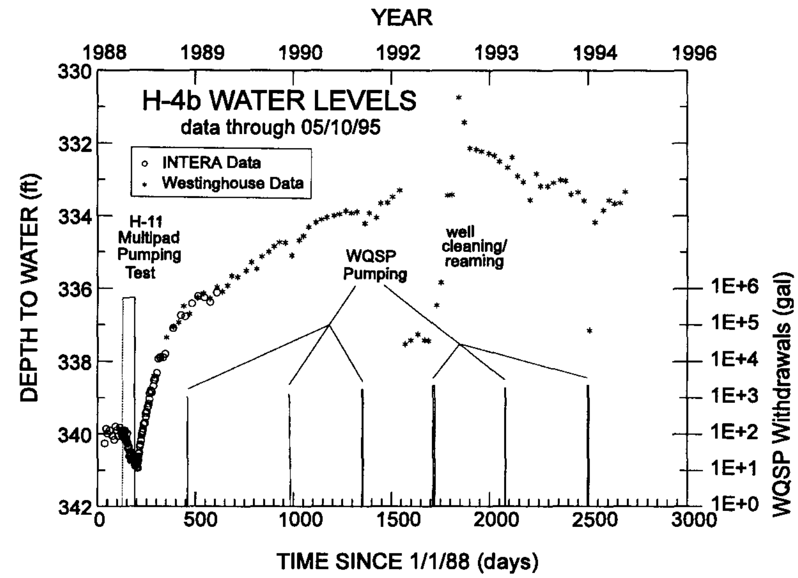


Figure 2.3-7. Well H-4b water levels.

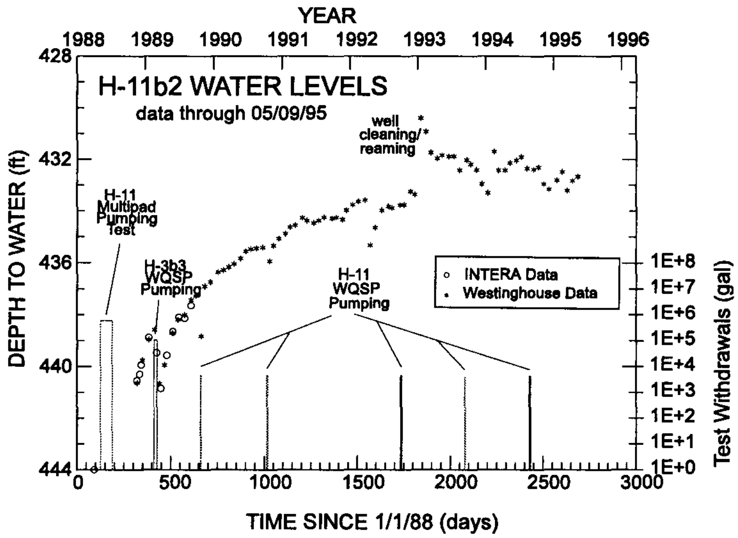


Figure 2.3-8. Well H-11b2 water levels.

After the H-11b2 multipad pumping test, there was pumping at H-3 that effected the water levels at H-11. After the recovery from the H-3 pumping test, the water level continued to rise. The plot shows the response to the cleaning exercise. The water level rose with the density change. The water level has continued to rise since then (with the rest of the response very similar to that at H-4b).

Well P-15 shows the same type of response (as H-11b2).

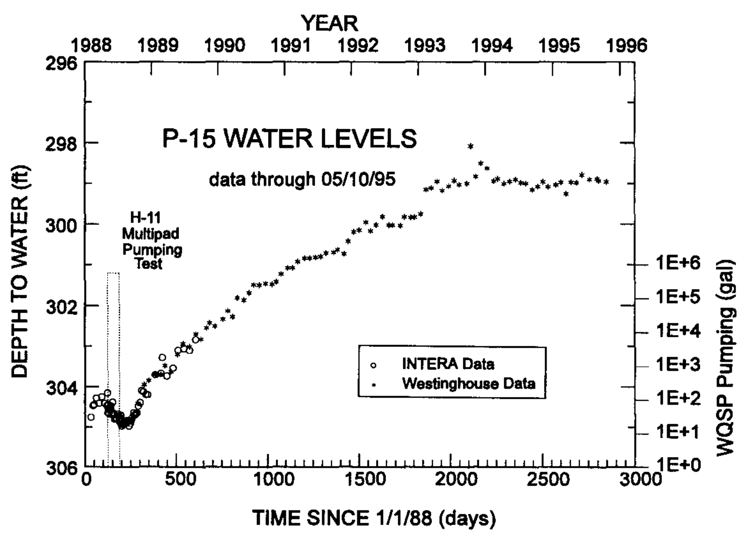


Figure 2.3-9. Well P-15 water levels.

Well H-10 lies northeast of H-9. Well H-10 has quite low transmissivity. It is a very tight well. It appears that whatever happened at H-9 or in the vicinity of H-9 took a number of years to propagate over to H-10 because of the low permeability. It wasn't until the end of 1990 and beginning of 1991 that the water level in H-10 began to take off. The water level has definitely climbed about three feet in the last three or four years.

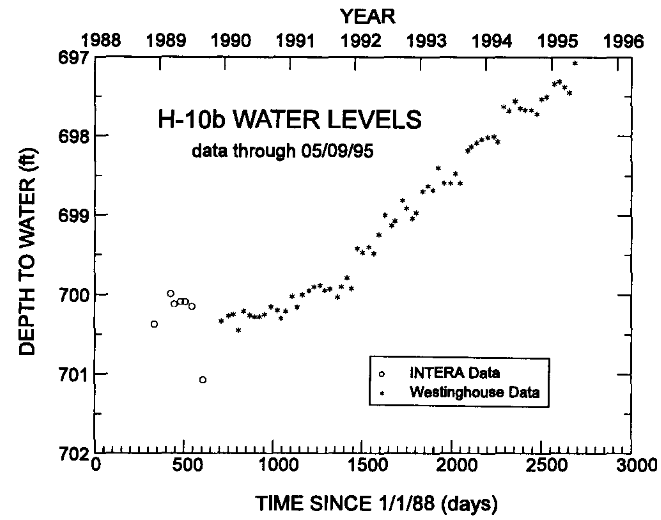


Figure 2.3-10. Well H-10 water levels.

Well H-7 lies off to the west in an extremely high permeability region. H-7 may also be under water table conditions. The scale in the water level plot is on the order of three feet. What appear to be large amplitude fluctuations are actually less than a foot in water level change. Most of these changes are probably due to barometric effects, earth tides, or something of that nature. The changes are just a fraction of a foot. But, one gets the sense that, for

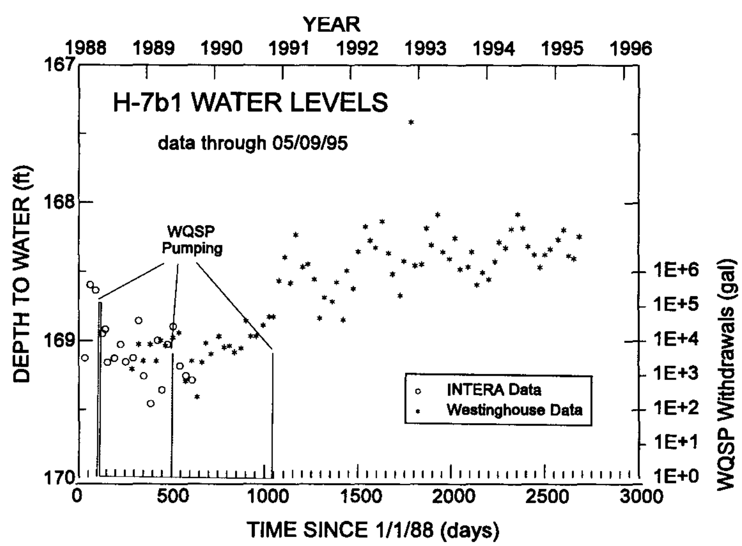


Figure 2.3-11. Well H-7 water levels.

years, the water level seems to be stable at about 169 feet. One does get a sense that the water level is climbing a bit at H-7.

So what might be going on? In 1990, Marsh LaVenue looked at all these rising water levels to the south and went out looking for injection wells in the vicinity of H-9 that might be a cause of this kind of a water level rise. He identified a number of injection wells, some of which the operators thought might be leaking. We really had no evidence that the leakage was specifically going into the Culebra. We were mainly interested in figuring out if that type of a hypothesis, that is a leaking injection well somewhere in the vicinity of H-9, could cause the types of water level rises that we have observed.

LaVenue identified one well not too far from H-9 that was injecting about 12 gallons per minute into a deeper formation. So we decided to play a "what if" game. What if some of the water being injected into this well is actually leaking into the Culebra? Using the existing regional groundwater flow model, LaVenue simulated injection at that well location. LaVenue found that if he put the full 12 gpm, into the Culebra, at that location, he could very nearly match the observed water level rises. Now that is in no way, shape, or form, proof that that [salt water disposal] well is the cause of these water level rises. It merely shows that if something is being injected into the Culebra, in that region, and at about 12 gallons per minute, you can get this kind of a response. It confirms our hypothesis that it really does take some kind of discrete event, turning on a pump, turning on injection, something changing to cause these kinds of water level responses.

From my standpoint, it's really not important what well might be responsible for this. It could be any well out there. The point is, in the future, we won't know. In a hundred years from now we won't know what wells might be leaking. We won't know what casing has failed, what cement jobs have gone bad. The point is simply that other units can be connected to the Culebra. They can cause changes in the water levels.

So what is the overall implications with respect to compliance? Well, in this particular instance, this well is to the south of the WIPP Site. Rising water levels to the south, that propagate to the north, as they propagate, they diminish in magnitude. What this in effect does, in this instance, is decrease the gradients, the natural gradients, within the Culebra, which are from north to south. So, under ordinary conditions, you have a particular gradient which in the event of a breach of the repository, would drive radionuclides to the south under the existing gradient. Well, what this kind of event does, is it decreases that gradient. So this would actually slow things down a bit. I don't think that is significant because I don't expect this to be a particularly long lived kind of response, probably on the order of tens of years, then it will damp out, reach some new equilibrium. Climate changes in the future could cause similar types of gradient changes, so I really don't think it's important. Let's continue to look at the other water levels and I will show you some other things that are going on.

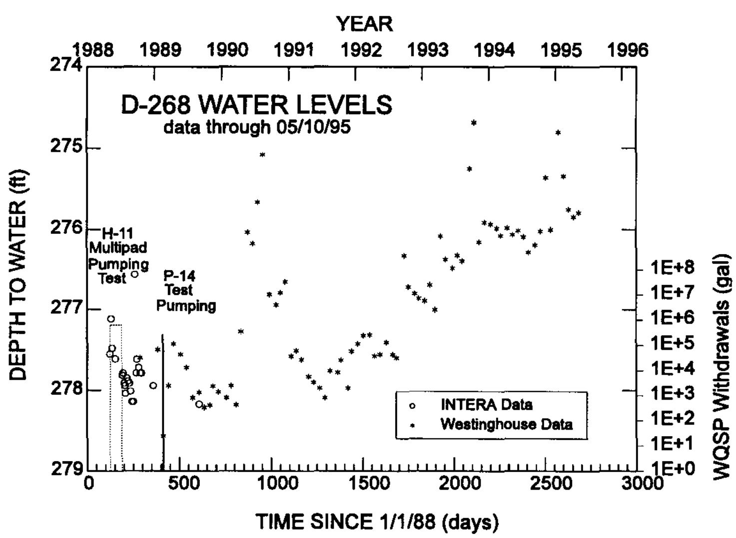
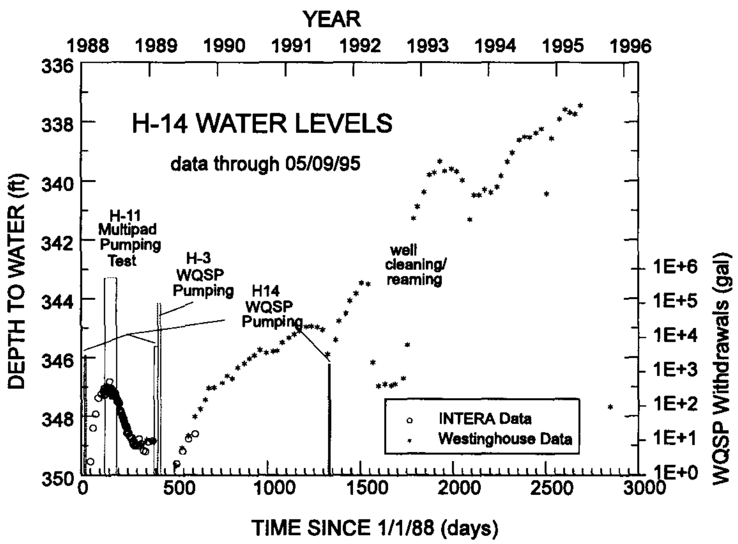


Figure 2.3-12. Well D-268 water levels.

D-268 is off the southwestern corner of the site. We have a troublesome packer in this well. It has to be continually reinflated. It likes to deflate. It sees a lot of water fluctuations as that packer loses its integrity and as the packer is reinflated and reestablishes its integrity. There may be a slight rise in the water level at D-268.



At H-14, there is the same type of response as observed at the other wells - a well cleaning exercise - pumped out - changes in fluid density.

Figure 2.3-13. Well H-14 water levels.

This is a greatly expanded scale, with sixty feet on the vertical scale to capture the response to the H-11 multipad pumping test. The water level continued to rise after the H-11 test. Then there was a packer failure in DOE-1. That packer has since been replaced and the water level is starting to recover from that event.

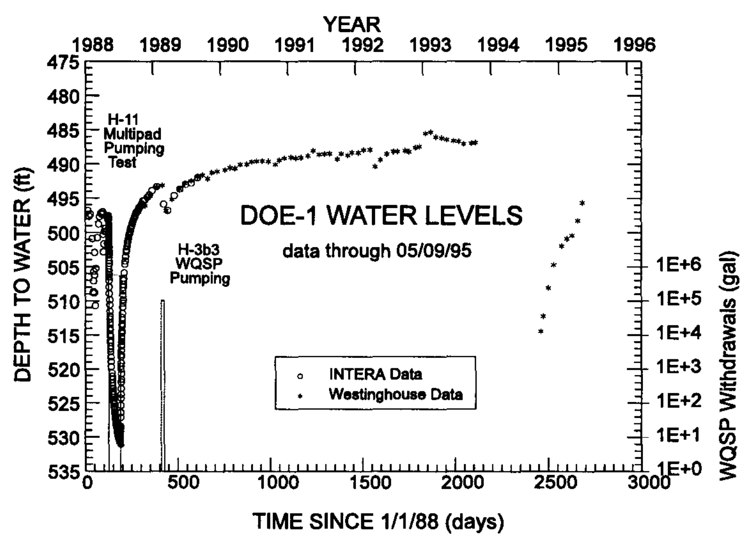


Figure 2.3-14. Well DOE-1 water levels.

Well H-15 shows a type of response similar to that of DOE-1.

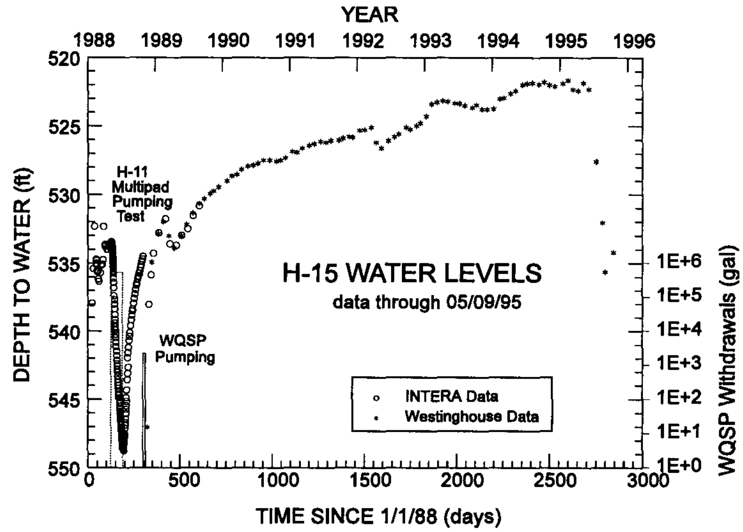


Figure 2.3-15. Well H-15 water levels.

2.3.1.2 Central Region of the WIPP Site

The shafts at WIPP caused a large cone depression in the Culebra. Starting back in 1981, when the exploratory shaft was first drilled, there has been leakage into all the shafts at the WIPP Site and that leakage has brought water levels down, in the Culebra, over the entire site. Over the years, there have been a number of episodes of shaft grouting which have been of varying effectiveness, and sometimes that effectiveness has been limited in time. So, some of the grouting jobs were repeated.

The most recent shaft at WIPP is the air intake shaft. Before the air intake shaft was drilled, we put in an observation well, H-16, fifty feet away to monitor the responses of the Culebra to the construction of the air intake shaft. The pressures that have been measured at H-16 since about August 1987 are shown. The stabilized pressure in the Culebra before the air intake shaft was drilled, was about 128 psig. When the pilot hole for the AIS was drilled, the hole was loaded with drilling mud. Once the drillers hit the Culebra, the pressure at H-16 rose in response to the pressure exerted by the drilling mud. Once the drillers holed through to the underground, the column of drilling mud shot into the underground resulting in an atmospheric pressure condition in the Culebra. So the pressure in the Culebra at H-16 dropped significantly at H-16. The drillers then upreamed through the Culebra. The pressure again dropped significantly at H-16. The air intact shaft was then lined. The pressure started recovering. Then Fred Gelbard went into the air intake shaft and drilled four horizontal core holes into the Culebra. That caused the pressure to drop at H-16 because of the free drainage into the holes. Those [core holes] were then pressure grouted because the pressure had increased and then the pressure started climbing again. The interesting thing about the pressure grouting is that by simply pressure grouting those four holes, the pressures rise, the buildup was much more than one might have expected. By grouting those holes, the overall leakage into the shaft was greatly reduced.

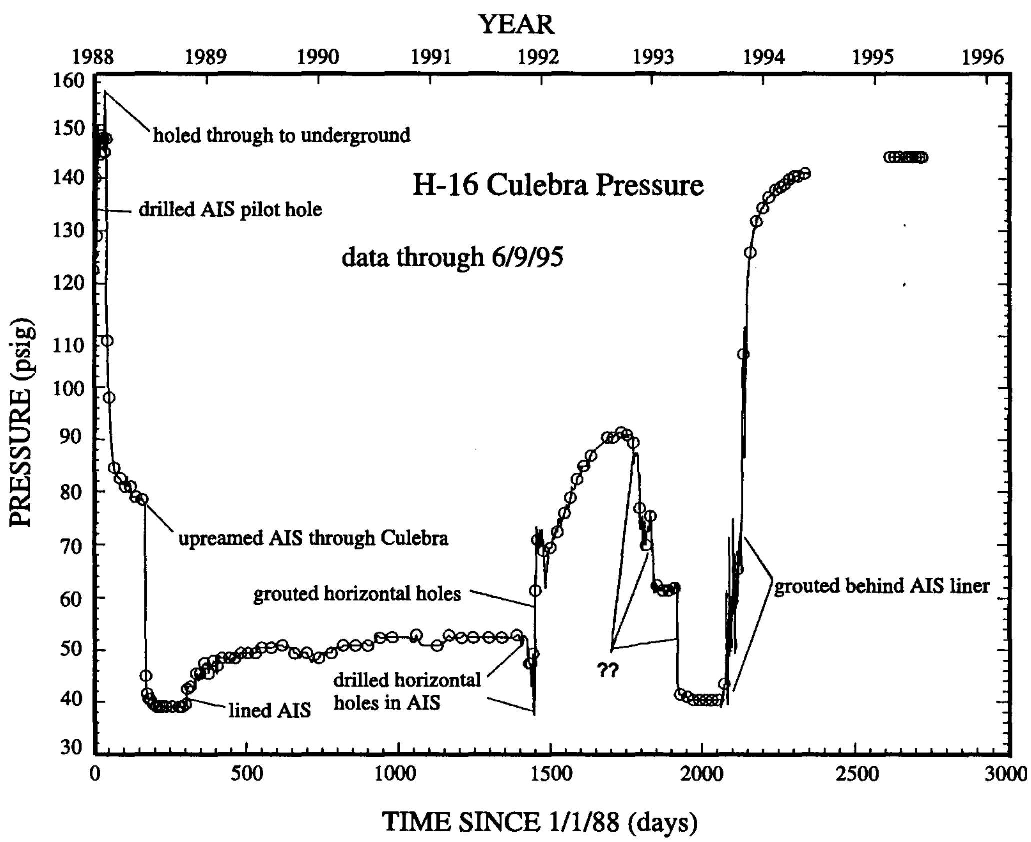


Figure 2.3-16. Well H-16 Culebra Pressures.

There were a number of episodes that I have not been able to pin down. Something happened around the air intake shaft that caused the pressure to drop in at least three distinct steps. I am not quite sure exactly what happened. The pressure stabilized around 40 psig until two summers ago when the project grouted behind the liner. This was a very serious grouting exercise and by far the most effective grouting exercise that has ever been done at WIPP. Sandia was working with the grouting contractor, providing the contractor with pressure data in almost real time. We could show them every single time they drilled a hole into the Culebra to grout. We could see the pressure response at H-16, the immediate drawdown response to drilling that hole. As soon as they did grout that hole, we saw the pressure spike associated with it. So we could track the effectiveness of their grouting program in progress. As soon as the grouting was completed, the pressure at H-16 rose and is now stabilized at 144 psig. Recall that in 1987, the level was stabilized at 128 psig. This grouting job was very effective. The pressure is now higher than it was before the air intake shaft went in. I spent this much time on this well because the other wells exhibit similar behavior. Well H-16 is only fifty feet from the air intake shaft but all of these responses propagated throughout the center of the site. Similar responses are seen for wells ERDA 9, H-1, H-2b2, H-3b2, WIPP-21, WIPP-22, WIPP-18, WIPP-19 and WIPP-12. The responses are more subdued with increased distance from the air intake shaft.

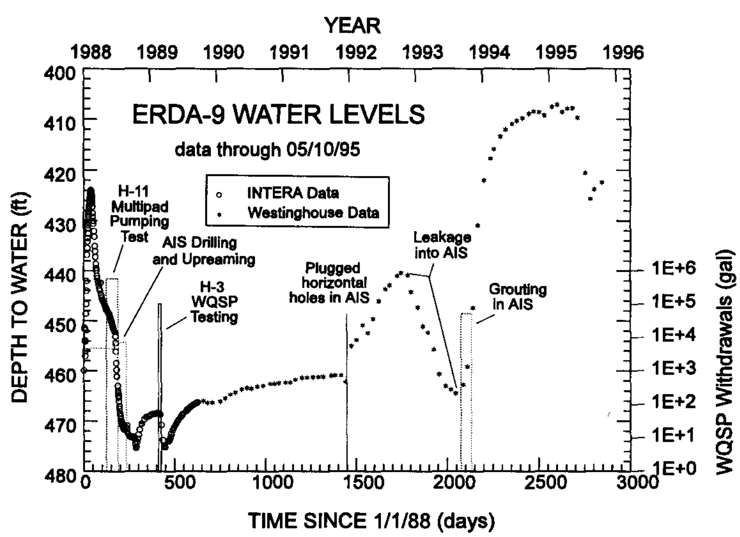


Figure 2.3-17. Well ERDA 9 water levels.

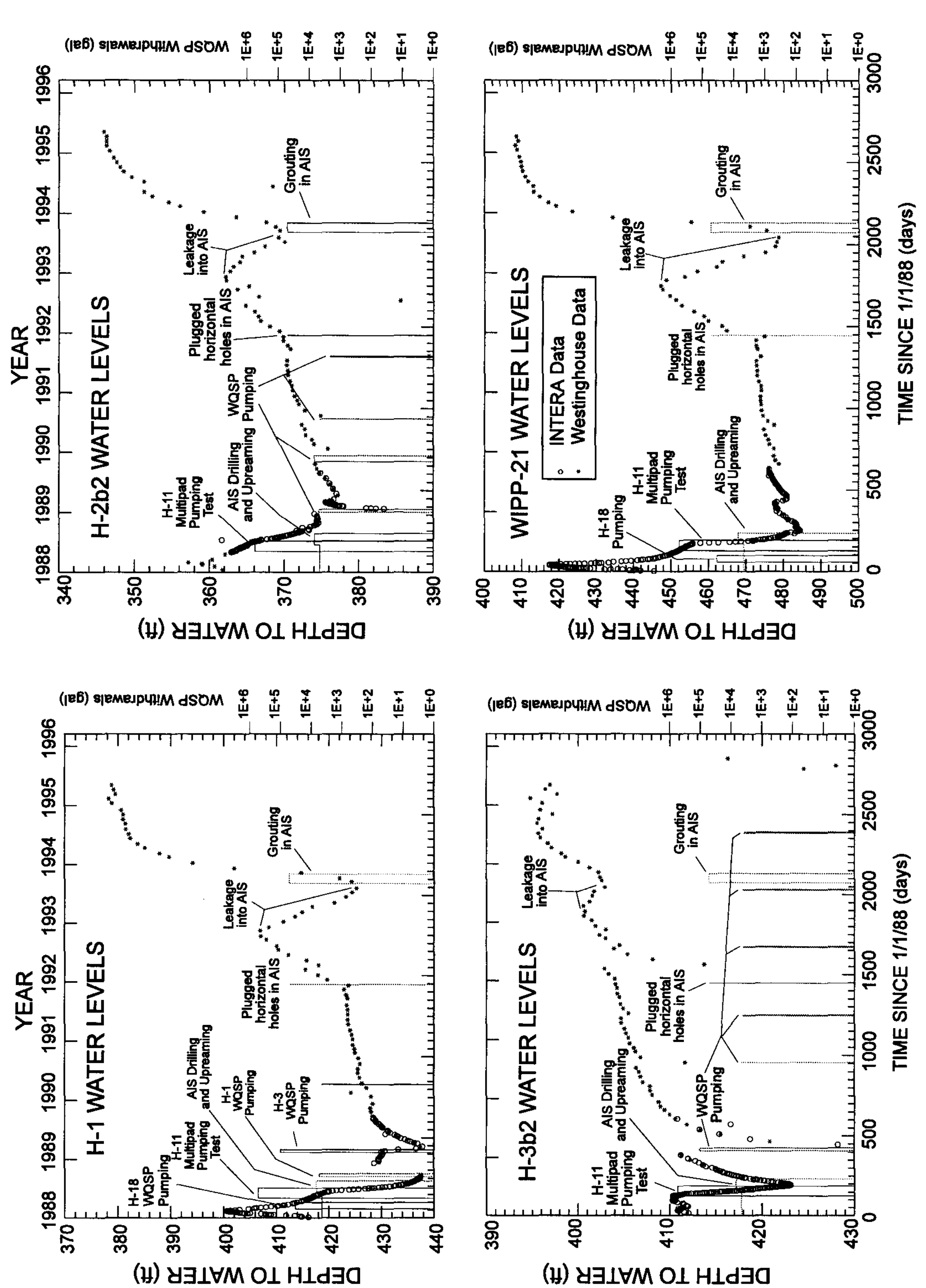


Figure 2.3-18. Wells H-1, H-2b2, H-3b2, and WIPP-21 water levels.

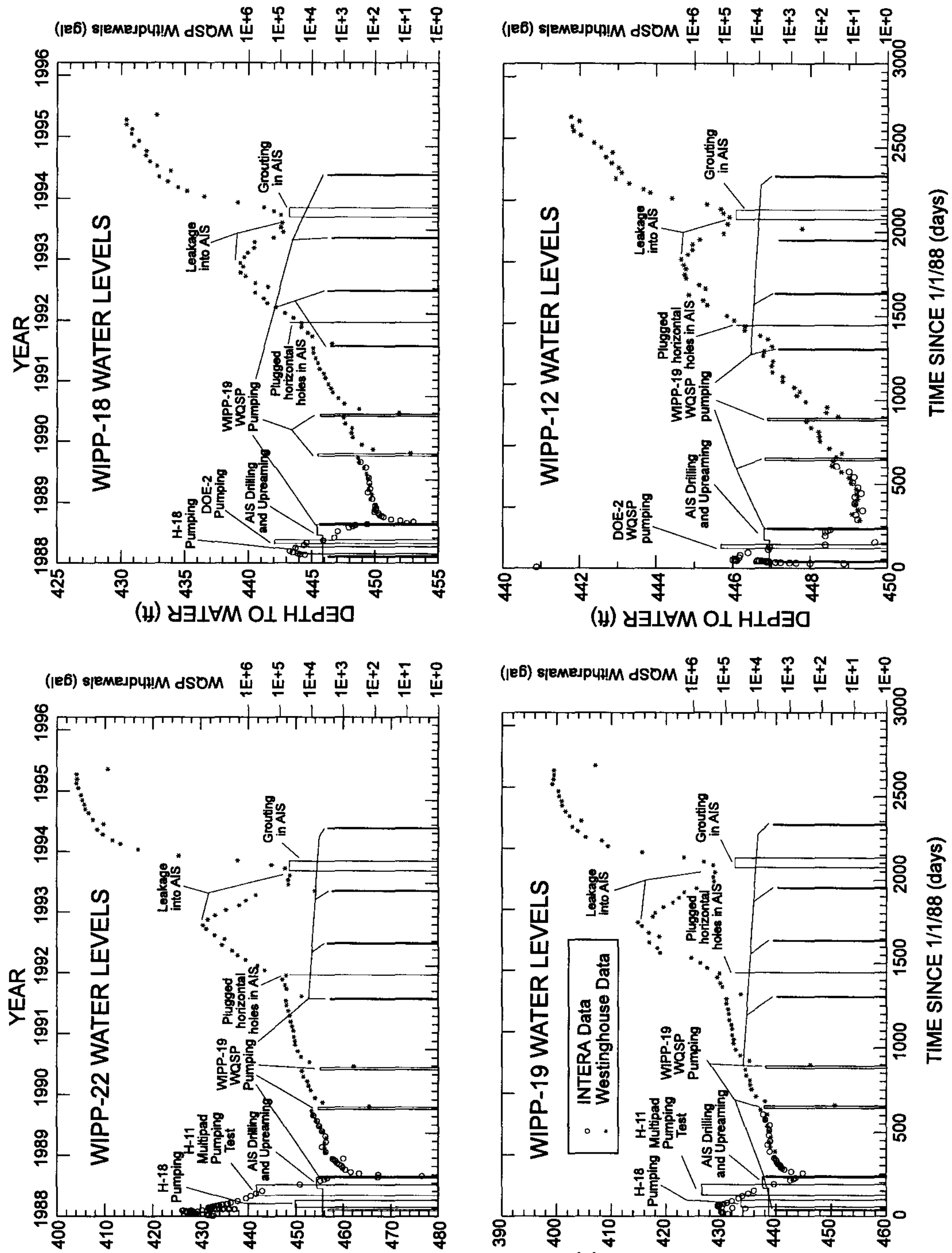


Figure 2.3-19. Wells WIPP-22, WIPP-18, WIPP-19, and WIPP-12 water levels.

Well H-18 shows a general rise in water levels.

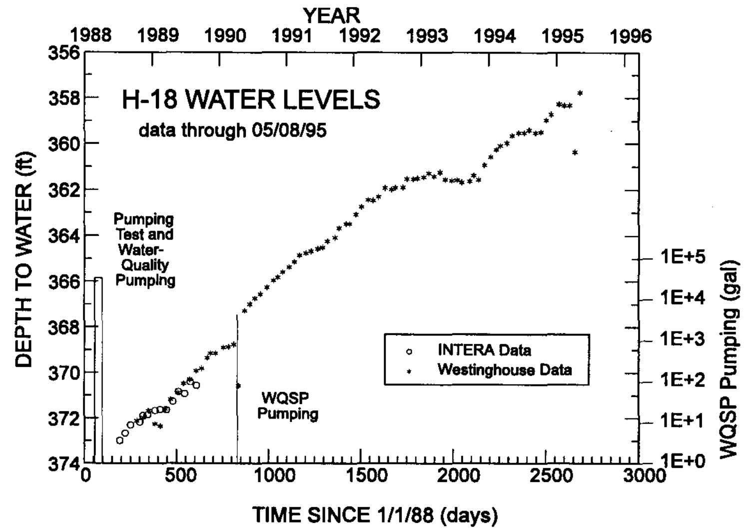


Figure 2.3-20. Well H-18 water levels.

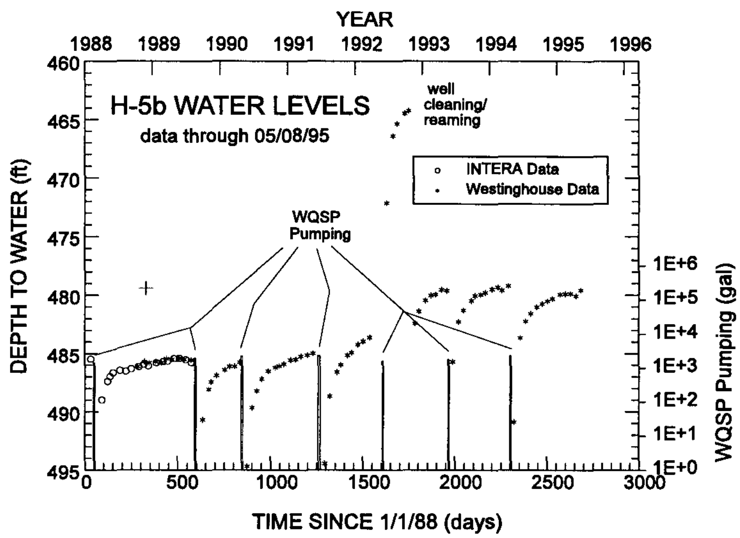


Figure 2.3-21. Well H-5b water levels.

Well H-5b is in the extreme northeast corner of the WIPP Site. It is in a very low permeability zone and it takes a lot to make anything happen at H-5. It is pretty much isolated from other events. It does show that for each water quality sampling, the well takes a time to recover and is still recovering when the next sample is taken. The water level sharply increased, for a while, in response to the well cleaning and reaming. Now the water level is in line with where it should be.

Well DOE-2 shows a water level rise up until mid-1992. Since then the water level has been falling off. This one is pretty anomalous. You don't see this kind of fall off in any of the surrounding wells. DOE-2 is like DOE-1 and Cabin Baby and some of the other wells. It has a bridge plug in the base of the casing which isolates the Culebra from the Salado and the Castile. There is another deep bridge plug which isolates the Castile from the Bell Canyon. Looking at the water level plot, I would guess that one or both of those bridge plugs have failed and we need to reenter that well and put in a new bridge to isolate the Culebra.

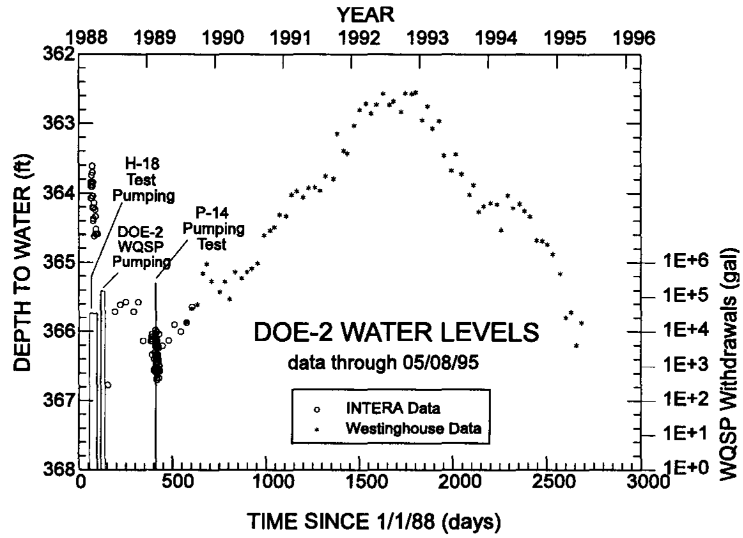


Figure 2.3-22. Well DOE-2 water levels.

WIPP-13 shows a water level rise. As you continue north towards Nash Draw, you see this kind of rise. This rise may be due to a combination of events. The wells are far enough away from the shaft so that they won't see a distinct response to a distinct episode at the air intake shaft. Instead you see a

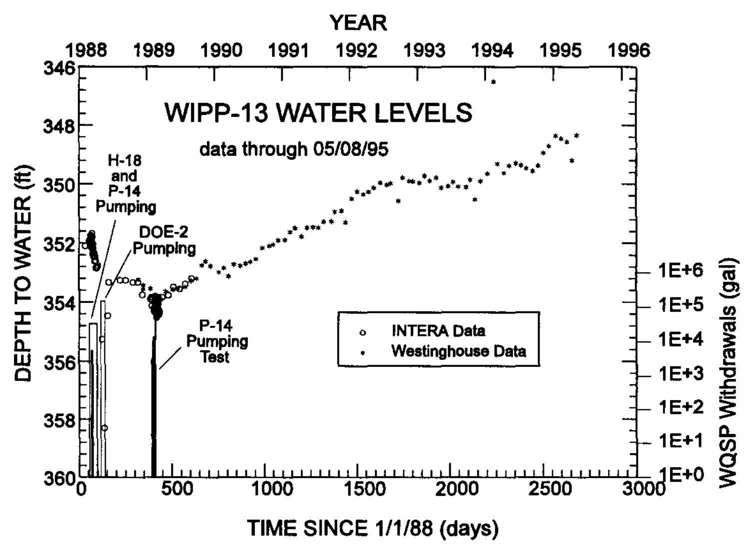


Figure 2.3-23. Well WIPP-13 water levels.

generalized response. In general, leakages into all of the shafts have decreased over the years. The rise in the wells to the north just reflects an overall recovery to the leakage into the WIPP shafts.

H-6 has risen on the order of about 4 or 5 feet since 1989. It is important to remember that H-6 has been there since the late 1970's. Even though it appears that the water level is rising, today's water level does not represent an all time high. Today's water level is approaching the water level of the late 1970's before any of the WIPP shafts were drilled. This appears to be a recovery to the drainage into the WIPP shafts.

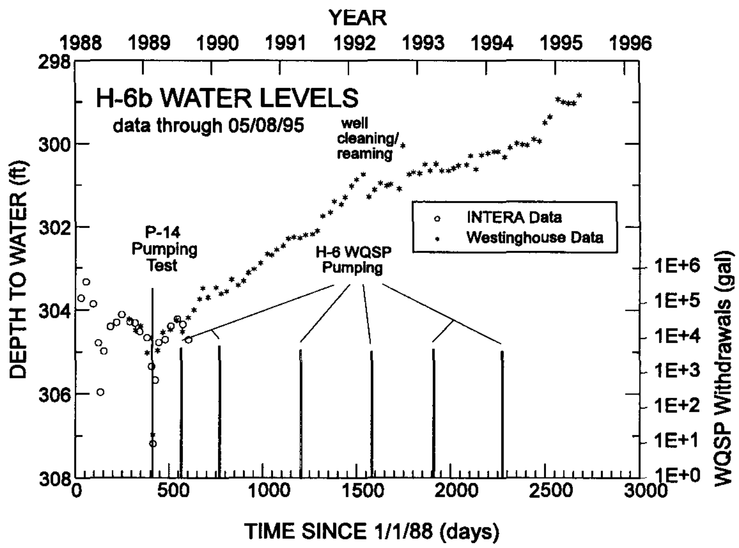


Figure 2.3-24. Well H-6b water levels.

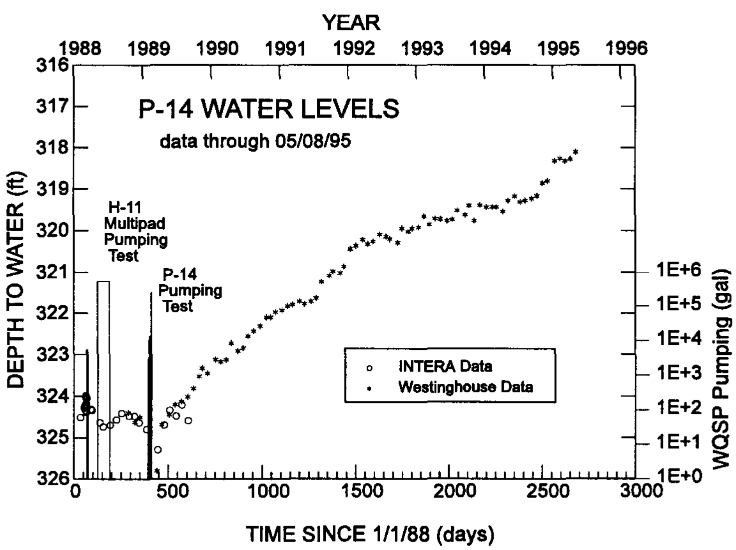


Figure 2.3-25. Well P-14 water levels.

P-14 is in a very high transmissivity region. The water level had been fairly stable. Now it looks like P-14 is going through an historic high.

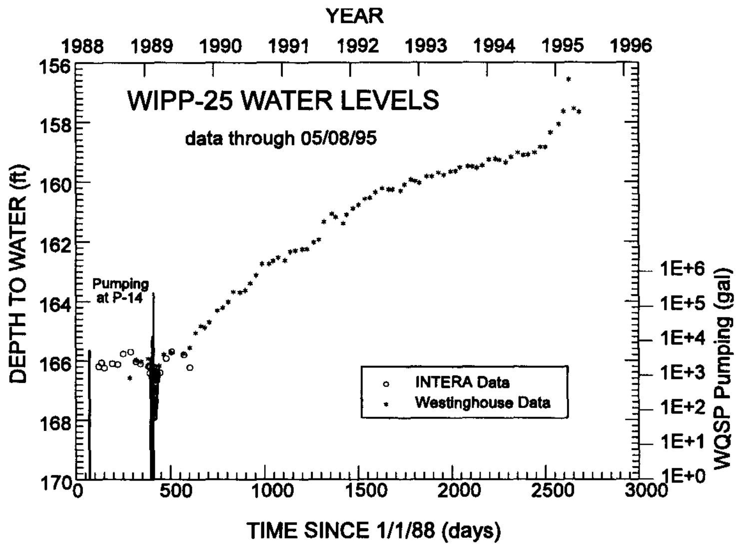


Figure 2.3-26. Well WIPP-25 water levels.

WIPP-25, in Nash Draw, shows a rise. WIPP-25 is in a high permeability region and it takes a fair amount of water to change the water level.

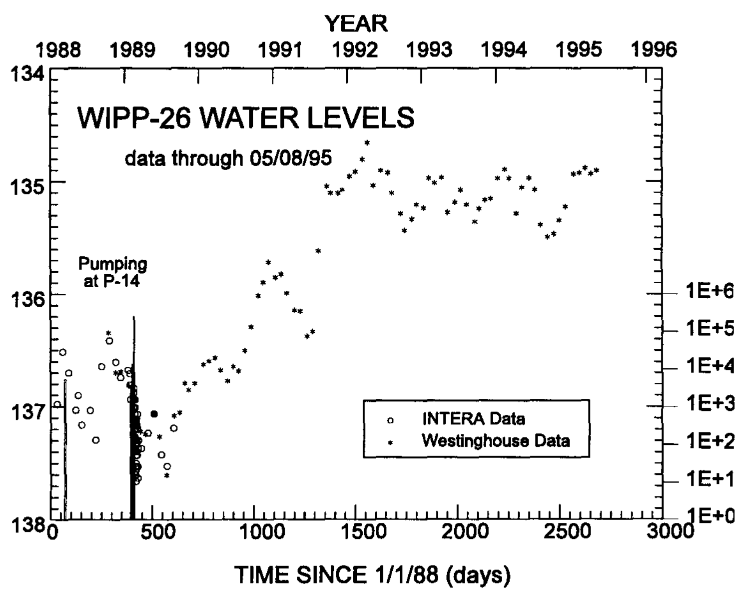


Figure 2.3-27. Well WIPP-26 water levels.

WIPP-26 seemed to be rising, but now it seems to have stopped.

2.3.1.3 Northern Region

WIPP-27 is in the northern part of Nash Draw, very close to one of the potash mines. The potash mines discharge various amounts of effluent into Nash Draw depending on their production. When there is not much production, there is not much discharge into Nash Draw. When there is more mining and more refining, they discharge more. WIPP-27 has a lot of distinct features. The plot of water level rise does not exhibit the noise seen in the plot for WIPP-26. Instead, WIPP-27 is responding to

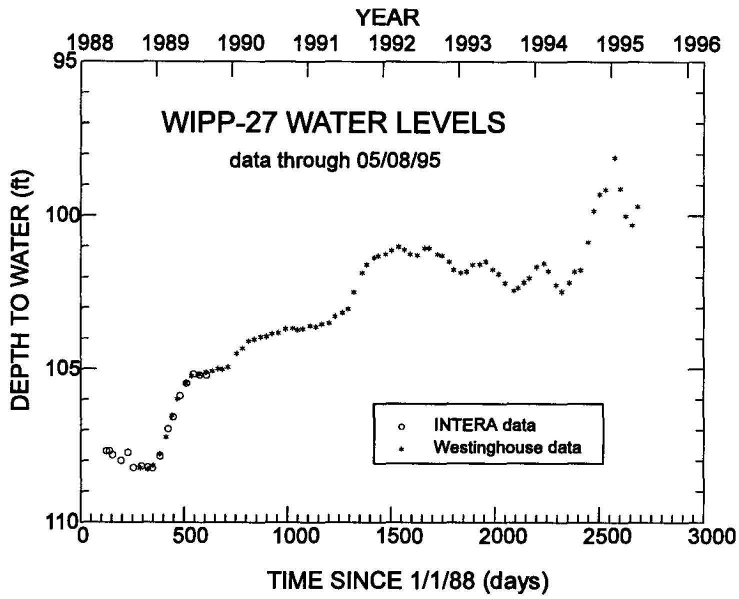


Figure 2.3-28. WIPP-27 water levels.

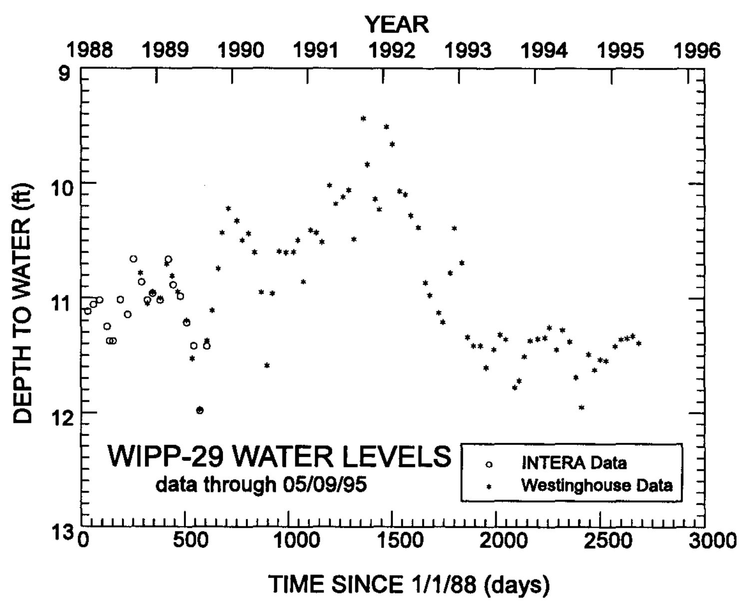


Figure 2.3-29. WIPP-29 water levels.

something fairly distinct. WIPP-27 appears to be providing a good indication of the discharge into Nash Draw. Some of these changes probably propagate through Nash Draw towards the northern part of the WIPP Site. But the changes get more diffuse as they get there.

WIPP-29 is so shallow, 11 feet to water, that it could be responding to almost anything.

WIPP-30 showed a rise, a stabilization for a few years, and now appears to be on another rise.

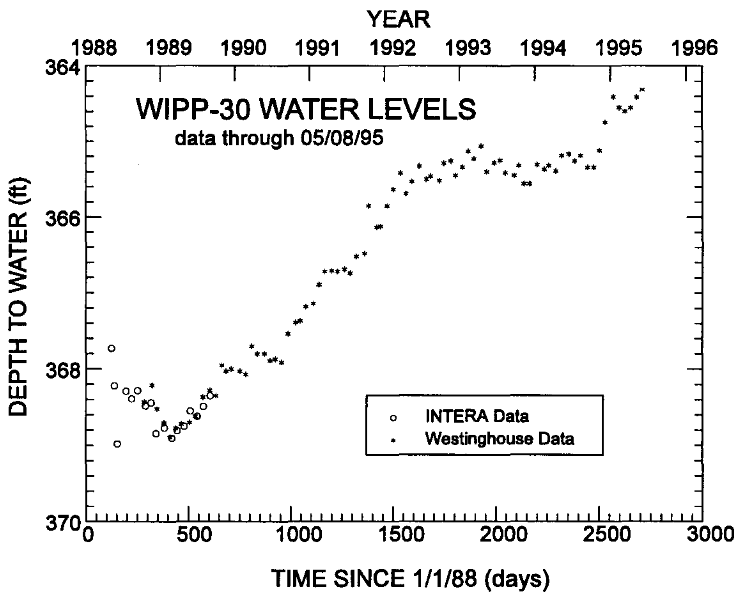


Figure 2.3-30. WIPP-30 water levels.

Well P-18 continues to rise. It is not clear where P-18 is headed. In contrast to all of the other plots, which begin in 1988, this plot begins in 1977. This is the complete water level history on P-18. Until

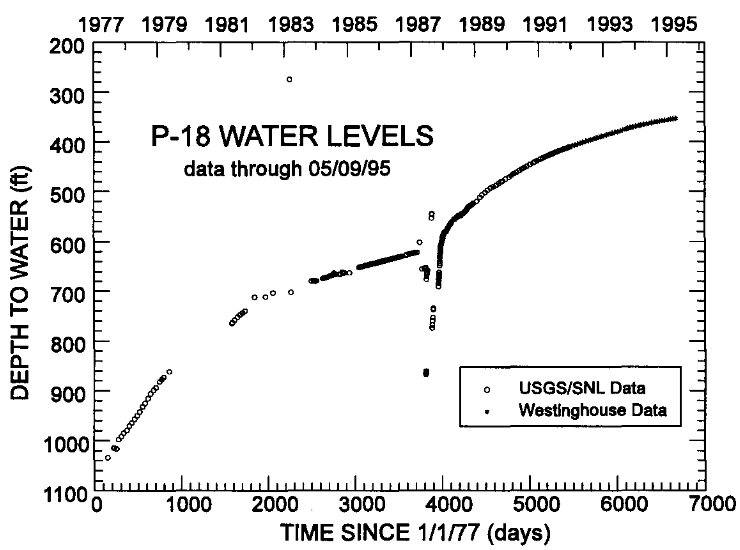


Figure 2.3-31. Well P-18 water levels.

about 1987, the water level was rising in a 4-inch well casing. It never actually stabilized. Then in 1987 we put a pip in the well. So, now the water level is rising in 2-3/8 inch tubing instead of 4 inch casing so it goes up faster because of the smaller diameter. The water level still hasn't stabilized there. A lot of people over the years, including myself, have hypothesized that we may not have the best connection to the Culebra in this well. There may be a problem with the cement bond. This is a cased, cemented, and perforated well. There may be a problem with the bridge plug at the bottom. There may be problem with the cement job. We don't have a lot of confidence that what we are seeing here is the Culebra.

2.3.1.4 Summary

To summarize, I see three different things going on with the water levels at the WIPP Site. To the south, centered around H-9, you see one very distinct water level rise that began abruptly in 1988, reached its peak at H-9 and seemed to propagate to the north, which I think is probably related to some kind of injection from some other well in that region. As you get to the center of the WIPP Site and more or less propagating out from the center of the WIPP Site you see recoveries and drawdowns related to events at the WIPP shafts. Those shafts are pretty well sealed right now, so the overall response you see today is rises in water level. As you move to the North and get into Nash Draw, I think you can probably see responses to the discharge of potash mill effluent into Nash Draw. I'm not sure about the availability of discharge records there. It might be possible to try to reconstruct a discharge history and try to relate that to the water levels we have seen. Again, I'm not sure that it's really relevant to WIPP compliance. The water levels and the flow directions are not from the WIPP Site towards Nash Draw. Any minor changes in gradient, in any event, are not going to effect the results of our performance assessment. We are not on such a hair trigger that a difference of 10% or even 100% is really going to make any difference.

2.3.1.5 <u>Questions</u>:

Dennis Powers: For wells H-7, WIPP-26, and WIPP-27. Are the data precise enough for annual changes?

Rick Beauheim: I have doubts about H-7. H-7 at one time pumped at 80 gpm and the responses we saw at the observation wells on the order of 100 feet away were dominated by earth tides. And the earth tidal responses were almost as great as the pumping test response. It may be of interest to no one but me, but earth tides are changes in water level affected by moon tidal affects and the changes in the configuration in the earth in response to tide. Actually, some of the first work on earth tides was done in Nash Draw, in the Culebra, back in the late 1920s, early 1930s. So H-7 is very close to the location where the very first earth tide research was done. The other ones, Dennis, -- yes I think it is possible that you could try to do that -- I'm not sure what you would turn up, but it might be worth a shot.

Tim Gum: Rick, on your model study where you indicated the 12 gallon per minute increases in fluid level, what was the total volume which had to be injected in order to get the total rise all the way?

Rick Beauheim: The way the modeling was done, the 12 gpm was turned on. I guess I'm not sure exactly when in 1988. In early 1988 this 12 gpm was turned on and was simply allowed to run for the duration of the modeling simulation. At the time that was done, the water levels were all continuing to rise. So the modeling was simply turned on and we watched the hydrograph to see if the simulator hydrograph matched what we observed.

Tim Gum: From 1988 on?

Rick Beauheim: From 1988 on to however long it ran. I honestly don't recall if we just ran a simulation through 1991 at the time or projected further. But we didn't turn it off and then on.

Tom Peake: Yes, do you think this affected your response times, due to rises from the South to the North, up to the Cabin Baby and H-4? Do you think that has any implications for suggesting that there are higher transmissivities in the South Central part of the WIPP site than are currently being modeled?

Rick Beauheim: I think you can look at the pattern of water level responses and learn something about the transmissivities. P-17 and H-17, for instance, lie on an east-west line. Yet their responses were different. I look at those two responses, H-17 and P-17, and what they say to me is there is a high transmissivity feature passing between those two wells. A few responses we observed tell me that the high transmissivity feature is more likely closer to P-17 than it is to H-17. Because the P-17 response seems clearer. It seems to catch the subtleties of the response better than the H-17 response. The propagation on toward Cabin Baby, H-4, P-15, I guess I really could not say whether it holds any surprises. I think it would provide an opportunity to take a closer look with our existing Culebra model to see if our current transmissivity distribution would match the responses that you see that much further away in detail.

Robert Neill: It is an extremely important area. In fact we have a half hour scheduled this afternoon to address this in greater detail. Rick, a quick question. Do you see any merit, at this point, in trying to obtain some water samples from these wells to examine, from a standpoint of chemistry, any change as both a function of location and a function of time?

Rick Beauheim: I really don't think so. We are looking at pressure transient propagation here which can be relatively rapid whereas actual transport of ground water is an extremely slow process. I don't think there is any chance at all of us seeing changes in water chemistry as a result of this.

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2.4. Observations of the Effects of Water Flooding on the Salado Formation

Dennis W. Powers, Consulting Geologist, Anthony, Texas

2.4.1 Synopsis

The Hartman vs. Texaco lawsuit and subsequent discussions with different people focused my attention on a physical condition common to several concerns. The basic physics or hydrology of liquid and gas movement laterally or vertically through the evaporites, especially the Salado, is common to decisions about oil and gas exploration vs. potash mining, deviated or vertical drilling through evaporites outside WIPP boundaries, and the fate of any gas generated by decomposition of waste at WIPP.

Exclusion zones for drilling and potash mining are presumed to be based on two principal concerns: safety and the desired development of resources. Exclusion zones presumably increase as real (or perceived) safety concerns increase; fewer resources are developed in consequence. Among the safety concerns is the possibility of lateral movement of hydrocarbons along evaporite beds from a leaking well into a mine. The same general setting can exist for WIPP from the nearest well to the underground workings. Gas generation at WIPP raised the possibility of movement away from the disposal mine to a boundary or well. And the Hartman Bates well raised the possibility of injected fluids reaching a well at a distance of about 2 miles from the injection field boundary and in a formation overlying the injection horizon.

Perhaps each situation has to be resolved separately (monetary settlement for Hartman, scenario analysis for WIPP, some other means for potash vs. oil and gas exploration). Nonetheless, as similar occasions arise, there will be a continuing need to understand the hydrology of liquid and gas transport parallel to bedding within the Salado or other rock units. There are probably no better investigations yet of these phenomena than for WIPP, and there will be increasing pressure to understand and apply the results to different versions of the same fundamental problem.

2.4.2 Presentation by Dennis Powers

Today I want to cover a few different topics. The title that is listed for you is a little bit misleading. First, I want to give you a little bit of my impression of some things out of the Hartman vs. Texaco lawsuit that struck me. I also want to talk about some common problems, some underlying principles of physics that are important to several different projects and several different ways of thinking about the Salado.

Today, I am speaking on my own behalf and I am not here representing any organization at WIPP even though, I think most you are aware, I am under contract to one or more organizations to do work at WIPP. I am not a lawyer; this is not a legal analysis of the Hartman vs. Texaco case. I think that the comments that Bob Neill made at the beginning were important. This is not a rehash of that case. But there are some items of technical interest.

2.4.2.1 Background

Let's take a look at the setting for that well and the relationship to the Rhodes/Yates waterflooding unit principally operated by Texaco. In January 1991, Hartman and his company began to drill the Bates #2 well on an acquired lease that had previously been drilled by El Paso Natural Gas and had been producing for about 35 years before plugging and abandoning the Bates #1 well. The Bates lease is located in the southeast corner of New Mexico. It is located in the back reef and not in the Delaware Basin. It was drilled to try to produce Yates gas in the lease that Hartman had obtained. At about 2,240 feet the well begin to produce high volumes of high pressure brine. Drilling operations were stopped at 2,280 feet. The New Mexico Oil Conservation Division was notified. Out of concern that an underground blowout might occur, the driller was not allowed to shut the well in for any extended period of time. Casing had been cemented back to the surface from about 456 feet in an approved drilling plan.

The flow, at times, was on the order of 1,200 barrels per hour. Nearly 300 truck loads of brine were hauled away and a pipe line was put in to take brine away to the South Leonard Waterflood Unit. It took five days to work out a final solution in consultation with the New Mexico Oil Conservation Division. That solution was to cement the annulus first, to go back in and check the cement job, and then to cement back to the surface, leaving the drill pipe in place. Thus ended Bates #2.

At that point Hartman and his company began to wonder where this had come from. The question that came up - was this a natural flow or was it not natural, that is, brought by some other means such as the water flood unit operated at Rhodes-Yates field? I am giving you some of my impressions and can't speak to the actual thought processes of anyone involved, but late last fall I was contacted. It appeared that there would be a defense during the legal proceedings that this was a natural event, that it was similar to the high pressure brines in the Castile Formation and several wells in the vicinity of WIPP. It bears certain resemblances to the data that had been obtained from underground testing at the WIPP — data that had been obtained by drilling small diameter holes and testing them with rather sophisticated means over a period of time to determine what the pressure buildup was. Hartman called me to see if I would be available to help counter these arguments. I spent some time reviewing the data and decided that the approach that they wanted to take was consistent with what I believed was going on so I joined their team, for a while, to provide consulting services. I was named as a potential rebuttal witness. I did not testify at trial. That gives you a little bit of a background. I thought that was important so you would know where I was coming from and you can judge accordingly whatever is said.

Some notes - the Bates #1 was drilled in 1953 by El Paso Natural Gas. It produced, again, for about 35 years and then was plugged and abandoned. The Bates #2 well is approximately 100 feet away from Bates #1 well on the surface. To my knowledge, there are no directional surveys. I cannot tell you how far apart they might be at the bottom of the hole which is about 2,280 feet.

At the point where the flow began, there is an anhydrite unit. It's on the order of 10-15 feet thick, based on geophysical logs from that well and nearby wells that can be correlated. We are in the Salado Formation. I have not tried to correlate the individual marker beds with those in the Delaware Basin. It's my guess we are somewhere in the range of marker beds 140 to 142, which would put it below the WIPP repository horizon, which is just above marker bed 139. There is, on the natural gamma log signatures for that drill hole and others, a slight gamma kick at the base of that anhydrite, which is consistent with what we see in shafts and drill cores and other logs of boreholes. But there is probably some clay or argillaceous zones besides anhydrite.

The distance from the Bates #2 well to the administrative boundaries of the Rhodes-Yates water flooding operations is approximately two miles. Structurally, the Bates well is generally updip.

2.4.2.2 Observations

The salt water blowout and the subsequent case raised interesting technical issues. One was the unresolved differences in the estimates of the true pressure in the Bates #2 well. The New Mexico Oil Conservation Division was concerned that if the well were shut-in, the high pressure brine would be injected into other formations (an underground blowout). Hence, the well could not be shut-in for an extended period of time to obtain a good bottom hole shut-in pressure. The consultants for Hartman believed that the best shut-in pressure came after the annulus had been cemented and there had been circulation and flow equal to the cementing job which should have relieved any pressure problem, or most of the pressure brought on by a cementing job. That pressure was on the order of 1,000 psi at the surface. The consultants for Texaco had believed there was a more appropriate pressure that was several hundred psi lower. That would have brought the pressure gradient and the formation pressures down considerably from what the Hartman consultants had estimated. Nonetheless, the pressure measurements were less than desirable 1) because of the condition of the hole and 2) because of the inability to shut the well in and obtain a good shut-in pressure.

It was suggested that the pressure gradients can be used as indicators as to whether the water flows were induced by nature or induced by some other source. For the Rhodes-Yates water flood, the injection pressures at the surface ran 1,200 psi and above. Some injection pressures approached 2,000 psi at the surface. If those are correct, those surface injection pressures begin to produce pressure gradients greater than 1 psi per foot vertical. Typically, the measured pressure gradients from brine reservoirs in either the Castile or the very low flows in the Salado are considerably less than 1 psi per foot, ranging down to 0.8 psi per foot or less. The difference in pressures can be used to distinguish between natural or human induced occurrences.

There was testimony on both sides as to whether or not there were unaccounted injection fluids. The consultant for Hartman estimated that there might be as much as 20 million barrels of fluid that had been injected that was unaccounted for in terms of total production and storage capacity of the formation within the water flood unit. Consultants for Texaco testified that they did not believe, by their analysis, that there were any unaccounted for fluids.

There are differences between the geology at the Bates lease and the geology at the WIPP. The Bates well blowout was a large volume, high pressure flow. The bottom of the borehole was in the Salado Formation. The Castile does not exist in the area of the Bates well.

In the WIPP area there are high pressure, high volume reservoirs within the Castile. One brine reservoir was tapped at WIPP-12, approximately 1 mile north of the site center. Those kinds of brine reservoirs are in the Castile and are generally associated with a zone of relatively high deformation of the Castile, within a few miles of the margin of the Capitan Reef.

At the Bates #2 well, the Salado shows little deformation. It shows a general dip, but nothing of any magnitude comparable to the kinds of deformation observed in the Castile in the area of the Capitan Reef. The WIPP pressures from the Salado testing underground, suggests that the projected pressures will show a gradient on the surface much less than the Castile.

The Hartman-Bates well blowout raised interesting questions about expectations for institutional responses and institutional controls and how they change with time. Presumably they get better, but it is one thing that needs to be looked at.

There is a technical basis for scenario development. In the Hartman case, one has to either accept a natural cause or, if it is not natural, one must believe that fluid was transmitted along a bedding plane to the Bates lease perhaps for a distance of 2 miles. Transport along the bedding plane is the best explanation. For years the (WIPP) project has been concerned about gas, generated by waste degradation, either diffusing, fracing (fracturing), or otherwise moving along bedding planes. It is the same problem but moving in a different direction. With any kind of drilling, including water flood operation, around the boundaries at the site, the same issue comes back again. How are we going to address whether fluids can move along bedding planes or within the formation, a certain distance under different conditions? How will we address that?

BLM is having to try to address the issue, I believe, through litigation of the contrasting desires of oil and gas exploration vs. potash mining. How far away from mining is it safe to drill a hole or mine up to a hole? There are cases where mining has hit petroleum casing underground. That makes people nervous — that there is an oil or gas well and that you get that gas leaking into a mine. Several things are going to happen. None of them are good. The most benign is that their expenses go up to try to deal with a gassy mine and they go out of business. It is not very benign. People are working with stock holders. That might be one of the more benign consequences, if such a leak did occur. But of course, every time you change that boundary, you say, well, we need to protect the potash and keep the oil and gas away. That just simply magnifies the amount of resources unavailable for both sides. Obviously, if you were going to maximize the resources, what you'd like to be able to say is "It's safe". You can co-exist. Everybody gets their way that way. So those are some issues that have some common problems.

What I see is that everybody will probably attempt to solve it uniquely because nobody likes to try to produce a general solution for all of the world. It is expensive and difficult. If you can produce a simple solution for your problem or concern or issue, whatever it might be, if you can produce that solution for yourself very simply, you'll do it. But it might be good for the different organizations to be thinking about this with a little bit longer term (framework) and to recognize that there may be consequences, even unintended consequences, from one solution to another one's problems. Even if it's a modeling approach that makes certain assumptions that the modeler says don't cause a problem, somebody else might have some difficulty with those assumptions. We need to make sure that those are specific, unique, and identified as being adequate for that problem but not necessarily general assumptions. Those are a couple of the things I wanted to talk about this morning. I believe that the pressure on the WIPP underground data and related data from the WIPP will increase. By pressure I mean there will be a lot more demands for it and a lot more desire to interpret it, to make sense out of the particular application that you have, from BLM trying to resolve oil and gas versus potash mining, to other people. They need to be aware of that and to think about how best to integrate interactive folks. Thank you, any questions?

2.4.2.3 Questions:

Wendell Weart: Do you know, Dennis, if there is presently a standoff distance, either legal or practical that the industries have used to keep certain separation between potash excavations and petroleum holes?

Dennis Powers: The number I heard was 500 feet but I also know that some of the potash mines have generally, inadvertently drilled into a few, or mined into a few holes, too. Five hundred feet is the number I heard but I haven't seen it written down in some regulatory fashion - it may be there. And there may be somebody that knows that number better than I do.

Dan Stoelzel: You said there has been inadvertent mining into petroleum wells. To your knowledge, is there any record of gas leaking into these mines?

Dennis Powers: I haven't seen any, no. What they did, the records that I saw, indicated that the casings got marked up. Tungsten carbide bits will do that. And then there were various measures to go ahead and protect the drill casing. In one case, I'm trying to remember which mine it was, there was a caisson built and a big cement block support around it.

Dan Stoelzel: What about naturally occurring gas in the potash mines?

Dennis Powers: Well they are not classified as gassy mines with methane residence, but there are occasionally these blowouts of gas which have been trapped, most of which is nitrogen. Lokesh [Chaturvedi] has written, edited, and put together a volume that discusses gases occurring in the Salado Formation. That's one good source and there are other sources within some of the Sandia publications that describe some of the gases. But basically it is nitrogen-dominated and few other minor gases. But potash mining people desperately wish to avoid the gassy classification because if they ever wind up in a gassy classification, at least at this point, they'll be out of business. And right now I don't see any — there is no particular reason to fear that, as far as I know.

Chuck Byrum: Dennis, do you know why they inadvertently hit some well bores while they were mining?

Dennis Powers: No. It may be known, I just don't know.

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2.5 Geologic Considerations and the Implications for Waterflooding near WIPP

Lori J. Dotson, Sandia National Laboratories

Current Petroleum Practices and their Application to WIPP area Development

Daniel M. Stoelzel, Sandia National Laboratories

2.5.1 Combined Synopsis

A Rhodes Yates/Vacuum Field scenario (where injected water migrated to the overlying salt) is highly unlikely at WIPP because of: differences in geology, changes in oil-well completion practices from the 1940's, and improved reservoir management. In addition, new state regulations are in place to reduce the possibility of a petroleum well leaking into the Salado.

The differences in geology between WIPP and the Vacuum and Rhodes Yates Fields is significant. WIPP is located in a fore reef environment where a thick zone of anhydrite and halite (the Castile Formation) exists. Oil production is from the Brushy Canyon Formation at depths greater than 7,000 feet (5,000 feet below the WIPP repository). By contrast, the Castile Formation is missing at both the Vacuum and Rhodes Yates Fields which are located in reef and fore reef environments, respectively. Oil production at the Vacuum Field is from the San Andres and Grayburg Formations at depths of approximately 4,500 feet and oil production at the Rhodes Yates Field is from the Yates and Seven Rivers Formations at depths of approximately 3,000 feet. At the Rhodes Yates Field, for example, there is only a couple hundred feet of vertical separation between the Salado Formation and the waterflood injection zone. In addition, the oil pools near WIPP are characterized by channel sands with thin net pay zones, low permeabilities, high irreducible water saturations and high residual oil saturations. Therefore, large-scale waterflooding near WIPP is unlikely. The estimated life of the pools near WIPP is less than 10 years for primary production and less than 10 years for secondary production.

The petroleum industry has made many advances since the time when the Vacuum and Rhodes Yates fields were first developed. Improvements in drilling, casing, and cementing technology have greatly reduced the occurrences of leaks in oil wells. An industry-wide effort to reduce formation damage and increase production has led to improvements in completion design and advances in stimulation. Open-hole (non-cased) production/injection wells and nitroglycerin treatments are no longer used. Acid stimulation and hydraulic fracturing techniques have improved considerably in the last ten years. Service industry support has made this technology available to both the large and small operator. The availability of inexpensive software has lead to improved reservoir management, including waterflood design.

State regulations require a salt isolation casing string for all wells drilled in the WIPP area. Injection pressures are not allowed to exceed fracture pressures for all injection/disposal wells. Operators obey these regulations because the State has power to levy fines and/or shut wells in, should they become aware of a violation.

In conclusion, geological differences, modern petroleum development practices, and regulatory oversight will greatly reduce the risk of oil wells leaking to the Salado in the WIPP area.

2.5.2 Geologic Considerations and the Implications for Waterflooding near the Waste Isolation Pilot Plant - Presentation by Lori J. Dotson

There are three main points I'd like to make here.

1) The oil pools near WIPP are relatively small scale when compared to the Vacuum Field and the Rhodes Yates Field.

2) Large scale waterfloods are unlikely. It is not a foregone conclusion that all of the fields will be waterflooded or that any of the fields will be waterflooded.

3) Most importantly, there are a lot of geologic differences between the Rhodes-Yates Field, where the Hartman-Bates well was and WIPP. For one thing there is five thousand feet of vertical separation between the producing interval, at WIPP being the Brushy Canyon Formation of the Delaware Mountain Group and the WIPP repository. It is true that there is salt water disposal in the Bell Canyon Formation, but that is still a vertical separation of about 2,500 feet. In contrast, at the Rhodes-Yates field, you are only looking at a vertical separation of a few hundred feet between where Texaco was water injecting and Hartman encountered the blowout. The Vacuum Field is being produced from the San Andres and Grayburg Formations at approximately 4,500 feet. The Rhodes-Yates is being produced from the Yates and Seven Rivers Formation which is located about 3,000 feet below the ground surface. The producing interval of the Brushy Canyon is located about 3,000 feet below the Bell Canyon. The Castile Formation is present at the WIPP Site but is absent in the backreef at the Rhodes Yates Field.

As to the second point, about generally small pools and thin pay zones, at Livingston Ridge and Lost Tank, you heard Ron Broadhead talk about forty foot of net pay. That's where it is economic to produce oil. There are a lot of wells in the Livingston Ridge area where there is only ten to twenty feet perforated casing. So there are some pretty small pay zones. In contrast, at the Vacuum Field, one block that I looked at had three hundred feet of gross pay. So we're talking not an order of magnitude difference, but close to it. In the Los Medanos and Sand Dunes there are pay zones that range from less than twenty feet up to one hundred forty feet.

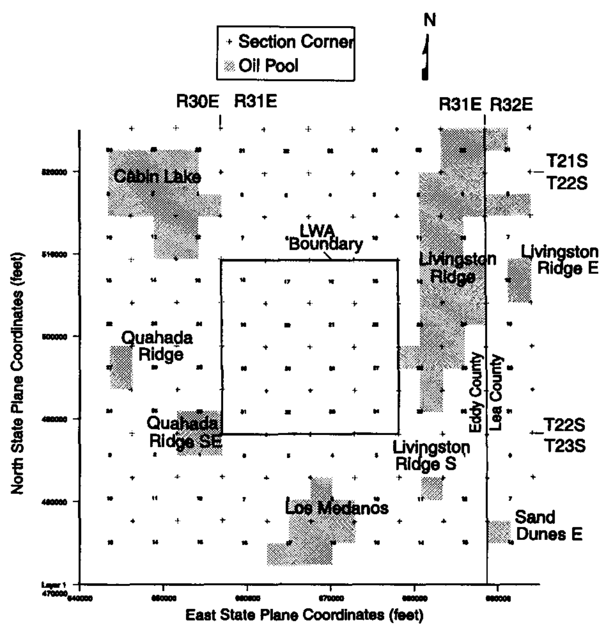

Figure 2.5.2-1. Producing oil field leases surrounding the WIPP.

Another point that Ron made that was really good, the primary production from area around WIPP from the Brushy Canyon is going to be less than ten years and for secondary production, less than ten years of secondary recovery. Production from these fields is going to play out in less than twenty years. Water injection, if water flooding took place, would be less than ten years. Just to give you a reference, the Vacuum Field for instance, over 300 million barrels of oil and 200 BCF of gas have been produced. I will have to get the exact figures from Ron, but we will have to leave that for the discussion. But we are looking at order of magnitudes difference between what is going on at the WIPP area and what we have at some of the larger fields.

This last point, the reservoir characteristics, the 7 to 24 millidarcies is actually a number for the Bell Canyon. The information for Brushy Canyon is actually pretty scarce and the characteristics of the Brushy are such that the permeability would actually be less. The Brushy Canyon is siltstone and sandstones, but also there is authigenic clays which tend to clog the pores and reduce the permeability somewhat. What this means is that water flooding could occur, but they may have to space the injection wells closer. But then you get into an economic question. There is a technical question and an economics question. It just may not be economical to drill additional wells. The reservoir is also characterized by highly irreducible water saturation and high residual oil saturation. That emphasizes my previous statement. Yes, you can waterflood these fields, you can waterflood those that have better characteristics, but it is an economics issue. If you have to drill additional wells, it may be too costly to get that oil out.

Cross-Section Depicting the Relative Locations of the Rhodes Yates Field and the WIPP Repository

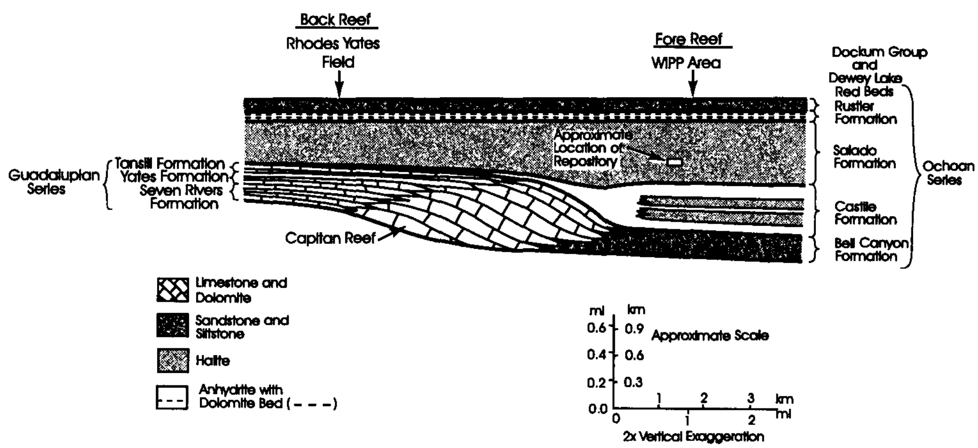

Figure 2.5.2-2. Cross-Section of Rhodes Yates Field and WIPP.

I really wanted to focus on the difference in the vertical separation at WIPP versus Rhodes-Yates which this figure illustrates quite nicely.

At the Vacuum Field, the permeabilities are up to 400 millidarcies. There is an order of magnitude difference. At Vacuum, like I already said, the pay zones are much thicker.

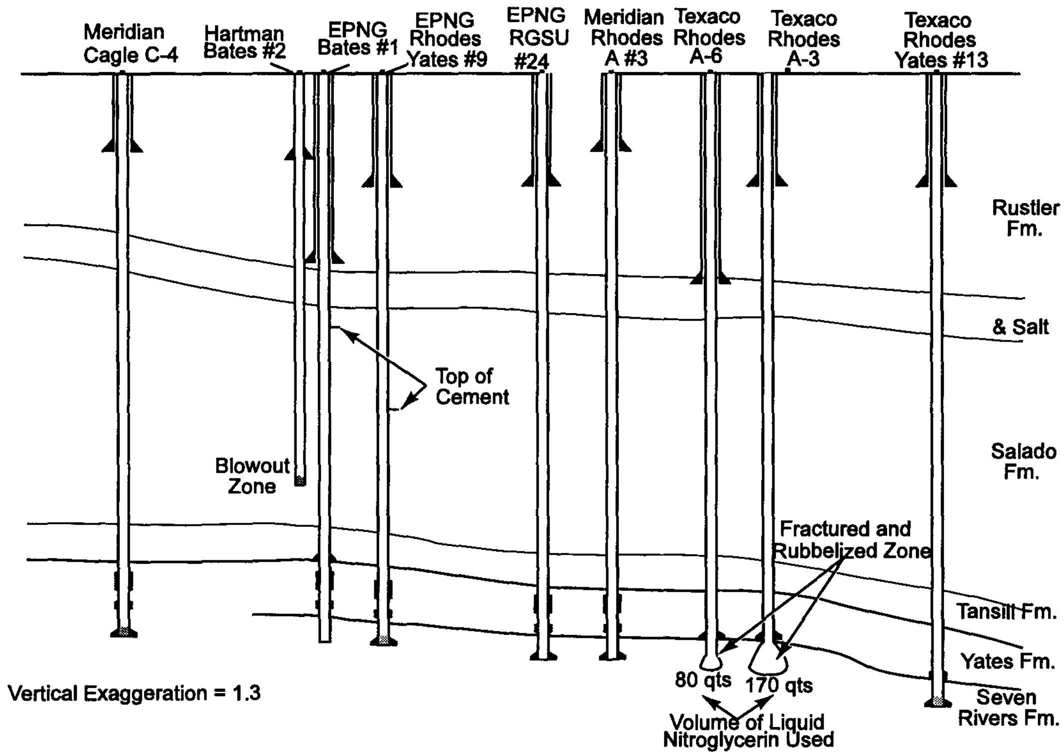

Figure 2.5.2-3. Schematic showing location of Hartman Blowout and Texaco Injection Zones.

This is a schematic showing where the Hartman well blew out and where you have water injection from the Texaco wells. Back in the "old days" a well was made more producible by pouring liquid nitroglycerin down the wells and basically just blow up the formation. So there are rubble and fractured zones. You don't know where your fluid is going at all. Like Dennis Powers stated, I also do not wish to comment on the legal issues of the Hartman-Texaco case. There were clearly practices that occurred back then that are not practiced now. Some of the casing, cementing, and developmental practices will be covered by Dan Stoelzel in his presentation. Between the Hartman blowout zone and the Texaco injection zone, there is hundreds of feet of vertical separation and also the suspect casing and cementing jobs. The figure shows where the surface casings are set. It is unclear from this figure what they are actually casing off. Some of these don't look like they extend down to the Culebra. There are really strange well constructions there.

Three main points:

1) Potential waterfloods near WIPP would be relatively small scale. I'm not saying that they would or would not waterflood, but it would be small scale if they occurred.

2) The fields will play out in less than twenty years. I think we are all in agreement on that.

3) The interval where they would inject water for a waterflood is 5000 feet beneath the WIPP repository. So you have quite a distance it would have to travel vertically to affect the repository.

2.5.2.1 Questions:

Wendell Weart: When were the injection wells completed - in what time frame?

Lori Dotson: This is something that Dan (Stoelzel) has more information on. In the Vacuum and Rhodes-Yates fields, for example, we are looking at the 30s and 40s and I think some of them in the 50s. But they are older wells, older construction. I hate to keep pushing everything off to Dan, but he has some really nice schematics that show the differences in well construction from the 30s and 40s to the present time. You are looking at wells that are over forty years old.

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2.5.3 Current Petroleum Practices and Their Application to WIPP Area Development - Presentation by Dan Stoelzel

With the older well completion techniques, especially in the Rhodes-Yates Field and Vacuum Field, there has been communication behind pipe caused by situations such as bad cement jobs. In these fields the injection wells were in communication with the overlying strata. In the Vacuum Field, for example, there was concern that some oil field injection wells would contaminate the Ogallala fresh water aquifer. The problems with the Rhodes-Yates waterflood were covered in previous presentations.

The possibility of water injection wells endangering the WIPP is highly unlikely. Neither a Rhodes-Yates nor a Vacuum field scenario will happen at WIPP because of the differences in geology, changes in oil well completion practices from the 1940's, and improved reservoir management. Current industry practices and controls that are in place reduce the risk of injection or disposal wells endangering the WIPP site. There have been changes in the petroleum practices from the 1930s and 1940s and 1950s, even up through the 1970s, versus today. New regulations, mainly statutory regulations, have come into effect. The presentation is divided into the major areas of drilling technology, production and completion technology, and reservoir management. The last 10 or 20 years have seen numerous advances in these areas.

2.5.3.1 Drilling Technology

Since the 1940s and 1950s, there have been considerable improvements in the cement that is used to cement the casing - higher bond strengths, better cement properties, and impermeable cements. Drilling mud technology has improved to limit pole washouts and lost circulation problems. This is especially true when drilling in familiar geology. Lost circulation control becomes a fairly exact science. This is important in the casing stage of a well. If there are lost circulation problems and washout problems, this could lead to communication or leaks behind pipe. Prudent operators know that any kind of leak behind a pipe is detrimental because it could lead to a loss of production, loss of reserves, and loss of revenue. Compared to drilling operations of the 1970's and early 1980's, drillers have a better understanding of operations such as block control and controlling kicks.

There have been numerous improvements in the last 10 to 20 years in corrosion control. Casing and tubing strings are inspected on the surface prior to running in the ground to eliminate potential leaks before running the casing. There are corrosion inhibitors that are routinely pumped into the tubing and casing to limit corrosion problems. Casing strings are routinely pressure checked. State regulations also mandate pressure testing of the casing. There is a lot of research and development in all these areas.

One point that hasn't been brought out yet is that most of the players in the Delaware Basin area, especially around WIPP, are small time operators. The smaller companies generally don't have the big research and development to support their oil and gas development. However, much research is transferred to the smaller companies through the service industry.

There have been significant advances in directional drilling and horizonal drilling in the last 30 years, but especially in the last 10 years. The costs for directional drilling have come way down. This is important for potential WIPP development because it is feasible to tap into much of the possible and probable reserves by directionally drilling from a surface location outside the land withdrawal area.

2.5.3.2 Completions

Once a well has been drilled and cased, substantial technology is used to develop the pay interval. There have been considerable improvements in perforating technology, tubing packers, gravel packing, well stimulation, fracturing, and acid stimulation. Open hole completions are rarely used in the industry and are definitely no longer used in the WIPP area. Generally, the production interval is cased and perforated. There have been advances in shape charge perforators, stimulation, and in hydraulic fracing technology, especially in the area of predictive modeling over the last ten years.

There have been substantial developments in fracture height control. Generally, oil companies do not want to hydraulically fracture out of their producing zones. To fracture out of zone could translate to loss of reserves. Operators definitely do not want to exceed fracture pressure in an injection well. The whole purpose for a waterflooding injector is to maintain pressure or inject into a producing horizon. If the operators are injecting out of zone, they are losing reserves.

Acid stimulation has come a long way. Acid stimulation is designed to specific rock types and fluid types.

2.5.3.3 Production

There have been numerous advances in wireline, coiled tubing workovers, and through tubing workovers that greatly reduce cost and could extend the economic lives of wells.

The preferred method of lift in the WIPP area is the sucker rod pump. However, there are alternatives such as gas lift, submersible pump, or plunger lift. Each of these have seen a lot of development in the last 10 to 20 years.

Routinely, coated tubulars are run, especially in injection wells because injection wells are recognized as a highly corrosive environment. Multiple completions are possible. By running dual completion strings, two or more zones can be simultaneously produced. Behind pipe reserves are typically recovered by successively plugging back as the operator comes up the hole.

Leaks are not good. If an operator is aware of a leak, he will generally take remedial action to fix that leak. The state is the regulatory agency that requires frequent pressure checking of tubing and casing. If a leak is detected, the operator must repair the leak.

2.5.3.4 Reservoir Management

One improvement in reservoir management includes the advent of affordable personal computers (PCs) and the availability of inexpensive software. During the last five years there have been significant advances in relatively inexpensive software to run on PCs. Whereas, the small company of the past didn't have the manpower or the money to afford this type of luxury item, now it's fairly routine. Various research firms and universities provide software support. Availability of the software has especially assisted the small time operators to optimize field development and field production.

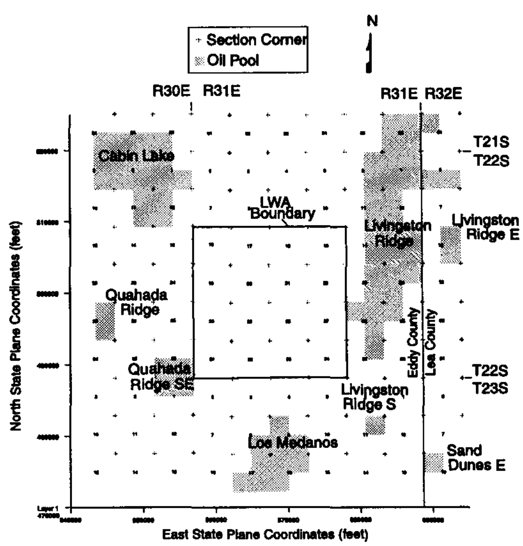

Figure 2.5.3-1. Producing petroleum leases adjacent to the WIPP Site.

The five spot water flood pattern is being used at Rhodes-Yates Field and at the Vacuum Field. However in the WIPP area it is highly unlikely that a five spot pattern would be used, especially with small pools. The decision to convert a well to water injection, in most cases will be more determined from the reservoir geology and geometry. For example, the Livingston Ridge Lost Tank Field is a channel sand. An in-line injection flooding pattern would be more likely. In this case, injectors would be located in the southern part of the field and drive oil updip to the producers to the north. For these small pools a five spot water flood pattern would be highly unlikely both economically and geologically.

Source water compatibility between the formation rock and the injected fluids is very important. This is relevant to the WIPP area because there has been some speculation that a future driller may decide to use, for example, Culebra fluid as source water for an injection project. This is highly unlikely. The oil bearing formations contain authigenic or interstitial clays. If less saline water was injected into such a formation, it would cause clay swelling and potential plugging of pore spaces. Injecting Culebra water would essentially ruin the well. At this time, none of the injection wells or disposal wells are using the Culebra for source water. And I expect that will be the same forever. Operators will typically find their source water from the same formation as their oil production.

In addition to source availability, economics is the big question. Can small operators afford the surface facilities and the additional costs to drill injection wells or convert producers into injectors? The small oil companies typically have fairly shallow pockets. A water flood requires substantial capital. The return on the investment will be several years down the road in the producing life of the field. Most small companies wouldn't be able to weather that economic return.

The amount of water being pumped into a pool is a direct function of your recoverable reserves. In the WIPP area, the oil is found in small pools. The operators are not going to be injecting large volumes of water, especially in view of the 10-20 year life that most of these pools will last through secondary recovery. In an injection project, operators will stay below the fracture pressure of a formation. Operators don't want to fracture out of zone and pump water into an unknown formation where it is not beneficial to their productive horizon.

2.5.3.5 Wells in the Vicinity of WIPP

The James E #12 well is operated by Phillips and produces from the Cabin Lake Pool. In 1988, the State of New Mexico published regulations on completing oil and gas wells in the potash area, which includes the WIPP area. There was concern about natural gas potentially leaking into potash mines. In the Vacuum Field, the State had seen communication potentially into both the Salado and the Ogallala. The state now requires all the oil and gas operators in the potash area to include a salt isolation casing string in their well design. The surface casing typically runs through the upper stratigraphic units such as the Dewey Lake Redbeds and the Culebra. The intermediate casing, which is required by the state, is cased off below the salt formations, the Salado and the Castile. The state also requires that production casing run to the surface.

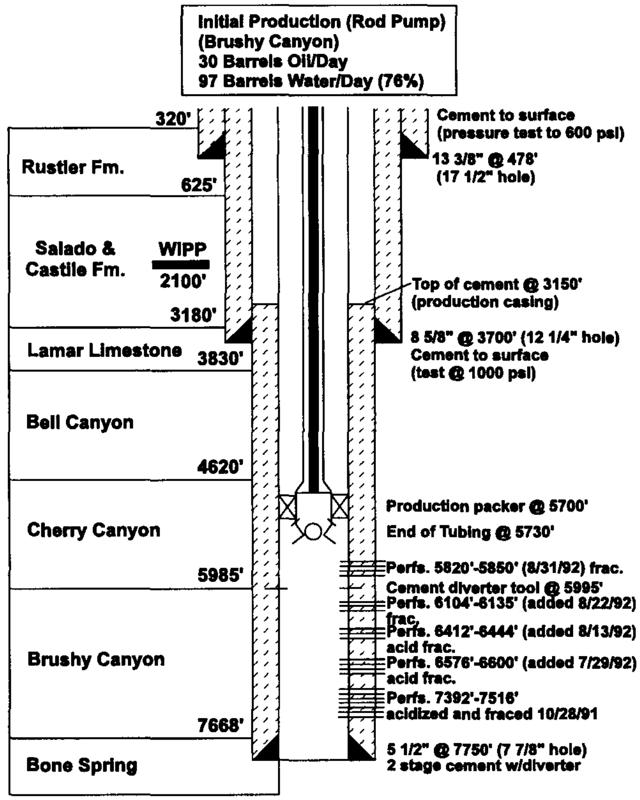

Figure 2.5.3-2. Typical Cabin Lake Pool Completion (James E#12).

The James Ranch Unit #19 well is operated by Enron and produces from the Quahada Ridge Delaware pool. The top of the cement surrounding the 5 1/2 inch production casing is at 2,680 feet. The bottom of the 8 5/8" salt isolation casing is at 3,850 feet. There is about 1,200 feet of cement as well as two sets of casing strings to help isolate the salt. The James Ranch Unit #19 is one of the better producing wells. The initial oil production rate was 213 barrels per day. The initial water production rate was 240 barrels of water per day. Initial production was over 50% water. We also see high water production from the Livingston Ridge. Seventy-six percent of the fluid production was water. These fields have a high water content and produce large volumes of the moveable water.

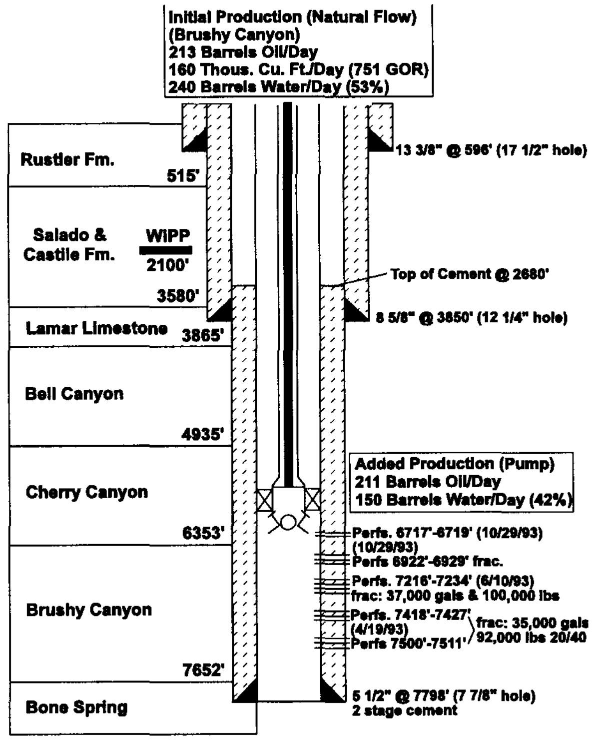

Figure 2.5.3-3. Typical Quahada Ridge Delaware Pool. James Ranch Unit #19.

A typical Livingston Ridge completion and a Morrow gas producer completion are shown. Each schematic shows a salt isolation string. For illustration purposes the WIPP horizon is also shown. The vertical separation between their production perforations and the WIPP horizon is on the order of 5,000 feet or more, which is much greater than that of the Vacuum Field and the Rhodes-Yates Field.

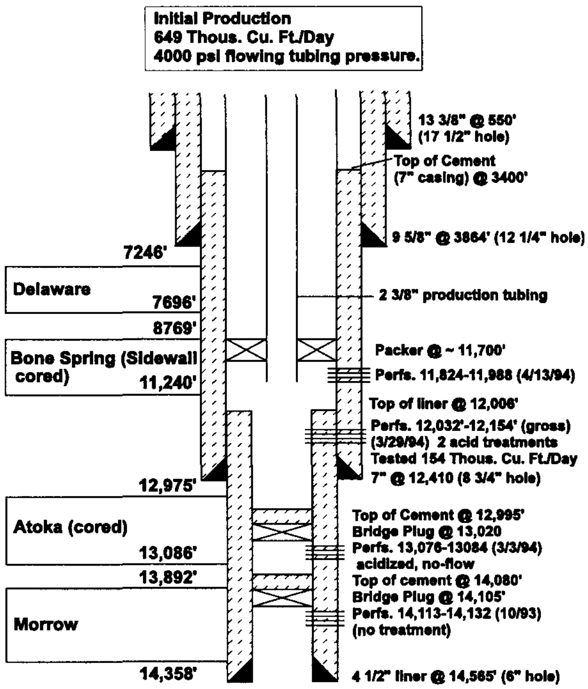

Figure 2.5.3-4. Typical Los Medaños Morrow Pool Apache 25 Federal #2.

The Morrow schematic illustrates the success of the plugback technique used by most operators. Probably the only reason this well is economical is because it has multiple pays. This well was originally perforated in the Morrow gas. It came in at a very high rate for this area, over 600,000 cubic feet a day. It was originally completed in the Morrow Formation in October 1993. By March 1994 this interval had been plugged back and the well completed in the Atoka Formation. In less than a year, this Morrow pay had depleted. The lower Atoka was tested but didn't have sufficient flow rate. The lower Atoka was plugged back and the well was completed in the upper Atoka.

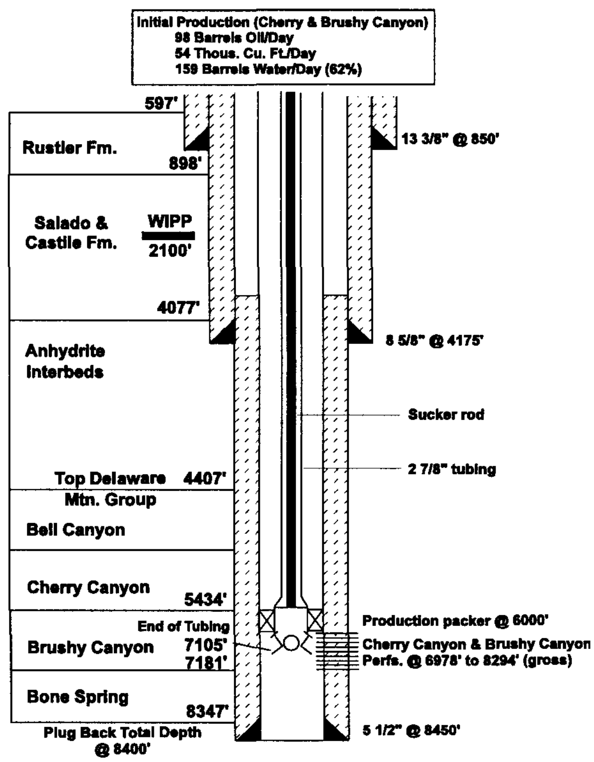

Figure 2.5.3-5. Typical Livingston Ridge/Lost Tank Completion.

The well is apparently producing from the upper Atoka, although this formation may also be plugged back. The information comes from the New Mexico Oil Conservation Division in Santa Fe. There is a six month to one year time delay on the Sundry Reports, so the information on these wells may be outdated.

2.5.3.6 Early Well Completion Practices

For comparative purposes, the schematics of the Vacuum Field and Rhodes-Yates Field completion are shown here. I didn't have direct well data for these wells. In the case of the Vacuum Field, the discovery well was drilled in 1929 with a cable tool rig. It wasn't developed until the late 1930s and early 1940s. Common practice, during that time, especially in carbonate formations where there is low flow due to tightness, the operator would nitro-frac the completed well. This is a general schematic of their discovery well. It was nitro-frac with 580 quarts of nitroglycerin. I'm not an explosive expert, but I would think that 580 quarts could do considerable damage not only to the formation but to everything else down there.

In the 1930s and 1940s the oil and gas industry was in its infancy. Safety issues, reservoir management issues, and formation damage issues were pretty much nonexistent. Since then, there have been substantial improvements. Similar to the Vacuum Field, the Rhodes-Yates fields were also nitro-fraced. An important thing to note about the typical Rhodes-Yates early completion is the small amount of separation from their open hole productive horizon from here to the Salado, approximately 100 to 200 feet. Furthermore, the wells were nitro-fraced.

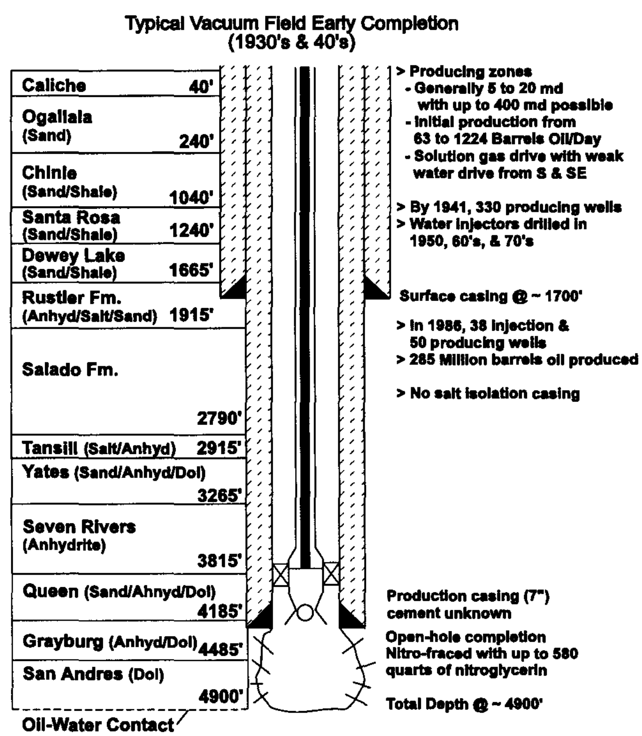

Figure 2.5.3-6. Typical Vacuum Field Completion for 1930s and 1940s.

Originally these early wells were drilled as producers in the 1940s, 1950s, and 1960s. As many of these production wells watered-out, they were reconverted to injection wells. They just pulled sucker rod pumps out and maybe changed out the tubing string. They didn't take any remedial action as far as casing this open hole interval or cement squeezing behind the body to isolate. They just turned it right around and started injecting into this thing. So it is no wonder that there is considerable potential for injection fluid to go anywhere other than where they want it to go. It is going to the path of least resistance.

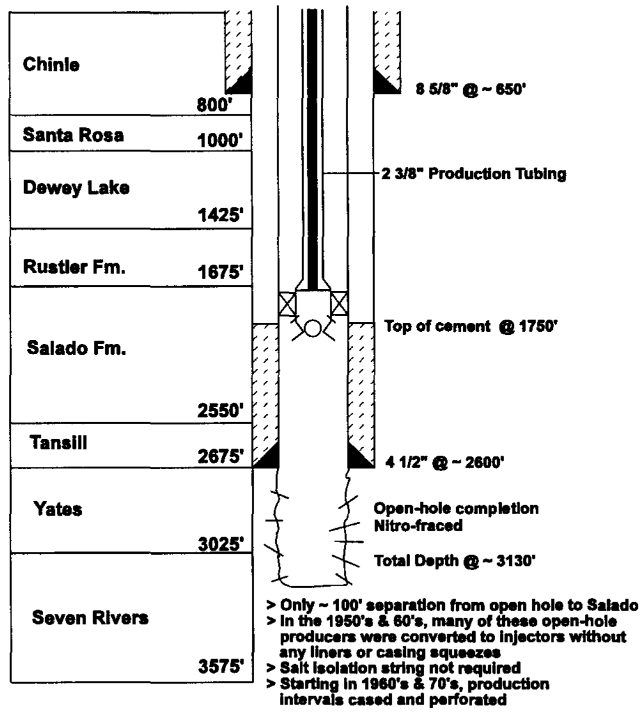

Figure 2.5.3-7. Typical Rhodes Yates-Seven Rivers early completion, 1940s-1950s.

The state rule on the salt isolation casing didn't come into effect until the late 1980s. Both these fields, the Vacuum Field and the Rhodes Yates Field, did not have salt isolation casing. As shown, the Salado is just behind one casing string. Early cementing and completion practices were such that, who knows where the cement went when they pumped it. A lot has improved since the days of these wells.

An older well, Todd 26 Federal #3, is shown. Todd 26 Federal #3 is the suspect well, about one and a half to two miles offset from the H9 WIPP test pad. It was here that Rick Beauheim observed the water table fluctuations. The rises in the Culebra due to potential leaking was attributed to this well. After looking at this schematic, I tend to agree with that. This well was completed in 1971. Originally it was drilled as a Cherry Canyon test well that was probably nonproductive. The well was converted to a disposal well. There was no salt isolation casing and it was an open hole completion somewhat similar to the Rhodes/Yates Field or Vacuum Field situation. This well was a disposal well for about 20 years. It is now plugged and abandoned. I am not sure when that was. I am trying to find out from the New Mexico Oil Conservation Division (NMOCD). There are very few records on this well. However, it is no longer disposing salt water.

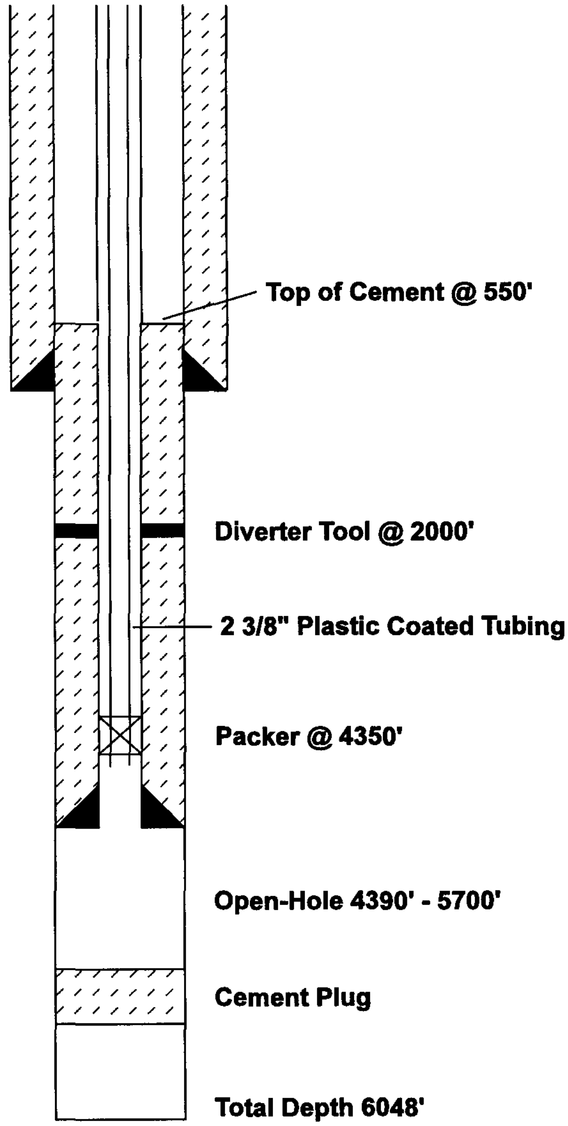

Figure 2.5.3-8. Texas American Oil Corporation Todd 26 Federal No. 3 Water Disposal Well.

A current salt water disposal design planned for the Livingston Ridge Field is shown. The plan shows the salt isolation casing. The production casing is run through the interval and perforated. The well was originally a strong producer. It is not uncommon to convert watered-out or nonproductive production wells to disposal or injection wells, which is the case for this well. The Sundry intent was filed on September 24, 1992. Surface injection pressure for this well is limited to 750 psi which is below fracture pressure. New state regulations require that operators stay below fracture pressures, either below 0.2 psi per foot above the hydrostatic gradient or below the fracture pressure as determined from injectivity tests.

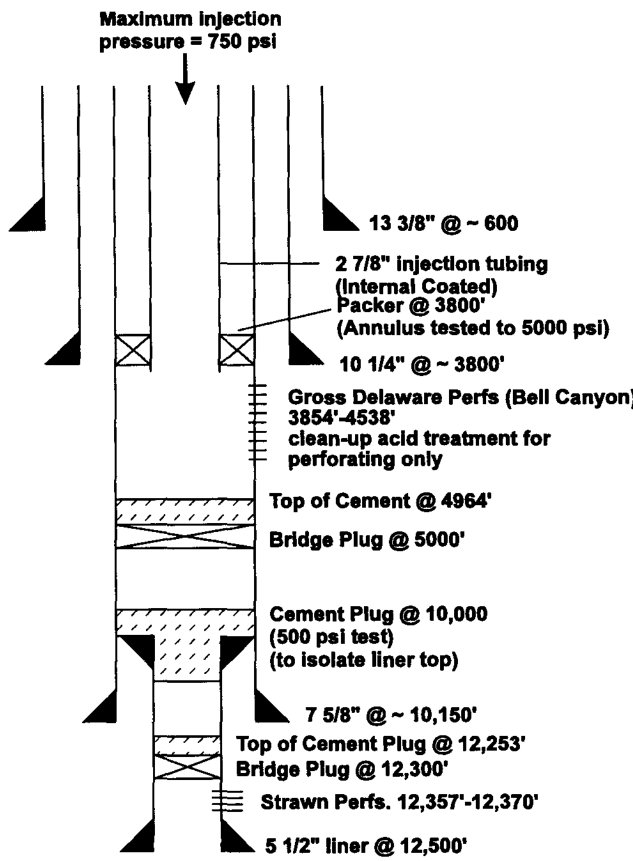

Figure 2.5.3-9. Current Salt Water Disposal Well Livingston Ridge Federal #9. Intent filed September 24, 1992.

2.5.3.7 Questions:

Robert Neill: Dan, you give a very compelling case for some of the current drilling practices and plugging practices. It is a great improvement over what has been done in the past. On the EPA standards, one is talking about what will be the behavior for human intrusion over long time periods. How comfortable do you feel with commitments requiring operators to keep injection pressures less than fracturing pressures and then going to EPA and arguing that this will continue to be true in the long term future.

Dan Stoelzel: I think it highly likely. Like anything the oil business does, it is driven by economics. Nobody can predict the price of oil in the future which is the governing driver for anything an oil operator does. These regulations are put into effect because of the experiences of the oil companies — the isolation string and the requirement not to exceed fracture pressure. That is not only a regulation but like I said, a common practice with the operators because it is not a good thing to exceed fracture pressure in injection wells. I think it is highly likely that if anything, more constraints and regulations will come into effect or if nothing else, it will remain the same. The industries evolved to this point and because of this we are getting a lot more reserves out of the ground than we did back in the 40s and 50s. You know it is a learning process and I think the oil industry is reaching the top of that curve. They have come a long way.

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2.6 Potential Effects of Oil and Gas Activities on the Salado and Overlying Formations

Matthew Silva

2.6.1 Synopsis

The EPA assurance requirements for the disposal of transuranic waste include the requirement that the site should avoid places where there has been mining for resources, where there is a reasonable expectation of exploration for scarce or easily accessible resources, and where there is a significant concentration of any material that is not widely available from other sources. The WIPP is sited in an area with a 64-year history of commercial mining in a potash enclave which represents 57% of the nation's potash reserves and 80% of the nation's domestic production. Further, there are substantial reserves of oil and gas in the vicinity of the repository.

It has long been recognized that oil fields in southeast New Mexico, overlain by the Salado Formation, have problems with waterfloods. For waterflood projects in Lea County, Ramey (1976) noted that water injected at around 3,600 feet was escaping from the injection interval, migrating upward to the base of the salt section and then moving horizontally through this section. Waterflows of 5,000 to 6,000 barrels per day and a recorded surface pressure of 1,600 pounds on wells outside waterflood areas were not uncommon. Later studies (Bailey 1990) found that in the Vacuum Field, water was indeed flowing along distinct horizons within the Salado. Chemical and isotopic analyses confirmed that the brines were not natural to the Salado. Casing leaks were thought to be the most logical pathway into the Salado. Casing leaks and cement degradation are not uncommon in the highly saline environment (LaVenue 1991).

In the vicinity of WIPP, there are oil and gas resources. Much of the drilling for oil and gas has been delayed by the presence of potash. Nonetheless, there has been drilling for oil and gas in areas known to contain less than economic quantities of potash. There is no question that waterflooding in the immediate vicinity of WIPP needs to be anticipated. First, the oil reservoirs in the area produce by solution gas drive (Broadhead and Speer 1993). Reservoirs which produce by solution gas drive are usually good candidates for waterflooding (Willhite 1986). Second, there is a waterflood underway in the Cabin Lake Field at the northwest corner of the WIPP Site. A nearby oil well, James A No. 2, has shown a good response with oil production increasing from less that 2,000 barrels per month to more than 4,000 barrels per month for that particular well. Third, there are eight waterfloods underway in the New Mexico portion of the Delaware Basin (Broadhead et al. 1995) and there is a history of waterflooding and enhanced oil recovery in the Texas portion of the Delaware Basin.

2.6.2 Presentation by Matthew Silva

The assurance requirements in the EPA Standards for the disposal of transuranic waste state that one should avoid areas with natural resources. The WIPP is not independent of the potash industry and the oil and gas industry, their schedules for resource recovery, and the problems associated with these industries. In the oil fields overlain by the Salado Formation, where we have experience with waterflooding, there is evidence of water escaping from the injection areas and migrating through the Salado. The Delaware Mountain Group, in the vicinity of the WIPP, is a strong candidate for future waterflooding.

The EPA standards for the disposal of transuranic wastes have assurance requirements. These assurance requirements are intended to accommodate the inherent uncertainty in calculating repository performance over the next 10,000 years. With respect to natural resources, the assurance requirements state that a site should avoid places where there has been mining for resources, where there is a reasonable expectation of exploration for scarce or easily accessible resources, where there is a significant concentration of any material that is not widely available from other sources.

The Known Potash Lease Area, as shown in Figure 2.6-1, is contained in an area roughly 30 miles by 30 miles. The 4 mile by 4 mile WIPP is located within the potash enclave. The first mining and second mining areas are shown. Potash has been commercially mined for 64 years - an area with a long history of mining. Potash in this area represents 57% of the nation's reserves and has consistently represented over 80% of the nation's domestic potash production - a relatively scarce resource. Oil and gas reserves are also found in this area - an easily accessible resource.

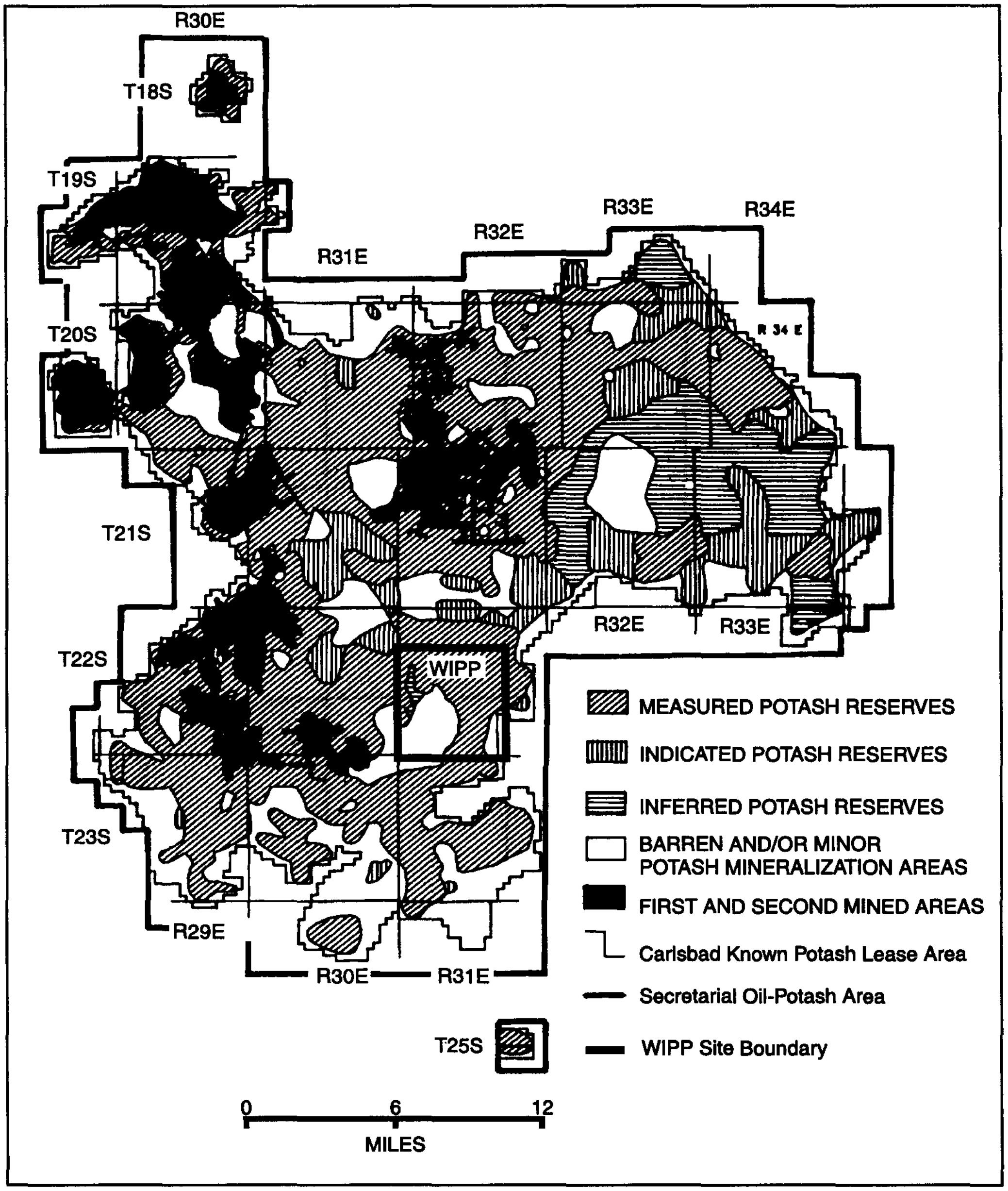

Figure 2.6-1. Potash resources (adapted from Olsen 1993).

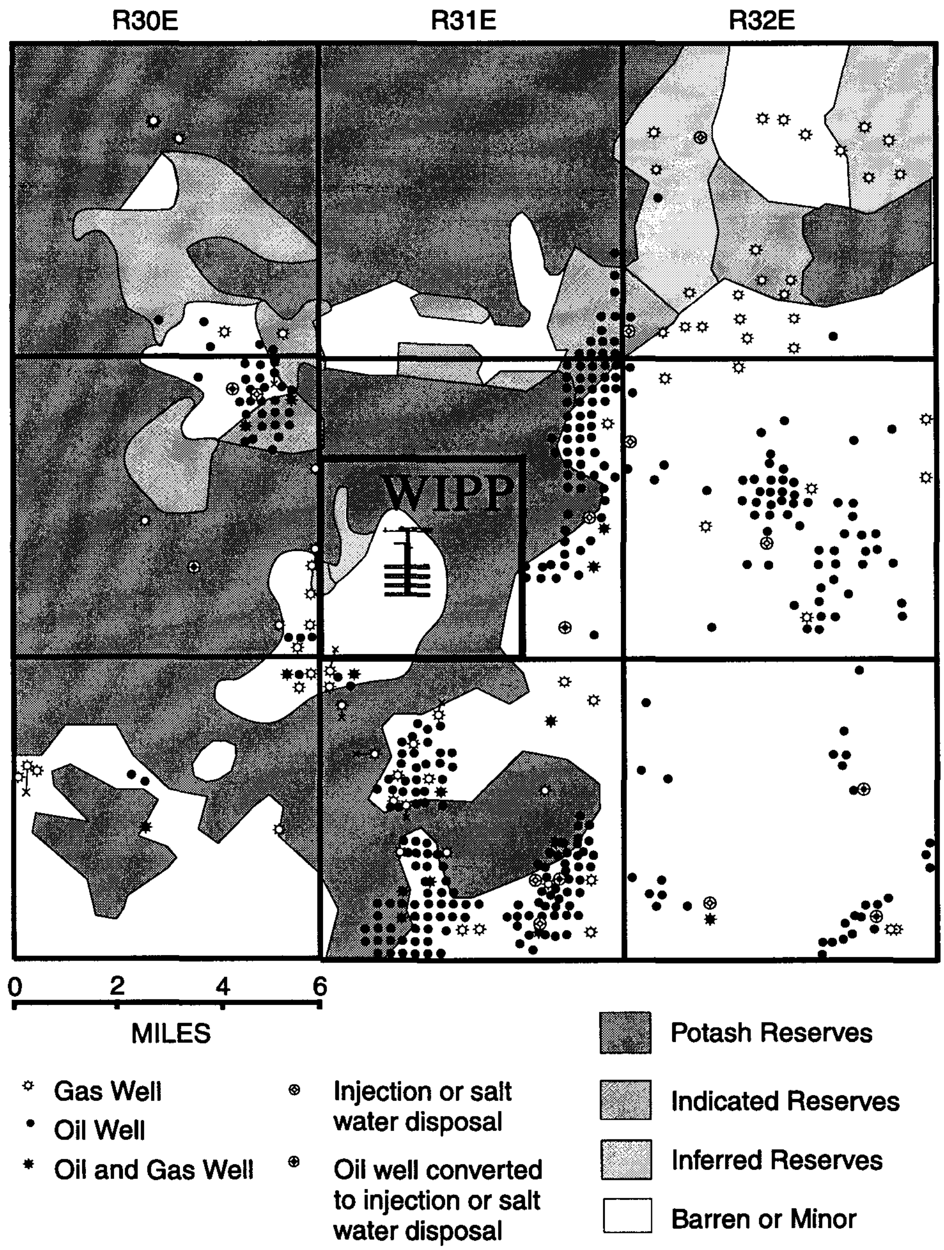

Figure 2.6-2. Oil and gas wells restricted from drilling through potash resources.

For the nine township area surrounding the WIPP, it is important to note that the current areal extent of the oil fields is constrained by the boundary of potash reserves and not the geographic limits of oil and gas.

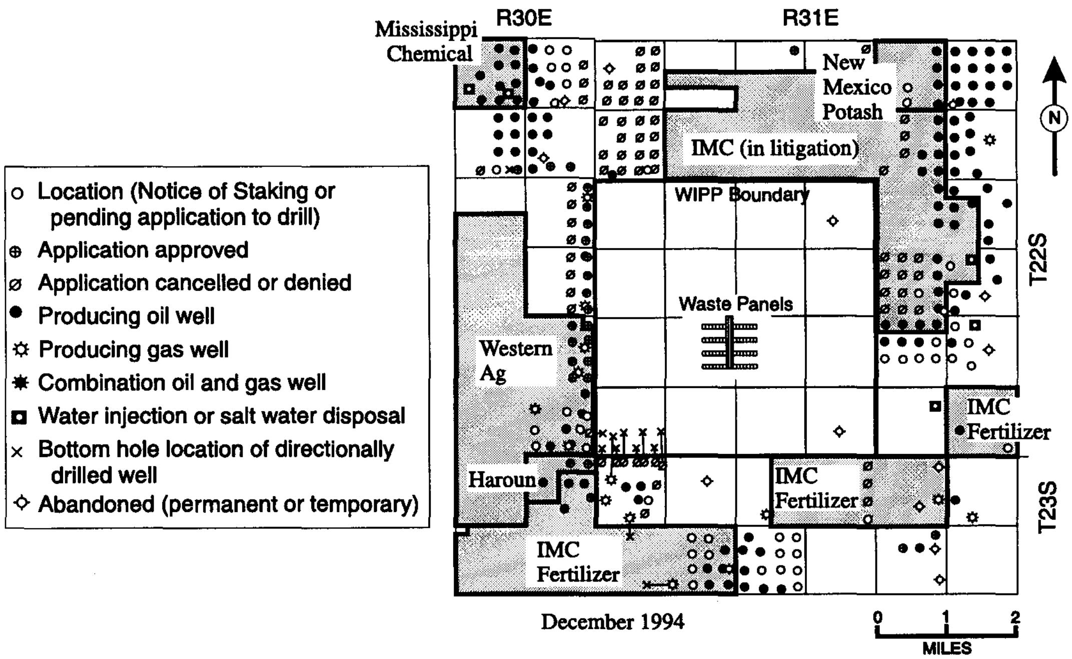

Figure 2.6-3. Resource activity and interest in the immediate vicinity of WIPP.

Will there be any more drilling near the WIPP boundary or is it restricted by the presence of potash reserves? Producing oil and gas wells and applications for permit to drill (APDs) within 2 miles of WIPP are shown in Figure 2.6-3. Applications include those that are pending, that have been cancelled, or that have been approved. Also shown are the active potash leases in the area. Oil and gas resource activities are restricted by the presence of potash. Further, it could be decades before drilling for oil and gas is allowed. Again, the limited number of existing oil and gas wells does not reflect the size of the oil fields, rather it reflects the presence of potash in an active potash leasing area.

Towards the southwest corner of the WIPP Site, the BLM has recently denied applications to slant drill eight wells to be completed within the WIPP Land Withdrawal Area. These applications have been denied for a couple of reasons, including the concerns about the injection of water.

A 1994 map from Midland Map Company indicates that Todd Federal #3 has been plugged and abandoned. Also Rick Beauheim showed evidence this morning of rising water levels in H-9 up until 1993. The water levels started to decline and are now rising again. Somewhere about that time this well was apparently shut in.

The oil wells producing from the Delaware Mountain Group are very large water producers. That reflects interstitial water, not a large edge water drive. There are a number of salt water disposal wells throughout the area already in operation. The David Ross AIT Federal #1 is an oil well that was converted to a salt water disposal well. It's within a mile of the WIPP site boundary. It injects from 40,000 barrels to 120,000 barrels a month as salt water disposal. Other than state regulations, there are no extra requirements on this particular well.

To the west of the WIPP there is an injection well in the potash area less than a mile from the mining operation of Western Ag. In 1994, when Western Ag learned that this particular well was being proposed as a salt water disposal well for Bass Enterprises, Western Ag proposed 12 stipulations. The stipulations included an annual analysis of the chemical composition of the water and the hydrocarbons and of any hydrosulfide that was being injected into that well. The stipulations also specified maximum injection pressures. Further, Western Ag wished to be notified immediately of any problems with tubing failure. While the David Ross AIT Federal #1 is within a mile of the WIPP site, there are no special provisions for this well. Yet for the well within a mile of potash operations, Western Ag was concerned with water being injected out of zone.

New Mexico has extensive experience with waterfloods in areas overlain by the Salado Formation. Serious problems have been documented for the past 20 years. In 1976, Joe Ramey, as the Director of the New Mexico Oil Conservation Division, identified the problem of "numerous salt water flows in and around waterfloods in Lea County." Basically the water was escaping out of the injection zone, up into the Salado Formation and then moving through the salt section, collapsing oil field well casings. Five thousand to six thousand barrels of water a day at 1,600 pounds per square inch pressure at the surface were not uncommon.

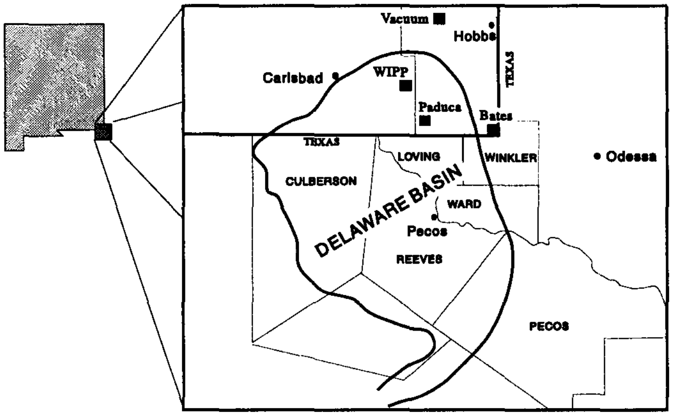

Figure 2.6-4. Delaware Basin.

In 1990, Jamie Bailey, a certified professional geologist and petroleum engineer for the New Mexico State Land Office, sent a memo to Marsh LaVenue on the observed water level rises in the Culebra aquifer during the 1988-1989 time frame. That memo cited the problems in the Vacuum Field waterfloods and the reports prepared by a committee of participating oil companies. The memo noted that waterflows occurred along 48 distinct horizons or interbeds within the Salado. Chemical and isotopic analysis confirmed that the brines were not natural to the Salado and these were injected brines. The memo concluded that failed casing was the most logical pathway into the Salado and observed that there were similar problems in other waterflood areas including the Eunice and Monument areas. Bailey identified a salt water disposal well, the Todd 26 Federal #3, as the most likely source of water to the Culebra aquifer based on the injection pressure history, the age of the particular well, and the location of the well.

There is more recent evidence of problems with waterflooding in New Mexico. The operator of the Bates Lease, Hartman, successfully demonstrated in court that water from the Rhodes/Yates Lease was being injected at high pressures and was migrating more than two miles to his lease. The Bates #1 was drilled in 1953. It was operated until 1988, at which time it was shut in. When it was drilled in 1953, there were no observed waterflows. The Bates #2 was drilled about one hundred feet to the east in January 1991. It experienced a very large salt water blowout. Two-hundred-ninety-eight truckloads of water had to be hauled away and a pipeline was constructed to the water injection unit at the Leonard Field.

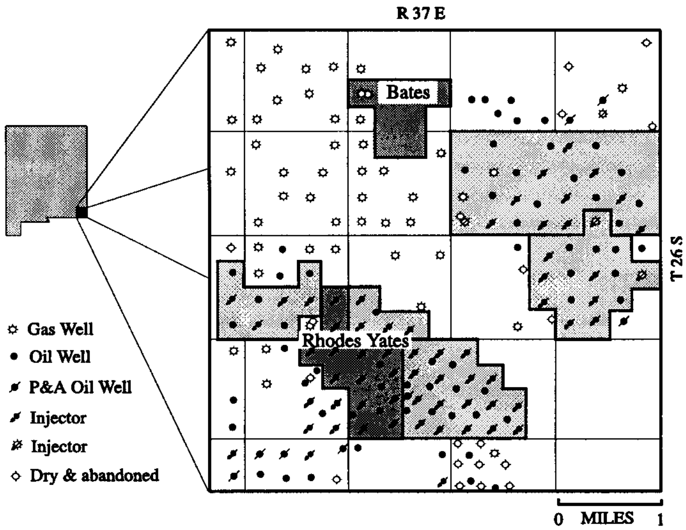

Figure 2.6-5. Bates Lease (Hartman), Rhodes Yates Waterflood (Texaco) and other nearby leases with injection wells.

Hartman argued that the Rhodes/Yates lease was the only water flood with an injection pressure gradient high enough to see the type of water pressure that was seen at the Bates Lease blowout. Hartman also argued that the waters were being injected higher than the rock fracture pressure of the interbeds of the Salado formation.

Are these wells in the area near WIPP waterflood candidates? The major Delaware Mountain Groups produce by solution gas drive (Broadhead and Speer 1993, 299). Solution-gas-drive reservoirs usually are good candidates for waterflooding (Willhite 1986, 3).

Adjacent to the WIPP Site Boundary, the No. 2 James A well responded favorably to waterflooding. This well is operated by Phillips, a major oil company, not a small operator. Initially, this well produced 4,000 barrels per month. As shown, production declined to

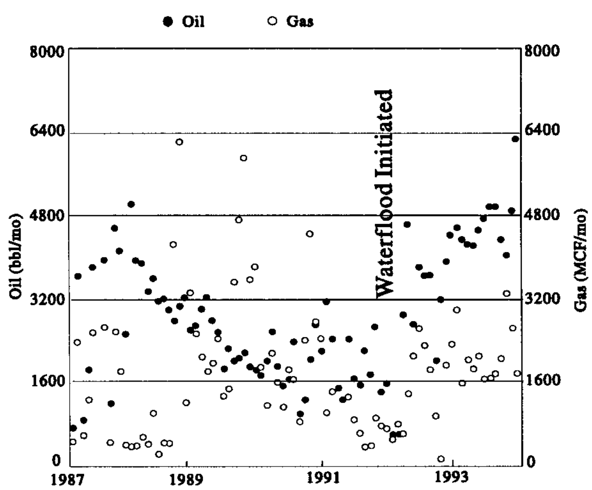

Figure 2.6-6. Response of No. 2 James A to waterflood.

less that 2,000 per month. The pressure maintenance waterflood was initiated with the conversion of one nearby well to waterflooding and later a second injection well. There was an immediate response, even to the one injector well. The oil production rate for the James #2A again exceeded 4,000 barrels per month.

Further, as noted by Broadhead, there are examples of successful waterfloods in the Delaware Basin. For example, the Paduca field which produces from the Delaware Mountain Group responded well to waterflooding as shown. A waterflood was initiated in 1968. Thus far primary production accounts for 8.6 million barrels cumulative production and waterflooding has produced an additional 5.2 million barrels. It is also worth noting that this Delaware Basin field has been in production for over 30 years and is still in production.

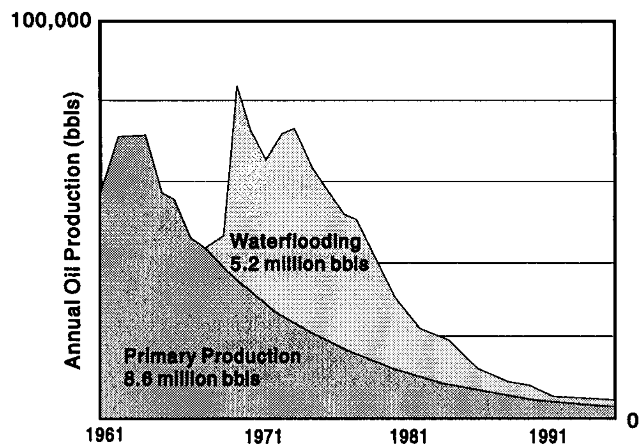

Figure 2.6-7. Paduca Oil Field Production.

2.6.2.1 Conclusions

The WIPP is sited in a mineral rich area and will be subject to the practices of the oil and gas industry and the potash industry. Drilling for oil and gas has been delayed primarily by the remaining presence of potash reserves. There is a history of waterflooding to improve oil recovery from producing fields throughout the Delaware Basin. There is also experience with water migrating out of the injection zone and into adjacent properties in the oil fields of southeast New Mexico. Near WIPP, there are a few new injection wells for the purposes of salt water disposal and waterflooding.

2.6.2.2 Questions:

Dan Stoelzel: Did you find any records of blowouts or casing collapse problems in offset producers. Did you see any of these type of incidences in your research?

Matthew Silva: I did not look in detail at the wells down there.

Dan Stoelzel: That is one thing I planned on doing. I just ran out of time. That would be an indicator that these disposal wells are indeed causing problems, you see it in offset wells both in the drilling phase and later in the production phase.

Matthew Silva: Certainly, part of the problem facing the project is that if you want to look at all of those, you have to look at each well on a case by case basis. It is a massive effort to try to understand that.

Wendell Weart: Something that is not directly related here, but I am curious that we now have such a proliferation of holes around the site which we did not have back around the late 70s and early 80s. Is there any information from those about encounters with brine reservoirs in the Castile?

Matthew Silva: Yes, we do have some information. About 2 years ago I did request from the various oil companies information on their water flows all which were in the Castile Formation around the WIPP site. About one third did respond with detailed records and another third did not respond at all. Some declined to provide that information.

Dan Stoelzel: Are you going to come forth with that information at some point?

Matthew Silva: As soon as I have time to put it together, I will.

Robert Neill: We will certainly share the information for the one third that did respond.[1]

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[1]That information was sent to Peter Swift on March 20, 1996.

2.7 Geological Features Across the Oil Fields of Southeast New Mexico and West Texas

Lokesh Chaturvedi

2.7.1 Synopsis

The Waste Isolation Pilot Plant (WIPP) is located in the northern part of the Delaware Basin. The Vacuum Field and the Bates Lease/Rhodes-Yates water flooding areas are situated in the shelf (backreef) areas, about 40 km northeast and 65 km southeast of WIPP respectively. Sratigraphically, the backreef equivalent of the oil producing upper Guadalupian Delaware Mountain Group Formations of Cherry Canyon and Bell Canyon, are the Artesia Group Formations of Grayburg, Queen, Seven Rivers, Yates and Tansill. San Andres limestone of the shelf is the stratigraphic equivalent of the lower Cherry Canyon Formation of the Delaware Basin. The Castile Formation is confined to the Delaware Basin only, but the Salado Formation extends more than 160 km beyond the margin of the Basin to the north and east into west Texas. In the southeast corner of New Mexico in the area of Rhodes-Yates waterflooding, the Salado Formation lies unconformably over the Artesia Group. Thus, a well penetrating through the Salado at the WIPP site would go through the Castile anhydrite and halite beds before entering the Bell Canyon Formation of the Delaware Mountain Group. At the Bates lease area, on the other hand, such a well enters the Tansill and the Yates Formations directly below the Salado. The vertical distance from the oil producing zones in the Cherry Canyon Formation surrounding the WIPP to the WIPP repository is approximately 1,200 to 1,800 m. In the backreef area, the distance between the Yates producing zones and the lower Salado is less, approximately 500 m. However, the Salado interbeds extend through the entire Salado from the Basin to the backreef and once pressurized fluids are injected into them, the Salado interbeds are expected to behave essentially the same way.

2.7.2 Presentation by Lokesh Chaturvedi

The point that Lori Dotson was making is that there is a difference in geology between the situation at the Bates lease and the situation at the WIPP Site. As stated in my synopsis, that difference is mainly in vertical distance. At the WIPP Site, it is the vertical distance between the Lower Salado and the Cherry Canyon or Brushy Canyon oil reservoirs. At the Bates lease it is the vertical distance between the gas producing Yates Formation and the level in the Salado of the salt water blowout in the Bates lease #2 borehole.

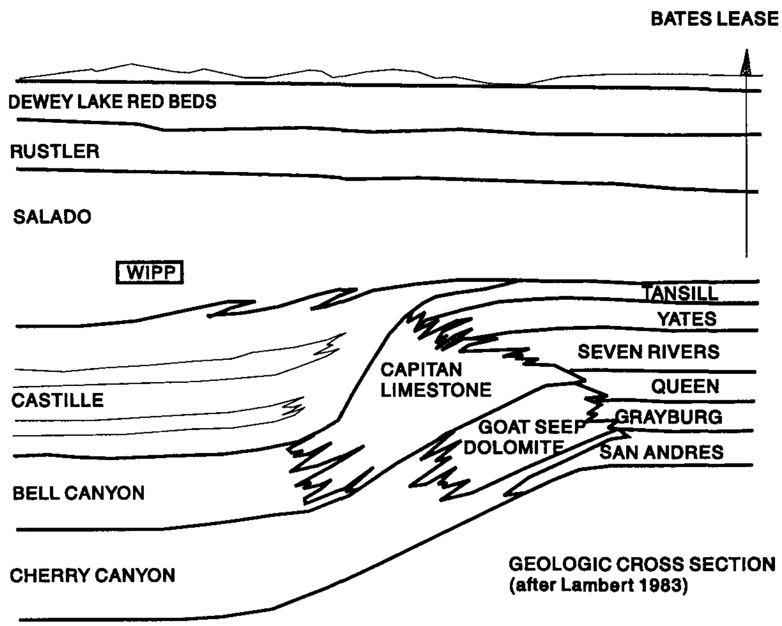

Figure 2.7-1. Geologic cross section at WIPP and Bates Lease (After Lambert 1983).

However, the main point of interest is that the Salado Formation is the formation that remains essentially the same across the reef. The thickness of the Salado decreases somewhat across the reef, but despite the forty mile distance between the WIPP and the Bates lease, the essential characteristics of the Salado, that of the presence of interbeds, remains the same. If the pressures are sufficient and the conditions are appropriate for water to leak out of the casing, water will be injected into an interbed in the Salado or possibly into the water bearing zones such as the Culebra and Magenta of the Rustler Formation.

There may be a vertical distance but if the pressures are sufficient to cause injection of water into the Salado or Culebra, then it seems to me, that what happened at the Bates lease is quite likely to happen at the WIPP Site. The distance between the Texaco wells and the Bates lease #2 well was about two miles. If we accept, as Dennis Powers described, that there were no likely natural sources of such huge quantities of salt water, then most likely the source of water was the waterflooded area in the Texaco lease. If that is what we believe to be the case, then we know that such an effect can be felt more than two miles away. We know it can be felt two miles away. We don't know if it can be felt more than two miles away. Since the oil wells around the WIPP Site are about two miles away from the repository, regardless of the vertical distance from the Salado to the oil producing zones, I do not see a difference in the essential characteristics of the situation, which is the presence of the Salado Formation and its interbeds.

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2.8 Perspectives from WIPP Performance Assessment

Peter Swift and Rip Anderson
Sandia National Laboratories

2.8.1 Synopsis

Two main EPA regulations address the long-term (10,000-year) performance of the WIPP: 40 CFR 191 sets standards for releases of radioactivity from the disposal system; and 40 CFR 268.6 applies to long-term releases of hazardous constituents (e.g., volatile organic compounds and heavy metals) regulated under RCRA. 40 CFR 191 provides a regulatory definition of performance assessment (PA) that applies to the WIPP. It is "an analysis that: (1) Identifies the processes and events that might affect the disposal system; (2) examines the effects of these processes and events on the performance of the disposal system; and (3) estimates the cumulative releases of radionuclides, considering the associated uncertainties caused by all significant processes and events." (40 CFR 191.12).

WIPP PA uses computational models to estimate cumulative radionuclide releases for selected scenarios. These scenarios are developed using a methodology which begins with establishing a comprehensive list of features, events, and processes (FEPs) which may affect the disposal system. These FEPs are then screened using four basic criteria: relevance, regulatory requirements, probability of occurrence, and consequence. Scenarios for system level modeling are constructed from those FEPs that remain following screening. To date, screening arguments are documented for approximately 800 of the 900 FEPs initially identified. Screening arguments remain to be developed or documented for many FEPs, including some related to oil and gas activities.

2.8.2 Presentation by Peter Swift

This is a brief overview of performance assessment methodology, more specifically, the development of scenarios for performance assessment. In an effort to address regulatory requirements, performance assessment calculates the long term performance of the repository for the next ten thousand years. There are two regulations of primary interest.

40 CFR Part 191 regulates the release of radioactivity from the site. It was promulgated in 1985, partially vacated by the court in 1987, and repromulgated in 1993. There are essentially three requirements:

- §191.13 limits the cumulative releases of radionuclides to the accessible environment for 10,000 years from essentially all causes.
- §191.15 limits the individual dose for "undisturbed performance" for 10,000 years. (Undisturbed is defined to exclude human intrusion).
- §191.24 requires protection of underground sources of drinking water for "undisturbed performance" for 10,000 years.

The first item, the cumulative release requirement, has been driving the performance assessment calculations.

The second regulation of interest, 40 CFR 268.6, implements RCRA for the long term. It limits the releases of hazardous constituents, such as VOCs, organics, and heavy metals, at the disposal unit boundary for 10,000 years of undisturbed performance.

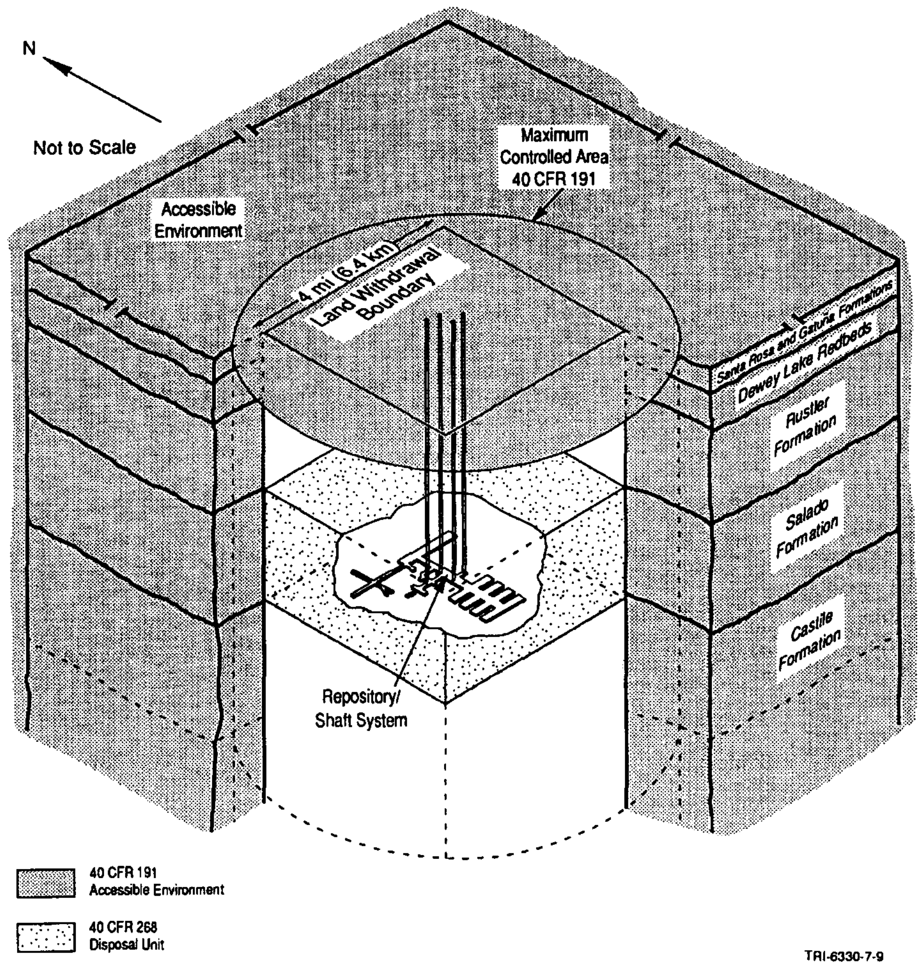

Figure 2.8-1. Accessible Environment and Disposal Unit Boundaries.

Shown here are the regulatory boundaries needed to assess performance measures. The repository is in the Salado Formation. It is underlain by the Castile Formation and the deeper hydrocarbon bearing units. The repository is overlain by the Rustler Formation which contains the Culebra, the formation in which Rick Beauheim observed the water level rises. Above that are the Dewey Lake Redbeds Formation and other relatively thin units such as the Santa Rosa Formation and the Gatuña Formation. The RCRA boundary, the RCRA disposal unit, is defined to be the Salado Formation inside the four mile area. Releases are of interest at the top of the Salado Formation, at the bottom of the Salado Formation, or laterally to the 4 mile by 4 mile boundary.

For 40 CFR Part 191, the disposing unit is defined a little differently. The boundary of the controlled area is a cylinder extending up to the ground surface and downward as well. Radionuclide releases are of interest if radionuclides reach the ground surface or if they migrate laterally through marker beds in the Salado or through the permeable units in the overlying formations. We estimate the releases and sum the releases over 10,000 years. That is the performance measure that is compared to the EPA standard. The standard is probabilistic and regulates the probability of cumulative releases, not the magnitude of them, but the probability of releases of a certain magnitude.

For the WIPP 40 CFR 191 defines performance assessment. Performance assessment:

- identifies processes and events that might effect the disposal system,
- examines the effects on system performance, and
- estimates cumulative releases, including uncertainties, caused by all significant events and processes.

Performance assessment tries to capture this uncertainty by posing three questions.

1) What are the things that can happen in the future? (Scenarios or S_i)

2) What are the probabilities of those things?

3) What are the consequences of these things, if they should happen?

Risk is represented by an equation which contains an ordered set: 1) scenarios, 2) scenario probabilities, and 3) scenario consequences.

$$Risk = \{(S_i,\ pS_i,\ cS_i),\ i=1...nS\}$$

Performance assessment, for 40 CFR Part 191, is basically an attempt to solve the risk equation.

The flow diagram shows the performance assessment methodology. The process starts by characterizing the system. For the WIPP, there are 3 main parts, the site geology, the engineered facility, and the waste to be emplaced.

Performance assessment needs to develop scenarios. These are the things that might happen. Their probability needs to be estimated and a computational modeling system is needed to simulate these scenarios and estimate the consequences. A Monte Carlo consequence modeling system is used to perform multiple simulations using different sample parameter values, which describe the key parameters of the system. The simulations yield a set of outcomes that describes the uncertainty in the modeling system. The effort calculates the consequences for different scenarios, estimates the scenario probabilities, and gives a result that can be compared to the regulatory standards. If the exercise is a preliminary performance assessment, as has been the case since the late 1980s, then the process executes a sensitivity analysis that iterates through the system. The final iteration leads to the preparation of an application.

The first step to develop scenarios is to establish a comprehensive list of features, events, and processes (FEPs). Events and processes are identified in the regulations. A feature is neither an event nor a process, it simply may exist at the site. The WIPP FEP list was developed from nine independently derived FEP lists from different programs around the world. Some WIPP specific FEPs were added. The "Master List" contained approximately 900 FEPs. Some of these were not particularly relevant to WIPP. But in the interest of completeness they were included on the initial list. That list is in concept, an open list. If someone can think of it, and it has merit of any sort, it should be on that list.

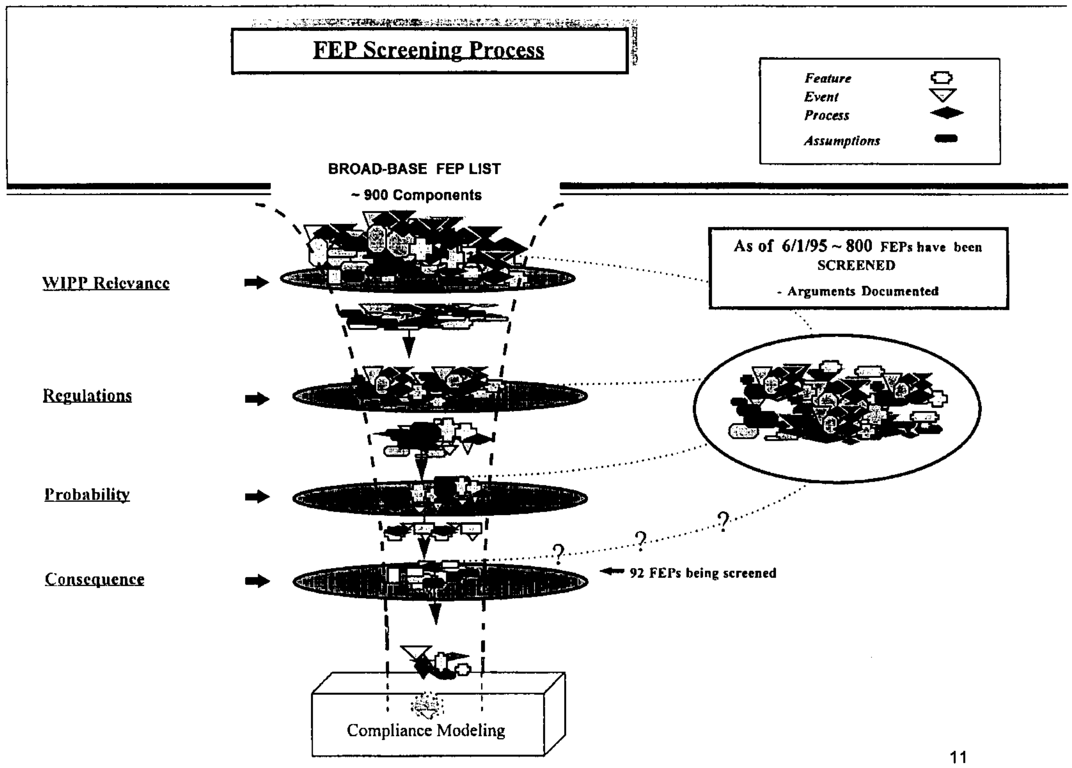

Figure 2.8-2. FEP Screening Process.

Next is the development of a screening argument. Screening does not mean screening out. It means screening either in or out of system level analysis. There are four screening criteria:

1) Relevancy

2) Regulation

3) Probability

4) Consequence

The first one is simply relevancy. For example, FEPs that relate to the disposal of high level waste or spent fuel are not relevant to WIPP.

The second is regulatory criteria. Two are important enough to mention here. First, the American regulatory period is limited to 10,000 years. FEPs beyond 10,000 years are not considered. Second, Appendix C of 40 CFR 191, specifies inadvertent and intermittent exploratory drilling as the most severe human intrusion scenario that should be considered.

The last two screening criteria are probability and consequence, assuming that the remaining FEPs, will be both relevant and included by the regulation. Then the process examines the probability of the FEP occurring and the consequences to the system. Regulation provides guidance for both of these. For probability, if a FEP can be shown to have less than one chance in 10,000 in 10,000 years, it need not be considered further. For consequence, if it can be shown that the performance measure would not be significantly changed by including the FEP in the analysis, then it need not be included. Of course, that presupposes there has been work done to support that consequence argument.

A schematic of the FEP screening process is shown. The order in which the first two screening criteria are applied is done on a case by case basis. At this time of the approximately 900 FEPs, work is ongoing for 92 of the remaining FEPs to determine their status.

2.8.2.1 Conclusions

Oil and gas related activities, e.g. waterflood injection, certainly are on our list along with other FEPs. Screening arguments remain to be developed and documented for several FEPs that are relevant here today, including waterflood injection. In other words, I don't have a screening argument today. I am not going to tell you what we decided to do about waterflood injection in terms of performance assessment modeling. In part, I am eager to hear what we learn here today and it would premature for us to come in with a conclusion already in hand. But I remind you that we will apply the three important criteria, probability, consequence, and the regulatory requirements.

2.8.2.2 <u>Questions</u>:

Robert Neill: In terms of the probabilities for screening, would you say that the probability of salt waterflooding or brine injection to improve oil recovery in the vicinity of WIPP is much, much less than 10^{-4} or much, much greater than 10^{-4}.

Peter Swift: At some locations the probability apparently is one, which is a good high number for a probability. I think it would be pointless of me to make the point any further. It depends on the location.

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2.9 Need for Water Flooding Scenario in WIPP Performance Assessment

William W.-L. Lee

2.9.1 Synopsis

After a series of presentations on the why, where and what-ifs of water-flooding, we come to the question of what does water-flooding mean for WIPP as a geologic repository of nuclear and mixed wastes. The USEPA requires performance assessments to include disruptive events or processes that are estimated to have more than one chance in 10,000 of occurring over 10,000 years. In the 1989, 1990, 1991 and 1992 WIPP performance assessments, the only disruptive event analyzed was human intrusion by drilling. WIPP has not analyzed a scenario specific to water-flooding.

In the most recent position paper on scenarios development, the DOE states:

> Fluid injection.
> Leakage from fluid injection wells associated with enhanced and improved oil and gas production, hydrocarbon storage, and disposal of unwanted liquids is retained for further consideration (p. 7-15).

Among the 124 FEPs being analyzed in side calculations, we find

- Interconnections within the controlled area for disturbed performance (to model effects of existing and future boreholes),
- Interconnections outside the controlled area for disturbed performance (to model effects of existing and future boreholes),
- Leakage from wells (from brine pockets, injection wells, fluids during drilling),
- Effects of mining inside or outside the controlled area,
- Connection to units beneath the repository,
- Current human activities outside the controlled area (e.g. hydrocarbon

extraction, fluid injection. (Anderson 1995).

While SNL/DOE has considered water-flooding, the impacts of water-flooding has not yet been analyzed in the compliance certification application.

2.9.2 Presentation by William W.-L. Lee

What does waterflooding mean and should it be incorporated into WIPP's performance assessment? Features, events, and processes (FEPs) that have a probability greater than 10^{-8} per year have to be considered in performance assessment. However, in the previous iterations of the WIPP performance assessment, the only disruptive event analyzed was human intrusion by drilling. And that is an important qualification.

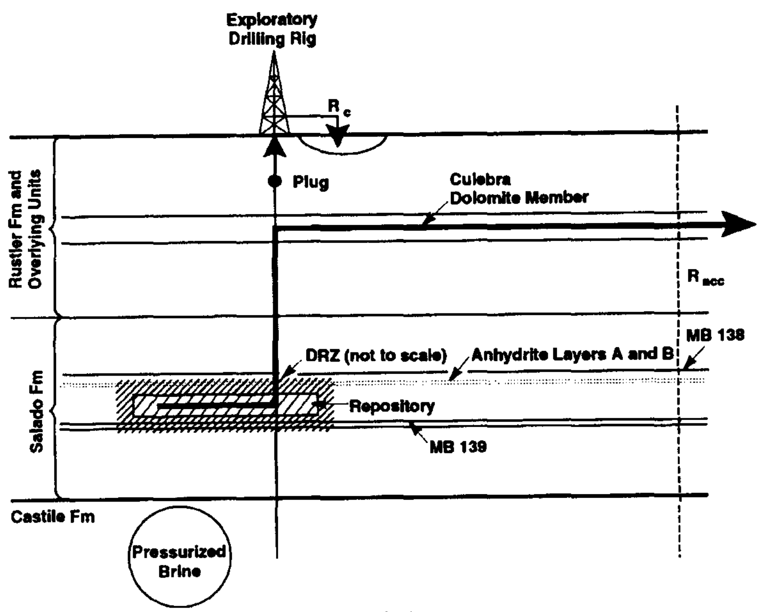

Figure 2.9-1. E2 Scenario

In the spirit of reviewing old work, I will show you the scenarios that were actually analyzed in the 1992 Performance Assessment. There was the E2 scenario in which a repository is pressurized with brine that flowed in from the Salado Formation, a driller hits the repository, and the pressurized waste moves up the well bore. There is a magic plug that diverts the material into the Culebra Dolomite. Compliance is measured at the accessible environment.

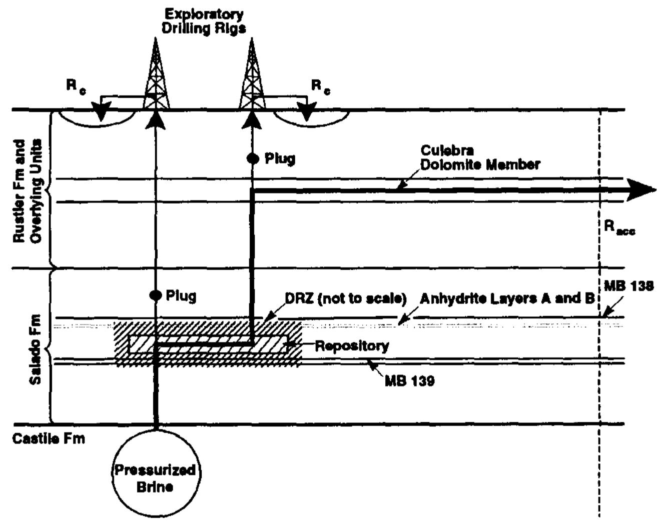

Figure 2.9-2. E1E2 Scenario.

In the E1E2 scenario, a driller first penetrates through the repository into a brine reservoir in the Castile Formation and thus floods the repository. A plug is put in place and there is now a brine pressurized repository. The E1 scenario is then superimposed on the E2 scenario.

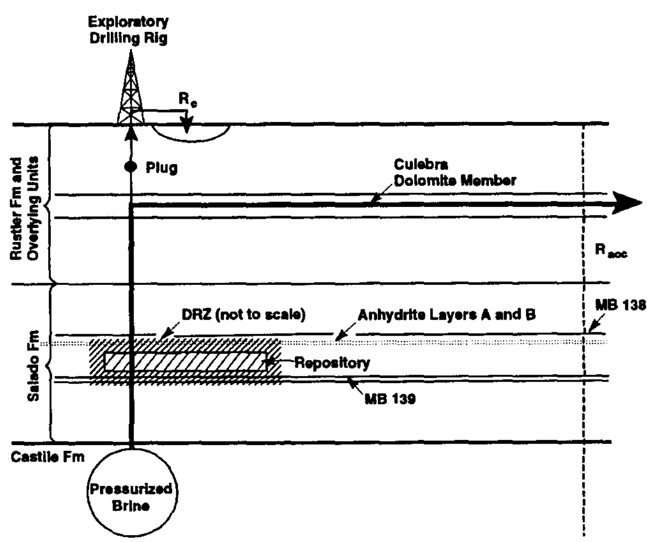

Figure 2.9-3. E1 Scenario.

The other possible scenario that was not analyzed by the 1992 PA was the E1 scenario which is the first half of the E1E2 scenario. The rationale given was that it is dominated by the E1E2 scenario although I believe Sandia has had some second thoughts about it.

Peter Swift just explained the process of screening FEPs. Starting with 900, two months ago there were 124 left. These are the ones related to waterflooding that are left.

- Interconnection within the control zone for disturbed performance and interconnection outside the disturbed performance.
- Leakage from wells including injection wells.
- Effects of mining inside or outside the control area.
- Connection to units below the repository.
- Human activity including fluid injection.

We have been told that Sandia National Laboratories is grinding away on side calculations to provide screening arguments for these FEPs. We await the results of these calculations.

The bottom line is this. Should the impact of potential waterflooding be in the current performance assessments and in particular, the draft application?

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END OF WORKSHOP PRESENTATIONS

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3. ANALYSES OF FLUID INJECTION ISSUES

Potential impact of fluid injection on the WIPP repository is analyzed in this chapter. The analysis uses the information presented at the workshop and that available in the literature and the public record.

As Chuck Byrum (EPA) noted in the afternoon discussion, waterflood and salt water disposal are two different processes regulated in different ways, designed in different ways, and the ultimate effects of each may be quite different. Kreitler et al. (1994, 4) described the difference between these two water injection activities. In waterflood projects, the presence of adjacent producing wells limits the extent of repressurization around the injectors. In contrast, salt water disposal wells are not used to increase oil production. Hence, brine may not always be injected into depressurized producing reservoirs. Initial fluid pressures in the disposal reservoirs may be hydrostatic, leading to overpressured conditions and upward fluid flow potentials. This analysis attempts to preserve the distinction between these two processes.

3.1 Salt Water Disposal

In his presentation, Beauheim showed data which led to his inescapable conclusion that a discreet human activity, most likely an injection well, caused the abrupt 1988 water level rise in wells south of the WIPP Site. Based on his own investigation, LaVenue (1991) also suggested the possibility of leakage from either a producing oil and gas well or a salt water disposal well in the area. Further, LaVenue (1991) speculated on the potential impact of a leaking well on the performance assessment calculations:

> If the recharge source is related to oil and gas wells in the area, it is not difficult to imagine significant increases and/or decreases in the water levels in the future as a result of additional recharge or discharge from oil and gas wells. Fortunately, there are almost no oil and gas wells within the

> WIPP-site boundary. Therefore, if wells are going to leak and have an impact upon the flow field, there is a higher probability that those wells will be located down-gradient or south of the WIPP site. Recharge from oil and gas wells south of the site should flatten the hydraulic gradient which would slightly increase ground-water travel time. If discharges from the Culebra occurs through a leaking oil or gas well south of the site, the hydraulic gradient would be slightly increased and the ground-water travel time would decrease (LaVenue 1991, 10-11).

In his presentation, Beauheim noted that higher potentiometric head in the Culebra in the southern part of the WIPP and south of the WIPP would flatten the hydraulic gradient and increase travel time. But he also emphasized that a change in gradient would not make a difference to the calculated performance assessment because of the relatively short life of such an injection activity. However, could a leaking injection well east, north, or northeast of the WIPP force large volumes of brine into the Culebra and significantly increase the gradient and reduce travel time? There are several new oil wells also producing large quantities of brine from the Delaware Mountain Group. To handle that waste brine, there are new salt water disposal wells operating just east of the WIPP Site. Wells are likely to be drilled to the north of WIPP when the area is open for drilling. The effect of higher heads in the Culebra in the north and east of the WIPP site should be analyzed in performance assessment.

3.1.1 Fluid Injection in the Culebra - *Bounded by Climate Change*

At the EEG workshop, Rip Anderson (SNL) acknowledged that the performance assessment effort, to date, has not specifically addressed fluid injection but that climate change would be in the final calculations. He maintained, however, that climate change assumption would bound any waterflooding scenarios because the climate change scenario takes the water table to the surface and that is the maximum possible water pressure. Anderson also stated that the presence of a

Castile brine pocket for the human intrusion scenario would cover any remaining concerns about waterflooding.

The 1995 DOE draft application to EPA (U.S. DOE 1995, Section 6.4.11) discusses climate change noting that the hydraulic head in the Culebra is raised to the land surface elevation along the northern boundary of the Culebra while the head remains fixed along the domains of the southern boundary. No results were presented. Rather, the draft document notes that the effect of climate change on groundwater flow is the subject of a current study.

3.1.2 Fluid Injection in the Culebra - *Not Bounded by Climate Change*

David Back (SC&A) questioned the DOE position that surface recharge bounded the impact of water level fluctuations in the Culebra. Back noted that the PA modeling assumed that the recharge would occur some miles to the northwest of the WIPP Site at the edge of the regional model. He pointed out that water from this recharge location would not pass through the WIPP site. Modeled this way, the water would flow south, through the higher transmissivity zone, straight to the assumed discharge area in Nash Draw, which is also west of the WIPP Site. However, if recharge occurred along the eastern edge of the WIPP, Back maintained that there would be an increase in the gradient, hence an increase in the flow rate through the Culebra over the WIPP.

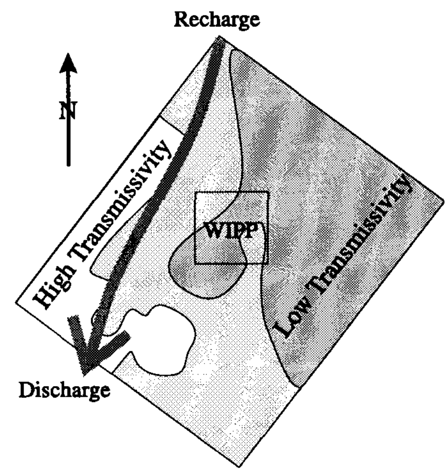

Figure 3-1. WIPP and Regional Flow Model for Culebra. Figure prepared by M.K. Silva.

3.1.3 Culebra Hydraulic Head Limited to Surface

Peter Swift (SNL) maintained that it is unlikely for a failed injection well to cause pressures in the Culebra that are above the head at the ground surface. Data that support his position include the 181 pressurized water flows logged into the NMOCD Hobbs call-in log (November 1978 to May 1994) for southeastern New Mexico and the eight additional waterflows identified by Van Kirk (1994). Waterflows appear to be largely confined to the Salado and other deeper formations. There does not appear to be any artesian flow from the overlying aquifers such as the Culebra.

The notion of surface limited hydraulic head can not apply to the Salado. In the Vacuum Field, waterfloods exerted sufficient pressure to collapse well casings and pressures as high as 1600 psi were measured at the surface outside of waterflood areas (Ramey 1976). As mentioned by Lokesh Chaturvedi and discussed by Dennis Powers, the 1991 Salado salt water blowout at Hartman's Bates Lease was pressurized far above the surface hydraulic head as Hartman inadvertently discovered.

3.1.4 Brine Flow into Overlying Aquifers

Citing information from Dan Stoelzel, Rip Anderson made the following two points. First, a difference occurs only if water enters the Salado and the repository. Second, water escaping lower injection zones would flow past the Salado and would flow into the more permeable Culebra. Dan Stoelzel also suggested the reason injected water in the Vacuum Field did not come to the surface was because it was potentially going into the Ogallala, which is very permeable near the surface. The mechanism postulated by Anderson and Stoelzel raises interesting questions. At the Vacuum Field, or in other parts of New Mexico, or in other parts of the nation, has there been contamination of overlying aquifers, such as the Ogallala, as a result of oil field waterflooding? Is WIPP relying on contamination of an overlying aquifer by oil field waste brine as an acceptable alternative to flooding the Salado?

Some information supports the notion of water from oil field operations contaminating overlying aquifers. The U.S. Government Accounting Office (GAO) published a 1989 report entitled "Drinking Water Safeguards Are Not Preventing Contamination From Injected Oil and Gas Wastes." Class II injection wells are used to dispose of brine produced with oil and gas or to reinject these fluids to enhance oil recovery. Although the full extent of the problem was unknown in 1989, EPA was aware of 23 cases in which drinking water was contaminated by Class II injection wells. For the 23 confirmed cases of contamination, there were three principal causes. Five cases resulted from leaks in the casing of the injection well, nine resulted from migration through nearby improperly abandoned wells, and nine resulted from injection into the underground drinking water (U.S. GAO 1989).

One case of confirmed contamination occurred in New Mexico. During the 1970s, 20 million gallons of water leaked from a Texaco disposal well in Lea County, New Mexico into portions of the Ogallala aquifer, an underground source of drinking water. Some of the brine migrated into a rancher's irrigation well, damaged his crop and, according to the rancher, ultimately caused the foreclosure of his farm property. On the basis of the results of a pressure test, the rancher successfully sued Texaco in 1977 for damages (U.S. GAO 1989, 25).[9]

In the 1970s, potential contamination of the Ogallala near various waterfloods in Lea County was of concern to the New Mexico Oil Conservation Division (Ramey 1976). After years of study, the Vacuum Field Salt Water Flow Committee [a committee of oil company representatives] indicated flow was confined to the top of the Tansil and the bottom of the Rustler (Bailey 1990), thus isolating the problem of flow largely to the Salado. Bailey's spot checking old oil well drilling

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[9] Texaco has since repaired the well and is now operating in compliance with Underground Injection Control although Texaco was not required to clean up the aquifer (U.S. GAO 1989, 25).

records indicated water flow drilling problems and numerous casing leak repairs in the Dewey Lake Red Beds and the Rustler in addition to the Salado (Bailey 1990).

3.1.5 Pressurized Brine Injection into the Salado

If there was salt water flow into the Ogallala at the Vacuum Field, as suggested by Dan Stoelzel, and into the Dewey Lake Red Beds and Rustler as indicated by Bailey (1990), can the performance assessment assume that overlying aquifers will serve as a relief valve for leaking wells in the WIPP vicinity, thus protecting the Salado, as suggested by Anderson and Stoelzel? It appears not. Despite the presence of overlying aquifers at the Vacuum Field, injected salt water exerted sufficient pressure to collapse well casings at the Salado horizon (Ramey 1976; LaVenue 1991). Similar observations of water flow through the Salado have been made in other oil fields with a history of waterflooding, including the oil fields near Oil Center, Monument, Eunice (Bailey 1990) and Jal (Hartman 1993).

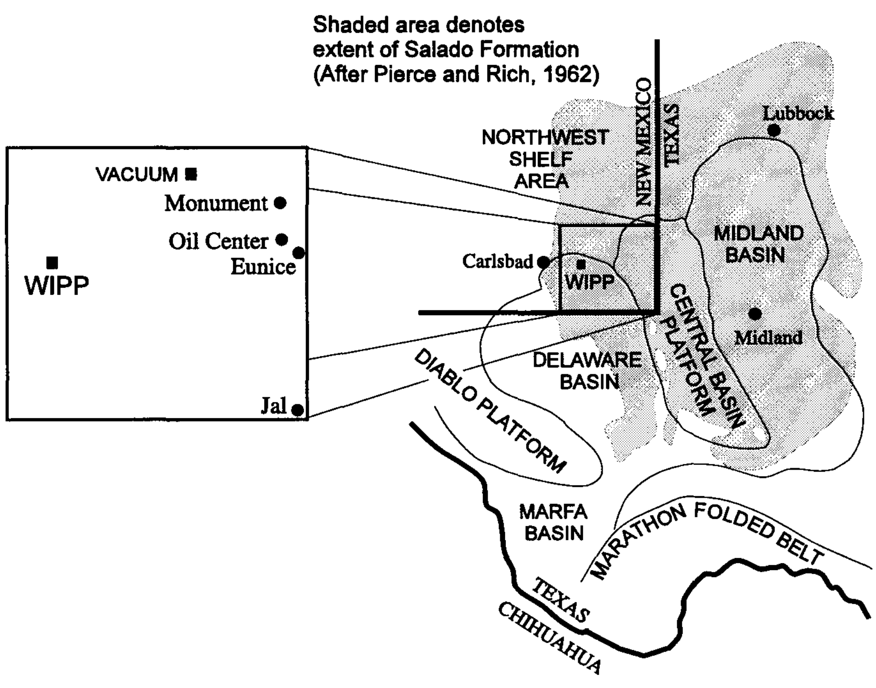

Figure 3-2. Areas overlain by Salado Formation.

Gallegos and Condon (1994) argued that the 189 water flows throughout District One of southeast New Mexico strongly correlated with waterflooding activities. These flows were in the Salado or at depths much greater than the overlying aquifers, strongly suggesting no relief mechanism. In light of this information, can the performance assessment defend the notion that brine escaping from an oil field waterflood or salt water disposal well will preferentially migrate into an overlying aquifer?

3.1.6 Devon Energy's Todd 26 Federal #3

As to the salt water injection well south of the WIPP Site, Dan Stoelzel commented that this well was probably responsible for the water level rises observed in H-9 (see Stoelzel's presentation). His conclusion was based on the schematic of the well completion. The well was originally completed in 1971 as a test well and immediately converted to a salt water disposal well. There is no salt isolation casing and it is an open hole completion similar to that of the Rhodes/Yates Field or the Vacuum Field. He commented that the well is now plugged and abandoned. Matthew Silva's reading of a commercial map also suggested that the well was abandoned.

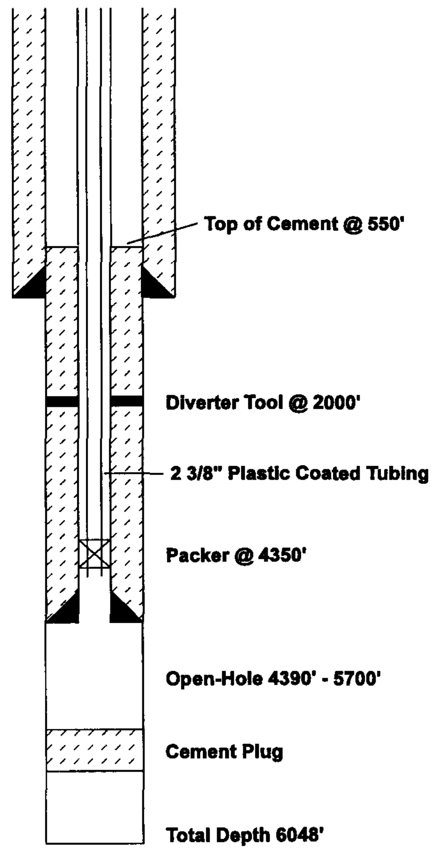

Figure 3-3. Texas Americal Oil Corporation Todd 26 Federal No. 3 Water Disposal Well (After Stoelzel).

It appears that the well was not plugged and abandoned and is still in service (Horsman 1995). The well is injecting into the Bell Canyon Formation, which is below the WIPP horizon. A comparison of the injection history at this well and

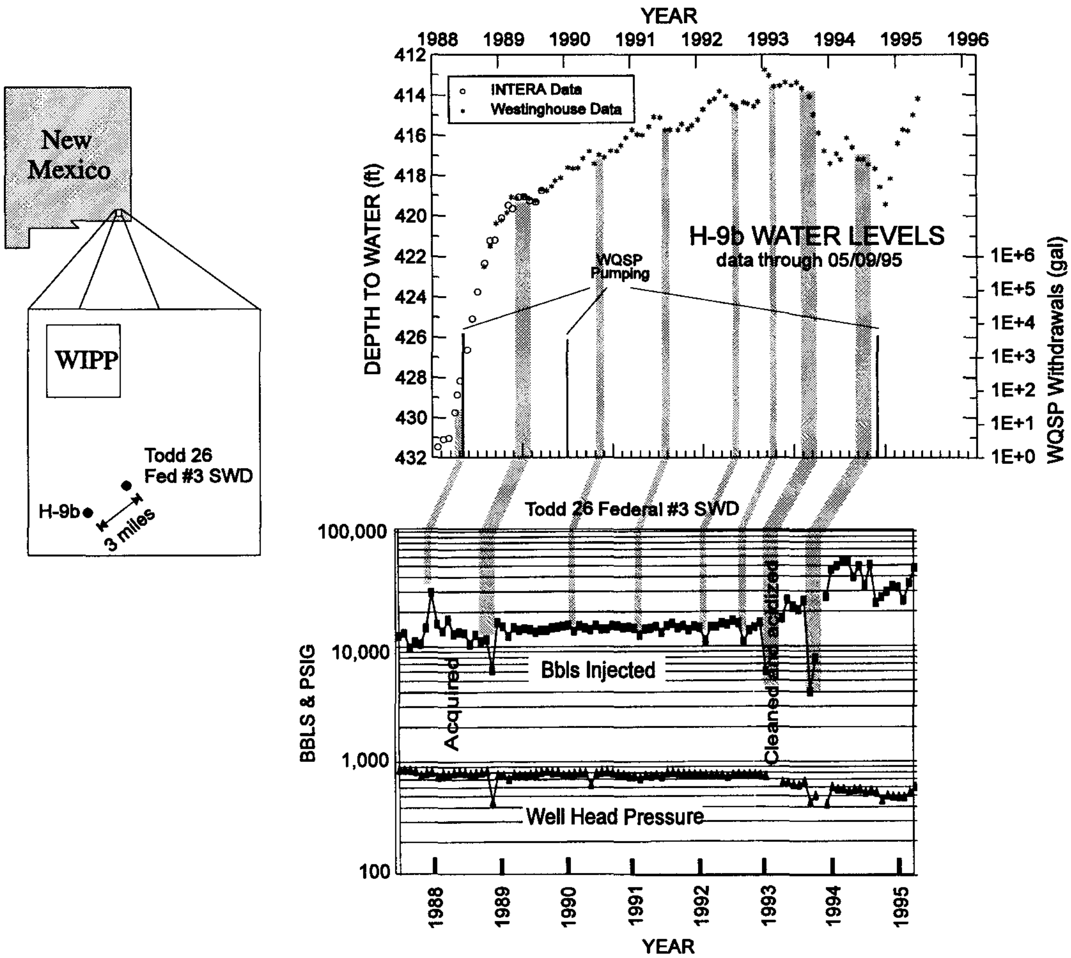

Figure 3-4. Todd 26 Federal #3 well injection data (Horsman 1995) and H-9 water level rises presented by Beauheim.

the water level rises at H-9 strongly suggests communication between the injection horizon, which is below the WIPP horizon, and the Culebra Dolomite, which is an aquifer above the WIPP horizon. There is more than 3,000 feet (980 m) of vertical separation between the horizons and approximately 3 miles (5 km) of horizontal separation between the wells.

Figure 3-4 strongly suggests a delayed response at well H-9 to injection events at the Todd 26 Federal #3. As noted in Richard Beauheim's presentation, the depth to water at well H-9 was essentially constant at 431 to 432 feet (141 m) for five years prior to April 1988. An increase in the injection rate from 10,000 barrels per month to 30,000 barrels per month in January 1988 corresponds with the observed water level rise at H-9, which began in April 1988. This increase in injection is the event mentioned by LaVenue (1991) as potentially causing a tubing failure. Seven subsequent reductions in injection at the salt water disposal well rate are followed by corresponding water level declines at the monitoring well. In January 1993, injection operation ceased for two months. The water level at H-9 fell to levels not seen since 1990. After 1993, there appears to be either a delay in the response or perhaps a response to other injection wells in the area. It is worth noting that two other salt water injection wells began operating in the same general vicinity as Todd 26 Federal #3; Todd 26 Federal #2 SWD in January 1993 and Todd 36 Federal #1 in September 1994 (Horsman 1995).

The observations invite the obvious question. Are there problems with the Todd 26 Federal #3 well as suggested by Bailey (1990), by LaVenue (1991), and in Stoelzel's discussion of the well completion? Subsequent to the EEG workshop, the well passed a scheduled, routine, mechanical integrity test on August 16, 1995. In response to a request from the U.S. EPA (Catanach 1996a), the New Mexico Oil Conservation Division had the well subjected to a radioactive tracer test on November 13, 1995, to determine if injected fluid is migrating upward through channels in the vicinity of the wellbore (LeMay 1995a).

> The results of the tracer surveys (analysis attached) indicate no channeling behind the production casing and no vertical migration of fluid from the injection interval. It is the opinion of the Division that no further testing of these wells [Todd 26 Federal #3 and David Ross AIT Federal #1] is necessary (Catanach 1996b).

Assuming the tests were conclusive with respect to the integrity of the tubing, the casing, and the cement, the results of the test raise more questions. Are there vertical conduits in the vicinity such as improperly abandoned wells and/or wells with deficient casing or cementing? Or are there vertical fractures in the vicinity that are not detectable by a radioactive survey of the wellbore area? Is there indeed a correlation between water injected and water level rises as suggested by the injection and water level rise data? If so, how does water injected more than 4,000 feet (1300 m) below the surface get through thousands of feet of two relatively impermeable bedded salt formations, the Castile and the Salado, and end up in an overlying aquifer? Is bedded salt, in the vicinity of water injection activities and abandoned oil and gas wells, truly a geologic barrier?

3.1.7 Yates' David Ross AIT Federal #1

Although there are several salt water injection wells in the area, this is the only salt water injection well operating within one mile of the WIPP Site at this time. During the afternoon deliberations, George Dials (DOE) raised the issue of institutional control noting that DOE has the opportunity to take credit for institutional control for up to 100 years and the DOE intends to maintain institutional control for at least 100 years.

As the only salt water disposal well operating within one mile of the WIPP site, the record on Yates' David Ross AIT Federal #1 provides interesting observations about institutional control.

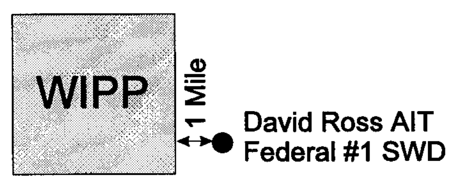

Figure 3-5. Location of David Ross AIT Federal #1 Salt Water Disposal Well.

First, the BLM received an application for permit to drill an oil well on January 17, 1991. The BLM approved the application on January 31, 1991, without obtaining a review from the DOE despite the October 26, 1990, Memorandum of Understanding (MOU) requiring it. The approval of this well completely bypassed "the controls that are crucial to protecting the site from inadvertent exploration" (Arthur 1992; Silva 1994, 46). The policy has been in place since 1983:

As an additional measure, the BLM will notify the DOE of any requests for resource recovery permits within one mile of the WIPP Site boundary so that the DOE will be aware of resource recovery activities near the Site (McGough 1983).

Second, when the well failed to produce much oil from the perforated zone, the operator proposed to convert it to a salt water disposal well. There was an objection, but it was not raised by the DOE. Mitchell Energy expressed concern about the loss of oil reserves as a result of brine injection into potential oil producing horizons and wished to limit injection pressures (Stephenson 1991). An agreement was reached between the two oil companies (Kellahin 1991) and the conversion to a salt water disposal well was approved on May 22, 1991 (LeMay 1991). The well was to be equipped to operate at a maximum pressure of 900 psi (LeMay 1991). Over the next several months, the well casing was perforated and zones within the approved interval were acidized and fractured until sufficient water could be injected (Goodlett 1991a, 1991b, 1991c, 1991d, 1991e, 1991f).

Third, the DOE continued to list this as an oil and gas well (Arthur 1993a, 1993b) and appeared unaware that this was a salt water disposal well despite the absence of oil production equipment, the presence of a battery of salt water tanks, the presence of a sign labeled "SWD," the "SWD" label on the BLM map, and BLM and NMOCD records clearly stating "salt water disposal well" (Silva 1994, 55-56; Kehrman 1995, 254, lines 18-20).

Fourth, the DOE, the EPA, the BLM, and others rely on the New Mexico Oil Conservation Division to ensure that water is not injected above the approved injection pressure. An examination of the public record (NMOCD 1996) indicates that the David Ross AIT Federal #1 was operated 20 psi above the approved injection pressure of 900 psi (LeMay 1991) during the months of September and October 1995, yet the well had been equipped so that it would not operate above 900 psi.

Government ownership, regulation, and public records are components of institutional control. The observations above raise questions about how much credit can be allowed for institutional control of the resource recovery activities in the vicinity of the WIPP site.

There does not appear to be an identifiable relationship between the injection of brine at the David Ross AIT Federal #1 and the water level rises at the P-18 well. The material presented by Rick Beauheim and the arguments submitted by Fant (1995) strongly suggest that there is insufficient evidence of direct communication between these wells. Fant (1995) makes a compelling argument that the P-18 well, which was originally drilled as a potash corehole, may be providing a connection between the Culebra and Magenta Formations. As noted by Rick Beauheim, there may be a problem in the P-18 well with the bridge plug, the cement job, or the cement bond.

3.2 Water Flooding

The problems with waterflooding in oil fields under the Salado Formation, or more specifically, the migration of injected water through the Salado Formation to adjacent properties, is well documented (Ramey 1976; Bailey 1990; LaVenue 1991; Hartman 1993, Herrera 1995). At the EEG workshop, Dan Stoelzel and Lori Dotson of Sandia National Laboratories maintained that at WIPP, migration of water through the interbeds of the Salado, such as occurred at the Rhodes Yates Field and the Vacuum Field, was highly unlikely for a variety of reasons. These included differences in geology, changes in oil-well completion practices from the 1940's, and improved reservoir management. Stoelzel and Dotson argued greater vertical separation at WIPP will protect the repository. They also argued that large scale water flooding near the WIPP is unlikely because the oil pools near WIPP are characterized by thin net pay zones, low permeabilities, high reducible water saturations and high residual oil saturations. They also maintained that oil production by primary and secondary recovery would require less than ten years each. These issues are discussed below.

3.2.1 Differences in Geology

With respect to water injection, Dan Stoelzel and Lori Dotson cited vertical separation as an additional protection for the WIPP. Their arguments rely on the observation that oil production near the WIPP occurs at depths greater than 7,000 feet (2300 m) or about 5,000 feet (1640 m) below the repository horizon. Oil production at the Vacuum Field occurs at approximately 4,500 feet (1480 m) and at Rhodes Yates at 3,000 feet (980 m). In their abstract, Dotson and Stoelzel state there was only a couple of hundred feet ~(65 m) of vertical separation between the Salado Formation and the waterflood injection zone at Rhodes-Yates. They also noted that the Castile Formation is missing at the Vacuum Field and the Rhodes Yates Field.

However, as noted by Lokesh Chaturvedi, there is one geologic feature common to the areas on either side of the reef. The Salado interbeds extend through the entire Salado across the Delaware Basin and over the backreef. Lokesh Chaturvedi maintained that once pressurized fluids are injected into the Salado interbeds at WIPP, the interbeds will behave essentially the same way as Salado interbeds at other locations.

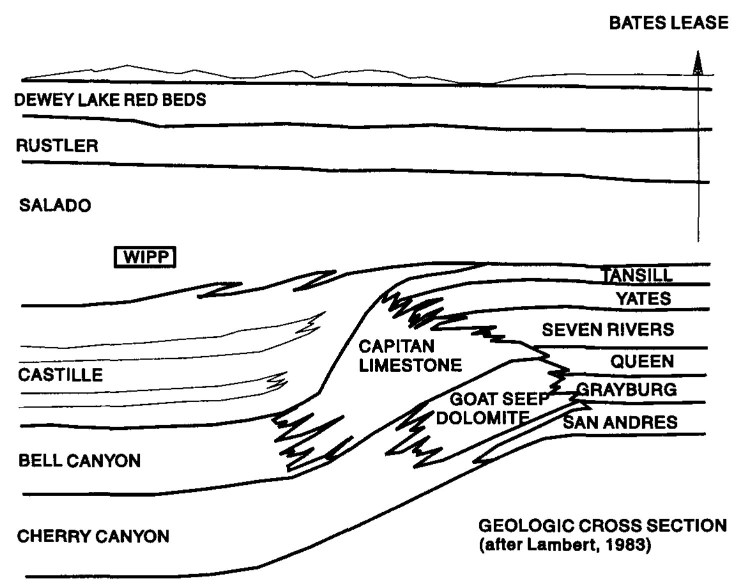

Figure 3-6. Continuity of Salado Formation.

In the afternoon deliberations, Dan Stoelzel and Lori Dotson offered opinions which contradicted the notion that vertical distance would protect the repository from communication with the deeper injection zones. For example, Dan Stoelzel maintained that the most likely source of water level rises in the Culebra at the H-9 well was the Todd 26 Federal #3 salt water disposal well. Matthew Silva observed that the salt water disposal well was injecting fluid in the interval from 4,400 to 5,700 feet (1440 m to 1870 m) below the surface. The water would have to migrate vertically 3,500 feet (1150 m) through the Castile and Salado to the overlying Culebra. That observation undermines Stoelzel and Dotson's position that such water migration would not occur because of about 3,000-5,000 feet (980 to 1640 m) vertical distance between the oil producing Delaware Mountain Group and the WIPP repository, or the overlying aquifers.

Lori Dotson commented that Silva's argument relied on the assumption that the water was leaking upward from the injection interval of 4,400 to 5,700 feet (1440 m to 1870 m). She maintained that the water could have been leaking from anywhere along the casing because that was a poorly designed injection well. Citing Stoelzel's earlier comments, Lori Dotson further commented that even if disposal brine was moving along the casing, it would take the path of least resistance and move into the Culebra. It would be easier for such water to enter the Culebra aquifer and not the Salado Formation. In bypassing the Castile and Salado Formations and flowing into the overlying aquifer, the oil field brine would not have an effect on performance assessment. But this explanation entirely undermines the "greater vertical distance" argument.

3.2.2 Livingston Ridge Delaware Waterflood

Dan Stoelzel maintained that small companies typically have shallow pockets and are unlikely to initiate water injection because of the cost to convert a production well into an injection well. It is worth noting that the active operators within two miles of the WIPP Site include Phillips, Texaco, Pogo, Yates, Enron, Bass, Mitchell Energy, and Santa Fe Energy.

On October 10, 1995, Pogo Producing submitted an application to begin a pilot pressure maintenance project[10] (Bruce 1995a). Pogo intends to inject water into the Brushy Canyon of the Livingston Ridge-Delaware Pool through a well approximately one mile east of the WIPP Site Boundary. The injection interval is from 7,050 feet to 7,068 feet (2313 m to 2319 m) for a total injection interval of 18 feet (6 m), a relatively narrow zone of perforations. The original spacing of the wells has not been changed. A production well is to be converted into an injection well. Pogo plans to inject 365,000 barrels of water per year. The operator of the pressure maintenance project anticipates that three wells will see increased oil production, Neff Federal #1 and #2 in Section 25 and Neff Federal #1 in Section 26 (LeMay 1995b, 3). The operator also requested an administrative procedure to expand the pressure maintenance project, and at a later date, to include additional lands and/or injection wells (LeMay 1995b, 4). The WIPP can anticipate waterflooding of the Livingston Ridge/Lost Tank Delaware by independent operators on yet to be determined patterns.

3.2.3 Likelihood of Large Scale Waterflooding

Lori Dotson maintained that the oil pools near WIPP are relatively small when compared to the Vacuum Field and the Rhodes Yates Field. Hence, the injection of large volumes of water is unlikely. She suggested that the Livingston Ridge and the Lost Tank Delaware oil fields are unlikely to be waterflooded on a large scale because:

[10] In a pressure maintenance program, water is injected to supplement declining reservoir energy. Pressure maintenance is a waterflood and often begins while the reservoir is still under primary production to maintain maximum production rates (Willhite 1986, 3, 190).

a) The pay zones are too thin, on the order of forty feet and several wells in the Livingston Ridge area with only ten to twenty feet of casing perforated.

b) The permeability of the Brushy Canyon is less than 7 to 24 millidarcies.

c) For waterflooding to occur, injection wells would have to be spaced closer together, which may be uneconomical.

d) The reservoir has a high irreducible water saturation and a high residual oil saturation.

However, Matthew Silva and Ron Broadhead noted that the Cabin Lake Field, at the northwest corner of the WIPP Site has shown good response to the pilot pressure maintenance project. The reservoirs in the Delaware Mountain Group produce primarily by solution gas drive. Citing the literature, Silva noted that solution gas drive wells are usually good candidates for waterflooding (Willhite 1986). In addition to citing experience and projected performance for the Paduca, Indian Draw, and East Shugart Fields, Broadhead also mentioned there was information, held proprietary by the oil companies operating in the area, indicating that they anticipated 70% to 80% increase in production by waterflooding the Brushy Canyon Formation.

3.2.4 Pay Zone Thickness

Lori Dotson maintained that large scale waterflooding would not occur in the vicinity of the WIPP because the pay zones were too thin. She stated that wells from the Livingston Ridge/Lost Tank portion of the Delaware were perforated for ten or twenty feet and suggested these were indicative of total pay zone potential.

However, a complete assessment of pay zone potential needs to also consider the typical completions for the Quahada Ridge Delaware Pool at the southwest corner of the WIPP, the typical well completions for the Cabin Lake Delaware Pool at the northwest corner of the WIPP, and the typical multizone well completions for the Livingston Ridge-Lost Tank Delaware.

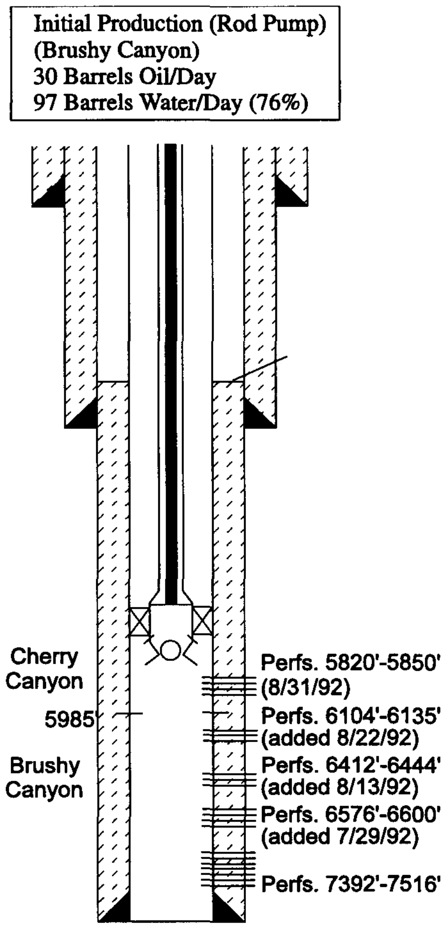

Figure 3-7. James E#12.
Typical Cabin Lake Completion.
After Dan Stoelzel.

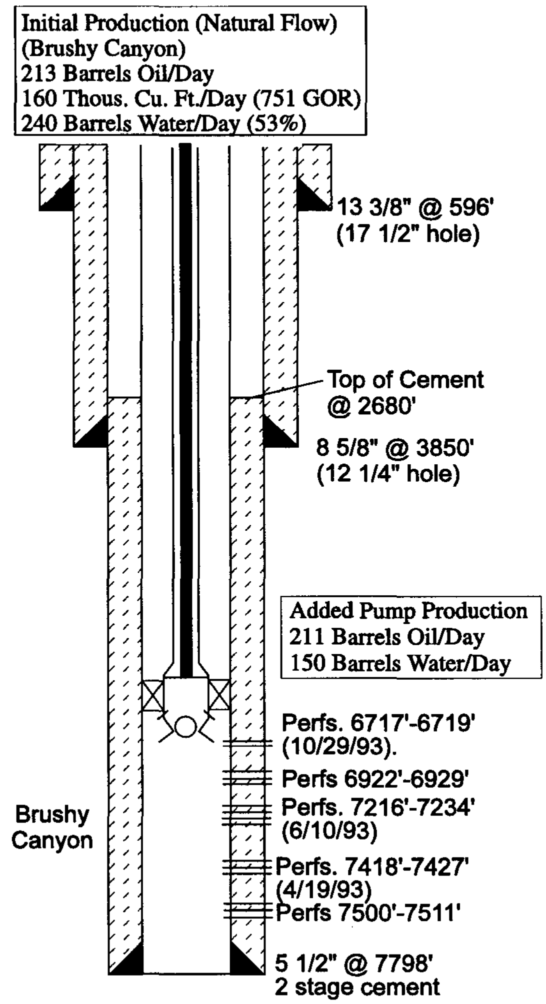

Figure 3-8. James Ranch Unit #19.
Typical Quahada Ridge Completion.
After Dan Stoelzel.

Stoelzel presented the James E#12 at Cabin Lake as a typical completion with five perforated zones totaling 231 feet (76 m). He presented the James Ranch Unit #19 as a typical Quahada Ridge completion with perforated zones totalling 47 feet (15 m).

Initial Production (Cherry & Brushy Canyon)
98 Barrels Oil/Day
54 Thous. Cu. Ft./Day
159 Barrels Water/Day (62%)

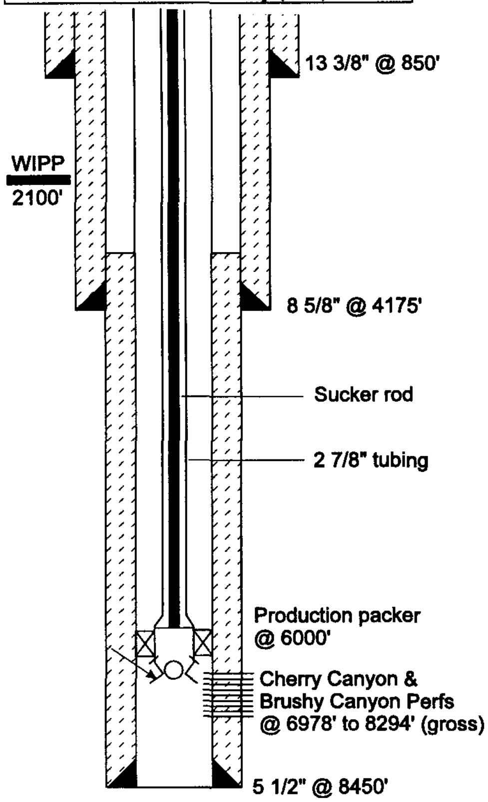

Figure 3-9. Typical Livingston Ridge/Lost Tank Completion. After Dan Stoelzel.

As to the Livingston Ridge/Lost Tank Field, it is true that Pogo Producing's completion records for Federal 23 wells #2, #3, and #5, on the lease immediately adjacent to the WIPP, are completed in the Brushy Canyon main pay zone with perforations ranging from fifteen feet to twenty feet (5 to 7 m). There are, however, other potentially producible zones, such as the B zone and D zone in the Lower Brushy Canyon as shown in Figure 20 of Broadhead et al. (1995). Moreover, the completion record for the Federal 23 Well #1 in that same lease, shows not only 19 feet (6 m) of perforation in the Brushy Canyon main pay, but also shows an additional 91 feet (30 m) of perforations in three other zones that have been temporarily abandoned. Broadhead et al. (1995, XI-16) noted that operators producing only from the main pay zone, at this time, may eventually re-enter their wells and perforate additional zones when the main pay zone ceases to yield economic volumes of oil. The completion records for the twelve additional wells that Pogo wishes to drill on forty acre spacings are not available because the federal government has denied Pogo's application to drill through the potash deposits (Burski 1994).[11]

[11]The EEG understands that this case may be in litigation and the EEG has no implied nor direct opinion in this case.

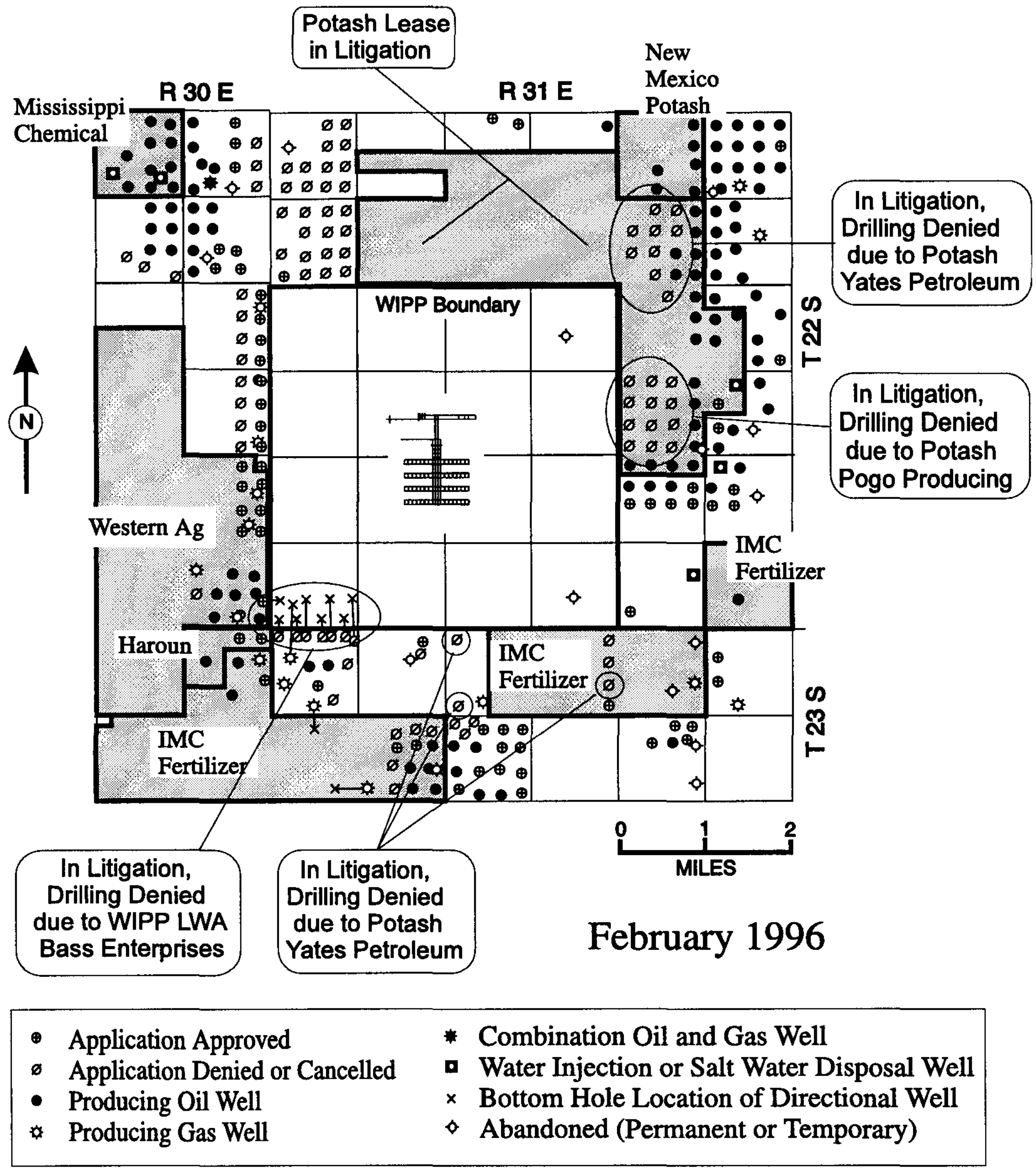

Figure 3-10. Current interest in resources surrounding the WIPP.

In arguing the ten to twenty feet of perforated casing as indicative of no large scale waterflooding, Lori Dotson did not discuss the Yates' wells in the Livingston Ridge. Yates Petroleum has drilled several wells in the west half of the Livingston Ridge but has completed them differently from other operators

(Broadhead et al. 1995, XI-16). All wells are perforated in the main pay and in most cases are also perforated in one to four other sandstones. While some of the completion records provide only the gross interval as shown in Figure 3-9, there is detailed perforation data for the first 3 wells in Section 11, T22S, R31E. Martha AIK Federal Well # 1 was perforated in three zones, 8236'-8308', 7960'-8015', and 7028'-7060', for a total of 159 feet (52 m) of perforations. Well # 2 was perforated in two zones, 6968'-6980' and 7035-7055', for a total of 42 feet (14 m). And Well #3 was also perforated in two zones for a total of 41 feet (13 m). Completion reports for wells #4, #5, and #6 provide only the gross interval of perforations. Wells 7 through 14 are waiting to be drilled. Due to the presence of potash deposits, the federal government has denied Yates' applications for permit to drill wells 7 through 14 (Burski 1994).[12]

3.2.5 Future Decades of Production in Oil Fields Surrounding the WIPP

Three presenters maintained that the oil fields surrounding the WIPP and producing from the Delaware Mountain group will have a maximum production life of less than twenty years. That position contradicts the position of the U.S. Department of Interior's Bureau of Land Management (DOI/BLM) (Woodard 1992, 3).

3.2.5.1 Position of the Department of Interior

The BLM denied Pogo Producing's twelve applications for permit to drill (APDs) in Section 23, T22S, R31E. This lease is immediately adjacent to the eastern boundary of the WIPP site. The APDs were denied because of possible impact on minable potash. Pogo Producing requested a U.S. BLM State Director Review. On March 18, 1992, the State Director of the U.S. BLM listened to a joint oral

[12]EEG understands that this case may be in litigation and the EEG has no implied nor direct opinion in this case.

presentation by Yates, Pogo, and Texaco. As part of their arguments, Pogo estimated mining operations would not reach the subject area for 20-30 years. During the oral presentation, Pogo's representative and Yates' Engineer maintained that the total projected economic life of the field, including tertiary recovery, would be 15 to 20 years. Therefore, they argued, their oil and gas operation would be completed before potash mining operations reached the area.

However, the BLM noted that the possible deeper gas plays, the current stripper well policy, and the diligence of operations make this estimate of oil field life too short. The BLM maintained that the total economic life could be double the 15 to 20 year estimate (Woodard 1992). In other words, based on its own experience, the BLM anticipates an oil field life of 30 to 40 years.

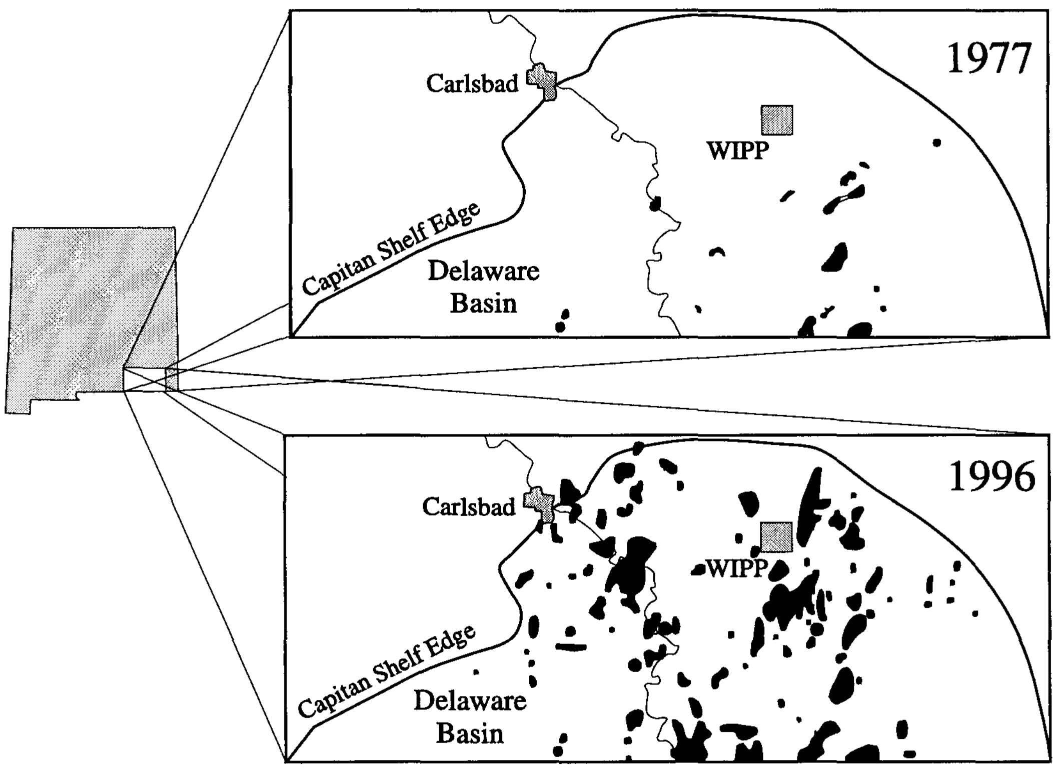

Figure 3-11. Delaware Mountain Group oil fields within the Capitan Shelf Edge of the Delaware Basin. After the Roswell Geological Society (1977) and Broadhead (1996).

Unfortunately, as indicated in Figure 3-11, the oil fields surrounding the WIPP having been only recently drilled, are not yet mature fields and cannot yet provide a direct determination of total field life. However, information in the literature and on public record for mature fields, in other areas of the Delaware Basin, suggest that primary production and waterflooding of the Delaware Mountain Group will generate at least thirty years and as much as fifty years of production after the initial development of a field. This suggests that the longer DOI/BLM estimate of 40 years (Woodard 1992) may be more correct.

Examples of successful waterfloods in the New Mexico portion of the Delaware Basin include Paduca, Indian Draw, and El Mar. The Paduca Field is an example of a successful waterflood that has been in production for over 30 years.

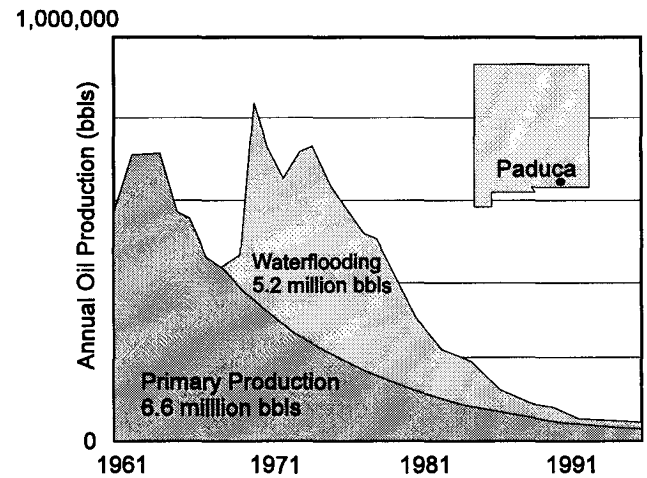

Figure 3-12. Production from Paduca Field. (Broadhead et al. 1995, Figure 38)

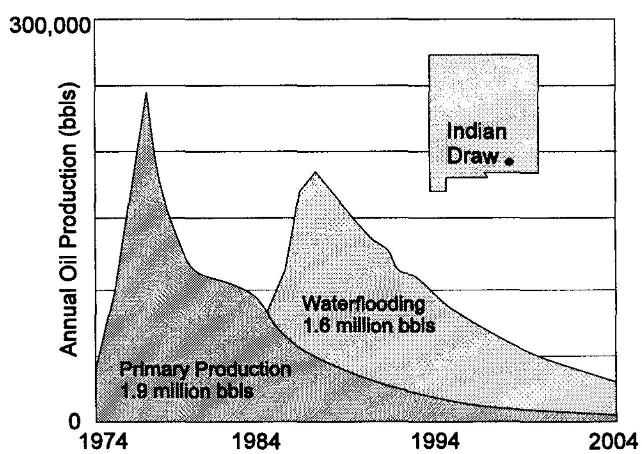

Figure 3-13. Production from Indian Draw. (After Broadhead et al. 1995, Figure 39).

Based on more than twenty years of actual production, including waterflooding initiated in 1980, the projections for the Indian Draw Field also indicate an anticipated oil field well life beyond 30 years.

One company operating in the Livingston Ridge area adjacent to the WIPP has submitted an affidavit which tends to support the position of a maximum of twenty years of operation (Boneau 1992, 2). Yates Petroleum maintains that oil and gas can be produced before any potash mining begins in this area (Boneau 1992, 2; Carroll and Bogle 1995, 33). As Broadhead (1995, XI-16) noted, Yates multiple zone completion practices are different from other operators in the area. Boneau states that Yates can complete primary and secondary development within 12 to 15 years. In the event of tertiary recovery, such as CO_2 flooding, the time would be extended by about five years for a maximum oil field life of twenty years. However, attorneys for Yates maintain that if there is waterflooding, "... the time to produce both primary and secondary oil should be in the range of 30 to 35 years" (Carroll and Bogle 1995, 33).

Comments by the University of Oklahoma Petroleum Engineering Professor Ron Evans at the EEG workshop tend to support oil field lifetimes closer to forty years:

> I will make this statement based on my experience in areas of Oklahoma. I do not believe that you are going to see oil production in the Delaware Basin cease totally in the next 20 years. I don't think that is going to happen. The tendency is like the food chain. You have the little people and you have the big people. Eventually it's the little people that are going to have that area and they'll tend to operate longer than say an Arco or Mobil would. I do not believe, for oil in the Delaware Basin, that production will cease within 20 years. I think it will be there 40 years from now because it will be in the hands of small operators.

3.2.5.2 Avalon Waterflood

Exxon (Bruce 1995c) filed for approval of an enhanced oil recovery project for the proposed Avalon Delaware Unit on May 9, 1995. The Avalon Field is about eight miles west of the potash area, hence the application is not encumbered by the presence of potash. Specifically, Exxon proposes to inject water into the Cherry Canyon and Brushy Canyon members of the Delaware Mountain Group to promote oil recovery. Cantrell and Kane (1993) describe the geology and history of primary production in detail and note average permeabilities of 1.5 millidarcies (md) for the upper Cherry Canyon Formation and 1.1 md for the lower Cherry Canyon and upper Brushy Canyon Formations.

As noted in the unitization proposal (Bruce 1995b), Exxon projected that a waterflood would extend the producing life of the unitized formation beyond the year 2030. As Exhibit #3, Exxon plotted projected waterflood operations beyond the year 2040 for a field that began oil production in 1983. In terms of total field life, Exxon projects this field will be producing for at least fifty years.

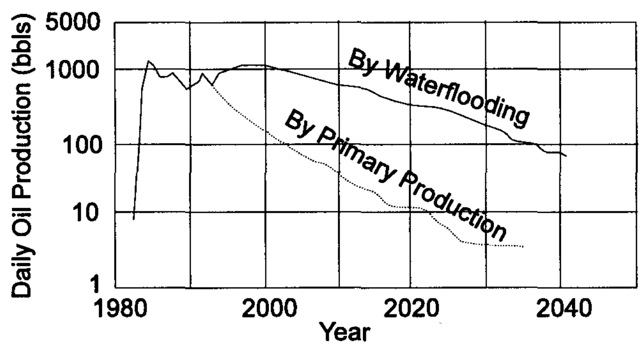

Figure 3-14. Waterflood vs. continued Primary Recovery at the Avalon Field (After Bruce 1995c).

3.2.5.3 Twofreds Waterflood and CO_2 Flood

The Twofreds Field, discovered in 1957 and developed by Mobil, is another example of the sequence of events, problems, and production longevity that might be anticipated for oil fields in the vicinity of the WIPP. The Twofreds is about 3/4 mile wide and is about five miles long with a net thickness averaging about 16 feet (5 m).

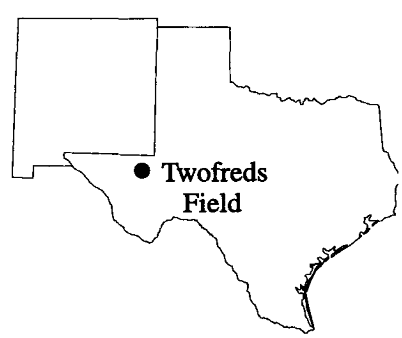

Figure 3-15. Location of Twofreds Field.

The Twofreds Field, like other Delaware fields, has always produced large volumes of water. After six years of primary production, a pilot water injection project with four injection wells was initiated in May 1963. The Twofreds was the first unitized waterflood in the Delaware Basin (Kirkpatrick et al. 1985). Success of the pilot project led to a full scale waterflood with 21 additional injection wells brought on line in January 1966. The waterflood project showed that oil from a Delaware reservoir with a high water cut could be recovered profitably (Jones 1968).

Early estimates anticipated that the Twofreds field would be depleted by 1975. However, carbon dioxide flooding extended the productive life of this field. HNG Fossil Fuel Company acquired the field from Mobil in 1973 for the purpose of initiating a carbon dioxide flood.

At the time of acquisition by HNG, most of the wells were in poor mechanical condition. Only 12 of the 89 wells were producing. Total field production ranged between 150 and 160 bbls oil per day. When the best producing well quit, total field production dropped to 100 bbls oil per day. There was a hole in the casing of the failed well. Many of the other production wells had been abandoned with rods, tubing, and other junk left in the well bores. And although the injection wells had been in waterflood service less than ten years, many had to be reworked to correct channelling problems. In some cases, the water had fingered through some zones, causing channels and leaks around the casing. These had to be repaired to prevent carbon dioxide from leaking out of the productive zone (Wash 1982)

By design, the Twofreds carbon dioxide injection wells were operated very close to the fracture pressure. Surface injection pressures were maintained at 1400 psi which resulted in a downhole bottom pressure of 3,000 psi, only about 100 psi below the fracture pressure. In describing the automatic pressure controls, the field superintendent, W.C. Mason noted:

> We walk a fine line between injection pressures and fracture pressures. If we were to exceed the fracture pressures, the gas would channel up the pipe and get out of zone. Therefore, we'd lose the drive off that well and all the oil that would have been pushed by the CO_2 (Wash 1982).

From 1957 to 1973, primary recovery produced 6.6 million bbls oil. From 1963 to 1973, secondary recovery produced 2 million barrels oil. By 1982, carbon dioxide flooding had produced an additional 2 million barrels of oil (Wash 1982). Carbon dioxide flooding increased oil recovery from 160 bbls oil per day to 1,000 bbls oil per day.

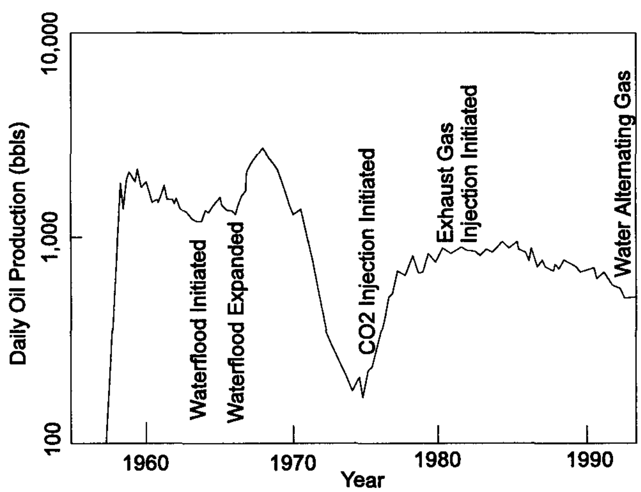

Figure 3-16. Production history of Twofreds (After Flanders and DePauw 1993).

The purpose of the Twofreds carbon dioxide flood was to demonstrate economic feasibility. The field continued to produce based on its economic merit (Kirkpatrick et al. 1985) and demonstrated that carbon dioxide can economically recover tertiary oil from a depleted, waterflooded Delaware sand reservoir (Flanders and DePauw 1993). As of 1993, oil production from the Twofreds was averaging about 500 bbls oil per day (Flanders and DePauw 1993). The Twofreds Field clearly shows that even in a field where the reservoir energy is quickly depleted, fluid injection can improve oil production and add decades to the productive life of a Delaware Basin oil field.

3.2.5.4 El Mar Waterflood and CO_2 Flood

Independent operators continue to explore ways to extend the life of oil field production in the Delaware Basin. The El Mar has been producing from the Bell

Canyon Formation of the Delaware Mountain Group by primary recovery since 1959 (Porter 1966) and by waterflooding since 1968 (Broadhead et al. 1995).

In 1988, Union Royalty purchased the El Mar Unit from Texaco and others. In 1993, the unit was a mature waterflood producing about 140 bbls oil per day. Union Royalty planned to increase production to 2,000 bbls per day using carbon dioxide flooding. In exchange for an interest in the produced oil, Amoco would supply carbon dioxide through a pipeline to be built by Enron from the Dollarhide Field (Moritis 1993). If the success of the Twofreds project is any indication, the El Mar, which has been producing for 37 years can anticipate two or three additional decades of production.

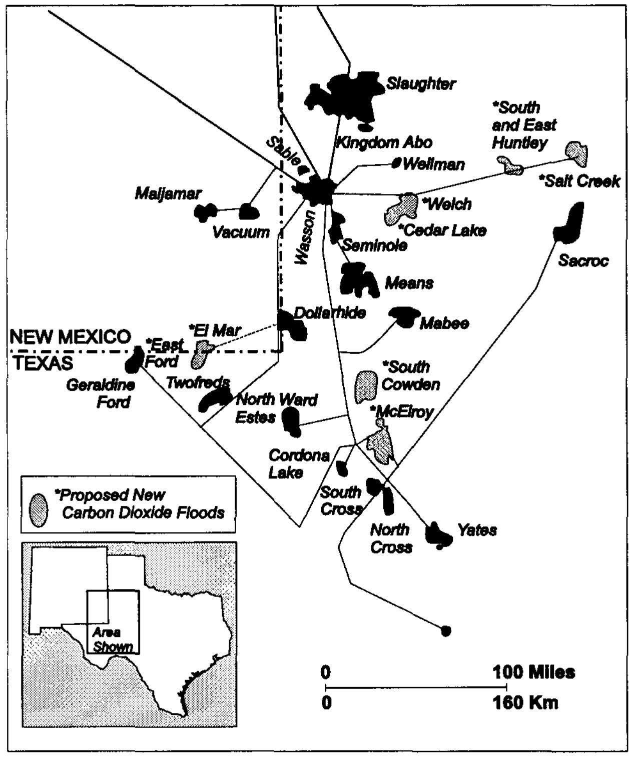

Figure 3-17. Permian Basin main CO_2 pipelines and CO_2 floods (Moritis, 1993).

3.2.6 Waterflood Volumes Around the WIPP

Lori Dotson maintained that waterflooding would not be a problem for the WIPP because such activity, if it occurred, would not be on the same scale as the Rhodes-Yates Field or the Vacuum Field waterfloods. There was disagreement about the amount of water needed to waterflood the oil fields surrounding the WIPP. Matthew Silva suggested that at WIPP, for ten million barrels of oil recoverable by waterflooding, 100 million barrels or more of injected water would be needed. Stoelzel questioned whether that amount of water would be used for such small pools of oil.

Waterflooding in the vicinity of the WIPP is just beginning and, thus far, experience is limited to pilot pressure maintenance programs. The proposed Avalon Unit provides insight into the anticipated amount of water that is needed to recover oil by waterflooding the Cherry Canyon and Brushy Canyon members of the Delaware Mountain Group. This field lies approximately eight miles west of the potash enclave and is not constrained by the presence of potash. At Avalon, Exxon, has calculated that an additional 8.2 million barrels of oil (Bruce 1995c) will be recovered by injecting 141 million barrels of water through nineteen injection wells. Hence, the anticipated ratio of water injected to oil recovered, for the forty-year life of the project, is 17.2.[13]

For the one mile band surrounding the WIPP Site, Broadhead estimated 13.8 million barrels of the proven and probable crude oil reserves that could be recovered by waterflooding. Assuming the Avalon injection ratio of 17.2, for the life of such a project, one can estimate the volume of injected water will be 237 million barrels of water.

Texaco's Rhodes-Yates Lease was two miles away from Hartman's Bates Lease. Assuming that 29 million barrels of oil can be recovered by waterflooding (0.66 million barrels oil per section) and an injection ratio of 17.2 barrels water per barrel oil, for a two-mile band about WIPP, 500 million barrels of water could be injected over the life of these waterfloods. Of course, this simple estimate of future waterflooding must be viewed with caution. It is based on the estimated performance of an analog and is limited to the extrapolation of only proven and

[13]The capital cost for the waterflood facilities at Avalon is estimated at $14.4 million and the estimated value of incremental production recovered from this project is estimated at $123 million based on a crude oil price of $15/ barrel (Bruce 1995a, 3).

probable reserves. It does not include possible reserves or undiscovered reserves of oil and gas underneath potash deposits.

Nonetheless, how does an anticipated 500 million barrels of water injected in the vicinity of WIPP compare with the Rhodes-Yates Field? At Rhodes-Yates, from 1964 through 1991, Texaco had injected approximately 41 million barrels of water through eighteen injectors (Hartman 1993, 5). This simple comparison strongly suggests that WIPP will eventually be surrounded by waterflood operations at least on the scale of the Rhodes-Yates Field and demonstrates that the two are comparable.

Actually, the pressure maintenance programs underway in the immediate vicinity of WIPP are already injecting far greater volumes of water than was injected in the pilot pressure maintenance program at Texaco's Rhodes-Yates Unit. Water from the two pilot injection wells at Rhodes-Yates totaled two million barrels from 1964 to 1974 or approximately 100,000 barrels water per well per year for a ten year period. Pogo Producing plans to inject 365,000 bbls of water per year into one well one mile east of the WIPP as part of its pilot pressure maintenance program in the Livingston Ridge Field.

At the Cabin Lake Unit, at the northwest corner of the WIPP Site, Phillips Petroleum has already begun operating two pressure maintenance wells. Water injection for pressure maintenance was initiated at the James A Well No. 12 (Sec 2, T22S, R30E) on February 18, 1992, and the James A Well No. 3 (Sec 2, T22S, R30E) on November 8, 1993 (Telford 1995). The volume of water injected through the James A Well No. 12 was 945,000 bbls for 1992, 1,121,000 bbls for 1993, and 738,000 bbls for 1994. The volume of water injected through the second pressure maintenance well in this area, the James A well No. 3 was 618,000 bbls for 1994. Based on the 1994 figures, these two wells are averaging approximately 1.4 million bbls water injected per year compared with 200,000 bbls water injected per year through the two pilot pressure maintenance wells at

Rhodes Yates. Furthermore, within ***three years*** of the initial operation, these two wells at the northwest corner of the WIPP Site had already injected four million barrels. This is more than twice the amount of water that was injected into the two pilot injection wells at Rhode-Yates in the ***ten year*** period following the initial operation of those wells. These observations strongly suggest that for the WIPP, the large scale waterflooding scenario cannot be ruled out on the basis of insufficient water injection.

In evaluating potential scenarios for the WIPP, the Hartman vs. Texaco case also demonstrates the need to consider the experience of other waterfloods despite any difference in size, in conditions, or in persons involved. Texaco argued to "exclude testimony relative to events or matters occurring in the waterfloods other than the Rhodes Yates waterflood, and to prohibit reference to other waterfloods by counsel for plaintiffs" (Lanphere and Sullivan 1994c; 1994d). Specifically, Texaco's attorneys maintained:

> On the other hand waterflood areas studied with respect to the 1977 hearings were larger waterflood projects than Rhodes Yates....
>
> The events in this case are vastly dissimilar in many respects to the events in the earlier waterfloods. There are fewer wells in the present field than were drilled in the earlier fields (Lanphere and Sullivan 1994d, 3,5)

Hartman's attorneys countered with the following argument:

> Texaco seeks to exclude by its Motion a wealth of data which correlates waterflows in Lea County to waterflood operations. The correlation is based upon public record documents which were generated by, among others, Texaco. The documents indicate that in the mid-1970s the New Mexico Oil Conservation Division determined that waterflood operations were causing waterflows, caused various operators, including Texaco, to establish committees to look into the issue, investigated specific injection

> wells and other aspects of waterflood operations in order to deal with the problem and never investigated naturally occurring sources of water as a potential explanation for waterflows which began to be reported after the start up of waterflood operations. The evidence shows that such waterflows were not randomly distributed, but are strongly correlated to waterflood operations (Gallegos and Condon 1994, 2).

In evaluating potential scenarios, the WIPP project needs to fully consider the experience of other waterfloods, particularly in light of the experience of oil fields overlain by the Salado. Such experience should not be rejected on the basis of difference in size (larger or smaller), differences in conditions, or differences in persons involved. There appears to be a technical basis as well as legal arguments for such consideration.

3.2.7 Availability of Water

Will there continue to be enough water for secondary recovery? Ron Evans commented on the increasing availability of water for oil field operations.

> If you look at water production in the United States, it has been going up significantly faster than overall oil production. We are producing more and more water in the United States than we ever have, in the oil producing regions of the United States.

More specifically, the volumes of water already being injected in the Delaware Basin, either for salt water disposal or pressure maintenance, do not hint at any water shortages for the purposes of oil field waterflooding. For example, the David Ross "AIT" Federal #1 salt water disposal well approximately one mile east of the WIPP Site typically injects between 80,000 and 100,000 barrels of brine per month. Other wells in the vicinity each typically inject volumes ranging between 10,000 and 100,000 barrels per month (Curry 1995; Hunt 1995; Garcia 1995;

Horsman 1995). Presumably, that water could be made available for waterflooding as reservoir pressures decline.

3.2.8 Formation and Well Bore Damage by Nitroglycerin Stimulation

Dan Stoelzel and Lori Dotson suggested that the practice of nitroglycerin blasting caused extensive formation and well bore damage in Rhodes-Yates Field and the Vacuum Field. They further maintained that because such practices are no longer used, there will be no such completion problems in the vicinity of the WIPP. The DOE has also adopted the position that the problems with Texaco's well completions in the Jal area resulted, in part, from the use of nitroglycerin blasting to stimulate the formation (McFadden 1996). However, the comments of Ron Evans tend to contradict the notion of extensive formation damage by nitro-fracing:

> The reason nitro-frac went out of business is because hydraulic fracturing is a superior stimulation technique. Hydraulic fracturing will give you much greater productivity increases than any nitro-frac ever did and that's well documented. Nitro-fracturing, as it was carried out in the late 40s and early 50s, did not destroy the cement shield. You can do the calculations and show, they place that little charge in the center of the formation and the maximum you could get would be of the order of about seven to ten feet zone of change in the radial direction and on the order of 15 feet in the vertical direction. That never even got you out of the Yates formation.

Hartman maintained that the excessive injection pressures in Texaco's Rhodes-Yates waterflood caused the salt water blowout on the Bates Lease. In commenting on the history of waterflood problems in New Mexico, Ramey (1995, XI-2) also states that water probably escaped from the injection zone and into the salt formations as a result of old improperly cemented and plugged wells and excessive injection pressures in oil field waterflood operations. These observations by Evans, Hartman, and Ramey, strongly suggest that stimulation by nitroglycerin fracturing was not the source of the problem. Rather, it was argued that excessive waterflood injection pressures were the problem (Hartman 1993; Van Kirk 1994).

3.2.9 New Injection Well in Excess of WIPP Lithostatic Pressure

Pogo Producing recently requested and received approval from the New Mexico Oil Conservation Division to operate a pressure maintenance well one mile east of the WIPP site at a maximum surface injection pressure of 1410 psi (9.7 MPa) (LeMay 1995b). Public notice was given and a hearing was held on November 16, 1995. The results of the hearing included the following findings:

> (5) IMC Global Operations, Inc. (IMC), a potash operator in this area, appeared at the hearing and expressed concerns about permitting injection wells in close proximity to potash mining operations. Specifically, IMC is concerned that injected fluid will escape or otherwise migrate from the proposed injection interval into potash bearing formations.
>
> (6) Testimony presented in this case indicates that potash mining operations occur at depths of approximately 1,300 feet to 2,000 feet.
>
> (7) Evidence and testimony present by the applicant indicate that the proposed pilot pressure maintenance project is located:
>
>> a) within the Known Potash Leasing Area as describe within Division Order No. R-111-P;
>>
>> b) directly adjacent to a potash lease which encompasses portions of Section 3 through 5, 8 through 11, 13 through 14, 23 through 24, and 26, Township 22 South, Range 31 East, NMPM. The ownership of this potash lease is undetermined at this time due to ongoing litigation between IMC Global Operations, Inc. and Yates Petroleum Corporation;
>>
>> c) approximately eight miles from IMC's existing potash mine workings; and,

d) one mile from the outer boundary of the Waste Isolation Pilot Project (WIPP)

(8) The applicant notified the Department of Energy (DOE) of its application in this case, however, no representative of that agency appeared at the hearing. (LeMay, 1995b).

The findings also state that injection at an initial surface injection pressure of 1,410 psi should not result in the fracture of the proposed injection interval or confining strata. The well is designed such that the intended horizon for injection is approximately 7,000 feet below the surface.

But in the event of a leak, channeling behind casing, or movement through a vertical fracture, can brine be injected into the Salado Formation? In such an event, under the sustained pressure of a waterflood, what is the fracture pressure of the Salado Formation at the WIPP horizon and what is the hydrostatic pressure of the injected fluid at the WIPP horizon?

The lithostatic pressure at the WIPP horizon is 14.9 MPa (2160 psi). Assuming a brine with a specific gravity of 1.1 and an approved surface injection pressure of 9.7 MPa (1,410 psi), the injected brine can exert a hydrostatic pressure of approximately 16.8 MPa (2440 psi) at the WIPP horizon.

With respect to anhydrite or interbed fracturing, the WIPP conceptual model assumes that repository fracturing or dilation of existing fractures will be less than the lithostatic pressure (Howarth et al. 1995, Section 2.1.2.2). That assumption largely reflects experimental evidence in the excavated areas where the stress fields have been substantially changed. The anhydrite at the injection well bore may or may not be fractured, either naturally or by the drilling activity. Interbeds contain natural fractures which may be partially healed (U.S. DOE 1995, 6-73).

Experimental results indicate the fracture pressure for intact rock to be higher than lithostatic (Beauheim et al. 1993). However, the experiments of Beauheim et al. (1993) were designed to last only a few minutes, hence, they subjected the rock to a very rapid increase in fluid pressure. An injection well operates on the order

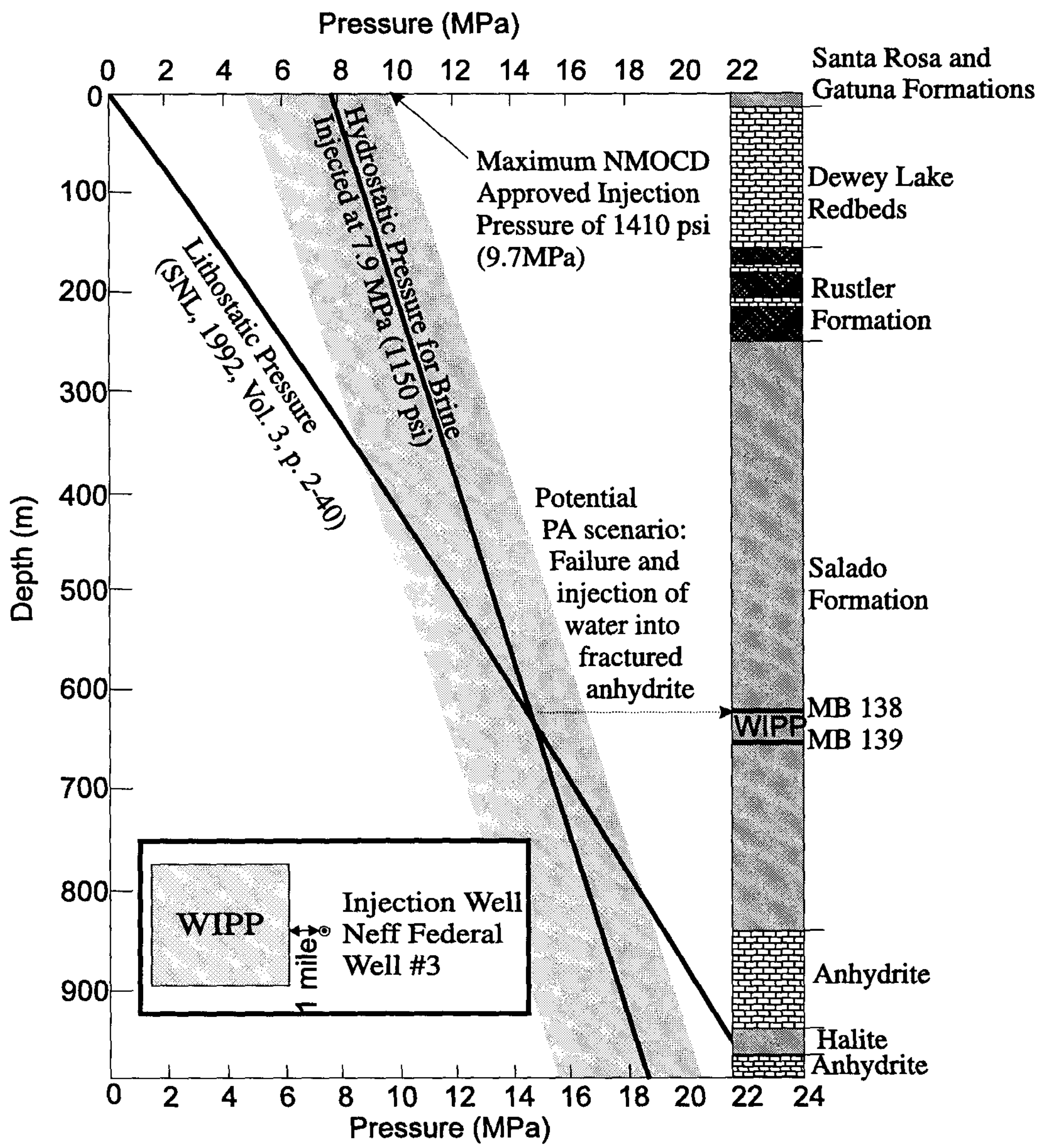

Figure 3-18. Approved Injection Pressure for Neff Federal Well #3 and Potential PA Scenario.

of years or decades. For fracture initiation and vertical fracture propagation, fracture pressures are lower for formations penetrated by an invading fluid (Haimson and Fairhurst 1967, Fairhurst 1968). Atkinson (1987, Chap. 4 and 5) also cautions about subcritical crack growth in the presence of a chemically active environment.

Rather than speculate on the potential for creating a new fracture or propagating an existing fracture in an anhydrite or other marker bed under pressure for a long period of time, this report notes that a pressure maintenance well, approximately one mile from the WIPP, has been approved to operate at an injection pressure 1.9 MPa (280 psi) above the lithostatic pressure at the WIPP horizon. Such a well typically injects brine over a period of several years. The plot of lithostatic pressure and hydrostatic pressure strongly suggests that, in the event of communication, fluid can be potentially injected into the anhydrite beds of the Salado Formation very near the WIPP horizon.

3.3 Regulations and the Salt Isolation Casing String

As noted by Dan Stoelzel, new state regulations require a salt isolation casing string for all wells drilled in the WIPP area. There are no specific oil and gas regulations that apply specifically to WIPP (Ramey 1995). Rather, the WIPP Site is located within the Potash Area near the eastern boundary. As a result of NMOCD Order R-111-P, signed April 21, 1988, all wells completed within the potash area must have a salt isolation string intended to protect the salt section from the intrusion of water and oil and gas (Ramey 1995, IX-1).

At the workshop, Armando Lopez (BLM) noted that a salt isolation string is not required for wells approximately one mile east of the WIPP Site. Exhibit A of R-111-P shows that Sections 26 and 35 (T22S, R31E) lie immediately adjacent to the WIPP site but are not part of the Known Potash Leasing Area. Hence, it appears the salt isolation string may not be required for all oil and gas wells completed in the vicinity of the WIPP.

In 1980, the Department of Energy intended to prohibit waterflooding within former control zone IV (U.S. DOE 1980, 8-4). The DOE surrender of that control was not based on any protective state or federal regulations, but on a report (Brausch et al. 1982) that incorrectly concluded that there would be no waterflooding because there was minimal recoverable oil.

As noted above, the state regulations for completing wells in the potash enclave are not specific to WIPP. In fact, R-111-P (LeMay et al. 1988) addresses only the incompatibilities between the activities of oil and gas production and potash production and does not mention WIPP. With respect to federal regulations, the Secretary of Interior makes it clear that one intent of the order is "to prevent the infiltration of oil, gas, or water into formations containing potash deposits or into mines or workings being utilized in the extraction of such deposits" (U.S. DOI 1986, III.A.4) However, this order is not intended to protect WIPP. Further, despite the salt isolation string requirement, federal and state agencies still restrict drilling for oil and gas through potash reserves or near potash mining operations.

Rather than rely on the intent of new regulations coincidental to the WIPP area, the DOE should fully consider the actual experience and implementation of existing regulations with respect to fluid injection. Such regulations have been in place for decades and provide a measure of the reliability. For example, the enabling orders for the Rhodes Yates waterflood (Campbell et al. 1964; Cargo et al. 1969; Ramey 1977) required operating in accordance with Rules 701, 702, and 703 (Hartman 1993, 4). Rule 702 requires cementing and casing of injection wells to prevent the movement of fluids out of zone. Rule 703 requires operation and maintenance practices to assure no significant fluid movement through vertical channels adjacent to the well bore. Further, the entire operation, including producing wells, must be operated and maintained to confine the injected fluids to approved intervals. The documented problems with the Rhodes Yates waterflood (Hartman 1993; Hererra 1995) and with waterfloods and salt water injection throughout the southeast New Mexico (Ramey; 1976; U.S. GAO 1989; Bailey 1990; Krietler 1994) clearly indicate the limitations of taking credit for state or federal regulations, new or old, for protecting WIPP.

3.4 Safety Analysis Report and Water Injection

Bill Bartlett (EEG) voiced concern at the workshop that waterflooding may need to be considered in the Safety Analysis Report (SAR) for operations. George Dials noted that waterflooding should be considered in the Final Safety Analysis Report only if data exists which shows a high probability event that could adversely affect the WIPP during the 35 year operating life. George Dials added "there is waterflooding going on in the vicinity of the WIPP as has been discussed today. And we see no great increase in brine inflows and no great increase in moisture or anything else in the facility."

It appears that even small increases in the water inflow into the facility have an impact on the continuous air monitors. WIPP operations rely on continuous air monitors to detect a release of radionuclides. This detection is needed to divert the flow of any contaminated air through the HEPA filters. Water flowing into the exhaust shaft at a depth of approximately 50 to 100 feet (16 to 33 m) was identified as a potential problem for continuous air monitoring. In a report on continuous air monitoring, Bartlett and Walker (1996) commented that air flow through the sampling filter would be reduced as salt aerosol and moisture combine and collect on the filter. Low air flow through the filters at an underground air sampler was observed in 1994 and 1995. Moisture was the likely cause, strongly suggesting that water leakage problems can influence CAM performance (Bartlett and Walker 1996, 39).

Samples collected near the exhaust shaft collar by the DOE have been analyzed (Dials 1996).[14] The samples were analyzed for metals and inorganic compounds, but there was no analyses for hydrocarbons. Although there has been an effort to determine the source of the water (Westinghouse 1995, 1996a, 1996b, 1996c), it appears that the source of this water remains unknown. Hence, questions remain. What is the source of the water? At what rate of water inflow does the intruding

[14] The inflow of water into the exhaust shaft was not discussed at the EEG workshop.

water create a problem for the air sampling system? And what happens when the water-flooding and brine injection activities become common place around the WIPP?

3.5 1995 DCCA - Features, Events, and Processes

When asked by Don Hancock (SRIC) how Sandia was going to determine the probability of waterflooding, Peter Swift (SNL) clarified that a feature, event, or process can be eliminated on the basis of one screening criterion. The three criteria of probability, consequence, and regulatory, are not all applied to each case. For example, if waterflooding is eliminated on the basis of "regulatory" criteria or "consequence" criteria, then there is no need to assign a probability. There is no need to calculate a consequence for an FEP that has been eliminated on the basis of another criteria. He also commented that he was not prepared to say how the project was going to screen waterflood FEPs. But he felt that an injection well failure at markerbed 139 with fluid migrating towards the WIPP site would be a low probability event that would be difficult to quantify.

On July 31, 1995, six weeks after the EEG workshop on waterflooding and salt water disposal, the DOE submitted a Draft Compliance Certification Application to demonstrate DOE met the requirements of the EPA Standards for the disposal of transuranic waste. As in 1991 and 1992, fluid injection was ***not*** included in the performance assessment calculations. All fluid injection was screened out on the basis of "regulatory guidance" (U.S. DOE 1995, 6-38). Furthermore, some human initiated events such as recent and ongoing fluid injection outside the controlled area were screened out on the basis of low consequence. No supporting documentation was supplied. Supporting documentation would be supplied with the final compliance application (U.S. DOE 1995, SCR-72).

The 1995 DCCA maintains that the screening procedure "is similar to that proposed by Cranwell et al. (1990, 5-10) and used in the 1991 and 1992 WIPP performance assessments" (U.S. DOE 1995, 6-2). However, Cranwell et al.

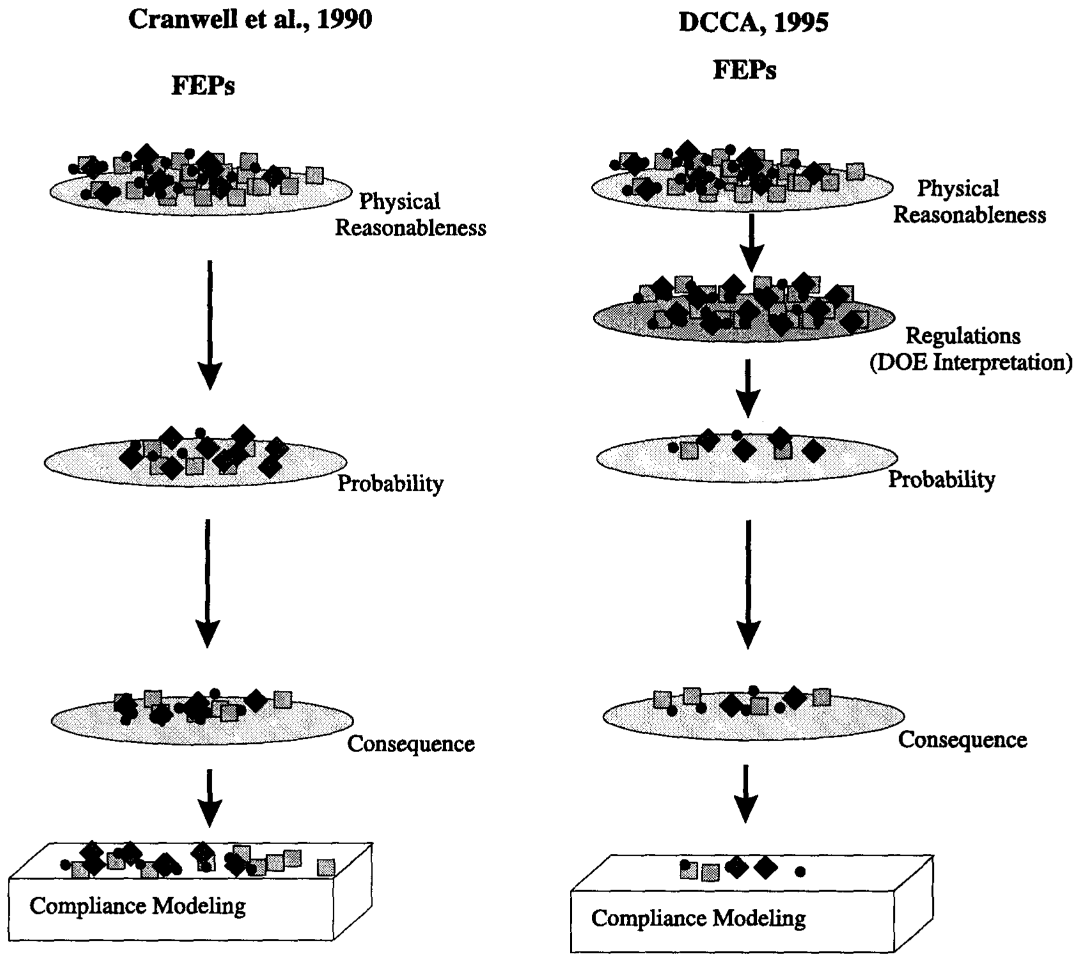

Figure 3-19. "Regulatory" sieve unique to WIPP.

(1990) did not discuss a "regulation" sieve to eliminate otherwise viable scenarios from consideration. This sieve is unique to WIPP (SNL 1992, Vol. 2, 4-3). Further, an inspection of the "regulation" sieve reveals it to be an interpretation of the non-binding guidance by the WIPP Performance Assessment Department which allows the WIPP Performance Assessment Department the latitude to eliminate any inadvertent human activity that could result in a consequence greater than those of exploratory drilling (SNL 1992, 4-4).

3.6 EPA Final Criteria (40 CFR 194) and Compliance Application Guidance

As required by the 1992 WIPP Land Withdrawal Act, the EPA published Criteria, (U.S. EPA 1996a) for determining if the Waste Isolation Pilot Plant will comply with the EPA's environmental radiation protection standards for the disposal of radioactive waste. The EPA also published the Compliance Application Guidance (U.S. EPA 1996b) as a companion to the final rule.

The EPA Final Criteria for the disposal of transuranic waste requires the DOE performance assessment to address the issue of waterflooding and salt water disposal with the following language:

> Performance assessments shall include an analysis of the effects on the disposal system of any activities that occur in the vicinity of the disposal system prior to disposal and are expected to occur in the vicinity of the disposal system soon after disposal. Such activities shall include, ***but shall not be limited to*** [15], existing boreholes and the development of any existing leases that can be reasonably expected to be developed in the near future, including boreholes and leases that may be used for fluid injection activities (U.S. EPA 1996a, 40 CFR 194.32 (c)).

As stated in the EPA Compliance Application Guidance (U.S. EPA 1996b):

> EPA recommends that the terms "near future" and "soon after disposal" for oil and gas drilling be considered to consist of the expected lives of the oil and gas fields in existing leases that can be reasonably expected to be developed in the vicinity of the WIPP.
>
> For mining, the terms "near future" and "soon after disposal" should be applied to the estimated lives of existing mines and plans for new mines in the vicinity of WIPP. EPA recommends that DOE use minable reserves in estimating mine lives and the extent of potential mining. When establishing the rate of growth for mines, DOE should consider both the

---

[15]Emphasis added.

historical growth for mines and the potential for new mines that may be developed in the vicinity of WIPP.

3.6.1 Near Future

For the WIPP project, the DOE has already elicited expert opinion on the definition of *near future* with respect to the recovery of natural resources in the vicinity of a 10,000 year repository.

> For the Boston Team, the near future is 0-300 years after the lapse of institutional controls (100 years after closure). The Southwest Team used a 100-500 year period after closure for the near future while the Washington A Team use the first 200 years after the lapse of active controls. The Washington B Team also adopted a 200-year definition for the near future (Hora et al 1991, V-7).

With respect to current resource development, there appears to be a consensus among this group of experts that the near future includes at least a few centuries; certainly no less than three centuries after closure or at least 3% of the full regulatory period.

3.6.2 Federal and State Plans for Full Resource Recovery

Within two miles of the area withdrawn for the WIPP, the WIPP is surrounded by forty eight sections of federal and state lands. These public lands are managed by either the U.S. Department of Interior or the State of New Mexico. These lands are within the Secretary's Boundary (U.S. DOI 1986) for the potash area. In addition to federal policy (U.S. DOI 1986) for the management of federal lands in the potash area, the management of the federal lands are also subject to the Federal Land Policy and Management Act (FLPMA 1989). The state lands are subject to state regulations protecting natural resources, specifically oil, gas, and potash (LeMay et al. 1988).

With respect to federal lands, it is the stated intent of the Secretary of Interior (U.S. DOI 1986) to "adequately protect the rights of the oil and gas, and potash lessees and operators," (U.S. DOI 1986, 39425). FLPMA intends for "the public lands to be managed in a manner which recognizes the nation's need for domestic sources of minerals, food, timber, and fiber..." (FLPMA 1989, §1702(12)). In addition, FLPMA requires the management of federal lands "be on the basis of multiple use and sustained yield unless otherwise specified by law" (FLPMA 1989, §1701 (7)). "The term multiple use means the management of the public lands and the various resource values so that they are utilized in the combination that will best meet the present and ***future needs*** [emphasis added] of the American people" (FLPMA 1989, §1702(c)). The term multiple use also means "a combination of balanced and diverse resource uses that take into account the ***long-term needs of future generations*** [emphasis added] for renewable and nonrenewable resources...." Sustained yield is defined as "the achievement and management ***in perpetuity*** [emphasis added] of a high-level annual or regular periodic output of the various renewable resources of the public land consistent with multiple use" (FLPMA 1989, §1702(h)). By federal law, human activities in the resource rich areas surrounding the WIPP do not appear to be not limited to the ***near future*** and are not limited to ***the expected use of existing leases***.

The objective of the rules and regulations of the state of New Mexico "is to prevent waste, protect correlative rights, assure maximum conservation of the oil, gas and potash resources of New Mexico, and permit the economic recovery of oil, gas, and potash minerals in the area hereinafter defined" (LeMay et al. 1988).

It is the policy and plans of both federal and state law to promote resource production on these public lands adjacent to the WIPP Land Withdrawal Area. None of the public lands adjacent to the WIPP have been withdrawn from resource development. Hence, the DOE application should assume that potash, crude oil, and natural gas will be allowed to be fully developed, including fluid injection activities necessary for resource recovery.

3.6.3 Oil and Gas Resources

In addition to the oil and gas reserves estimated by Broadhead et al. (1995), the application should also reflect that oil and gas reserves have not yet been quantified on many sections surrounding the WIPP site due to the U.S. Department of Interior and the State of New Mexico restrictions on drilling for petroleum in the potash deposits (U.S. DOI 1986; LeMay et al. 1988). Fifteen sections within the two mile band surrounding the WIPP do not have a single oil and/or gas well drilled into them. Or in terms of forty-acre units, of the 768 forty-acre units within two miles of the WIPP Boundary, 652 of the units do not yet have any oil or gas wells. In other words, 85% of the area immediately surrounding the WIPP has yet to be directly tested for oil and gas. The oil and gas leases in many of these areas have been assigned, but permission to drill has been denied and/or is in litigation (Burski 1994). Similarly, potash reserves are in litigation (Parker 1993) or have yet to be assigned although at least one potash company has stated that it intends to mine these reserves on public land (Morehouse 1995).

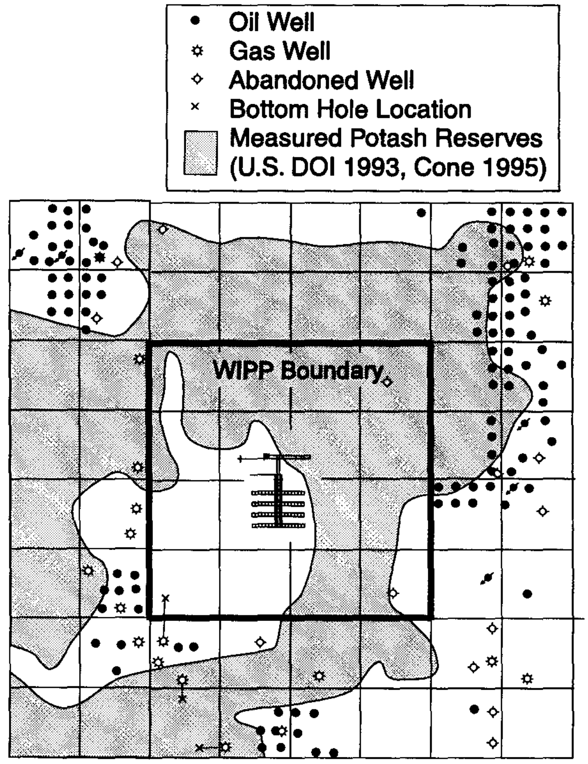

Figure 3-20. Actual oil, gas and injection well boreholes.

The nature of any resource recovery activity, including the oil and gas business, is such that today's non-economical resources often represent tomorrow's producible reserves. The application for a 10,000 year repository should reflect an understanding of that principle of natural resource economics and can not limit itself to a simple assumption of current economic value. And as emphasized in the executive summary of the 1995 natural resources study (NMBM&MR 1995), the discovery of reserves of oil and gas can hinge simply on a better interpretation of well logs. Hence, current estimates of oil and gas resources reflect, to some extent, the limits of the current interpretation of well logs. Due to the nature of oil and gas production, as practiced throughout southeastern New Mexico, throughout the Delaware Basin, and in the vicinity of the WIPP, the existing federal plans and state plans inherently include salt water disposal and waterflooding throughout each and every federal and state section surrounding the WIPP Site.

3.6.4 Fluid Injection for 10,000 Years

The DOE application may need to consider fluid injection adjacent to the site and within the site for the full 10,000 year period. In the 1991 DOE elicitation of expert opinion on future activities in the vicinity of the WIPP, only one of four teams addressed fluid injection. This team was aware of the need to dispose of waste brine associated with oil production (Gordon et al. 1990, C-29), but was not aware of the extent of drilling for crude oil in the vicinity of the WIPP (Silva 1994, 28-35). Hence, the elicitation panel concluded that the current level of industrial activity in the WIPP area to be low (Hora et al. 1991, IV-10). Nonetheless, three members of the this team assigned probabilities for injection of waste brine associated with other industrial activities for the full 10,000 years. Further, the probability of a larger number of such injection wells was predicted to increase with time for the full 10,000 year period (Hora et al. 1991, Table IV-16).

3.6.5 Areal Extent of Delays in Oil and Gas Production

As to potential delays in oil and gas production and fluid injection due to the presence of minable potash, that issue is still in deliberation (Burski 1994).

Furthermore, there appears to be some disagreement as to what constitutes minable potash. The estimates of potash resources prepared by Griswold (1995a) for the New Mexico Bureau of Mines and Mineral Resources acknowledges federal policy but uses an economic limit which is different from federal policy, resulting in minable areas substantially smaller than federal policy. Cone (1995) later cautioned Griswold about BLM policy and experience. Griswold (1995b) subsequently acknowledges that his interpretation of the estimated extent of potash reserves is "conservative." According to Cone (1995), the federal position for minable potash is 4 feet by 10% for sylvite ("40" contour) and 4 feet 4% for langbeinite ("16" contour). Hence, the federal position on the actual area of minable potash, which could impact the near future activity of oil field production and fluid injection, is significantly larger than that mapped by the "55" contour for sylvite and the "37.5" contour for langbeinite in the natural resources study by the New Mexico Bureau of Mines and Mineral Resources (1995). Drilling for oil and gas may be delayed over a much larger area, thus extending the time for such near future activities.

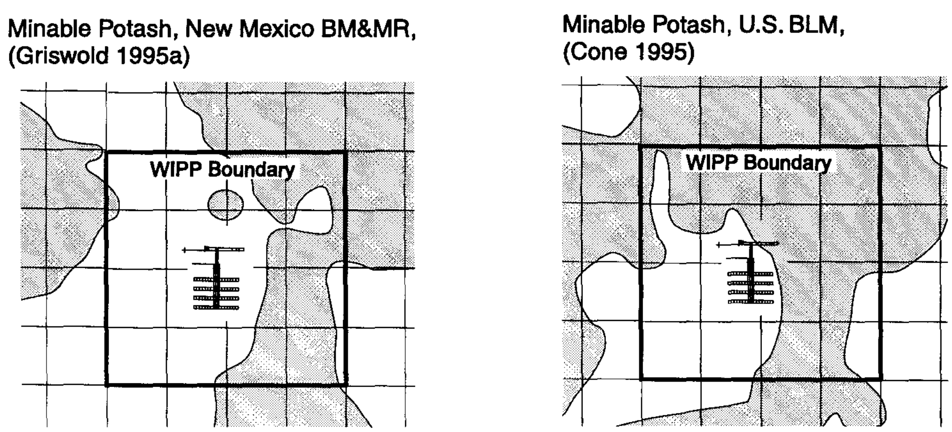

Figure 3-21. Areal extent of minable potash as determined by U.S. BLM and New Mexico Bureau of Mines and Mineral Resources.

3.6.6 Enhanced Oil Recovery by Carbon Dioxide or Gas Injection

The DOE application is sponsoring a new research effort that is exploring the use of pressure maintenance programs and advanced reservoir management to improve oil recovery from fourteen sands in the Brushy Canyon and Cherry Canyon members of the Nash Draw Unit (Strata Production 1996) in the potash enclave. One goal is to transfer the technology to oil and gas producers throughout the Permian Basin. The Department of Energy is sponsoring the project at an annual budget of 1.8 million dollars. The permeabilities in the sands are relatively low, ranging from 0.5 to 18 millidarcies. Although not stated in the progress report (Strata Production 1996), the low permeabilities strongly suggest that it may be necessary to inject a low viscosity fluid such as carbon dioxide or natural gas. Presumably, the Department of Energy is investing in this project, in the Delaware Basin, with the anticipation that such fluid injections will improve oil recovery. The DOE WIPP application should reflect this effort to enhance oil recovery in Delaware sands.

3.6.7 Summary

In summary, the DOE WIPP application to EPA can assume that for crude oil, there will be drilling on a minimum of forty acre spacings in the areas in litigation. There will also be drilling on a minimum of forty acre spacing in areas identified by Broadhead et al., (1995) known to contain proven and probable oil reserves, and there will be drilling into the fifteen yet to be explored sections within two miles of the WIPP. The extent of oil and gas resources remain to be determined. Experience has also shown that additional reserves are often discovered as a result of improvement in well log interpretation (NMBM&MR 1995). The DOE application needs to demonstrate an understanding of the economics of resource recovery and the concept of future reserves, an understanding of federal and state policy and plans regarding resource recovery on public lands, including pressurized fluid injection, an understanding of how pressurized fluids can transport radionuclides to the accessible environment, and an understanding that the EPA intends that the repository curb the release of radionuclides to the accessible environment for a 10,000 year regulatory period, not just the near future. The application can realistically anticipate that salt water disposal activities and waterflooding, as practiced in the Delaware Basin and in southeast New Mexico, will take place throughout the area surrounding the WIPP. The application needs to consider other fluid injection, such as gas pressure maintenance, and needs to anticipate industrial waste injection over the full 10,000 year life of the repository.

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5. LIST OF ACRONYMS

ANPR	Advance Notice of Proposed Rulemaking
APD	Applications for Permit to Drill
BBL	Barrels
BLM	Bureau of Land Management
CAO	Carlsbad Area Office
CARD	Citizens for Alternatives to Radioactive Dumping
CFR	Code of Federal Regulations
DCCA	Draft Compliance Certification Application
DOE	U.S. Department of Energy
DOI	Department of Interior
EEG	Environmental Evaluation Group
EPA	U.S. Environmental Protection Agency
ERDA	Energy Research and Development Administration
FEP	Features, events, and processes
FLPMA	Federal Land Policy and Management Act
GAO	U.S. Government Accounting Office
GPM	Gallons per minute
MOU	Memorandum of Understanding
MPa	Megapascal
NAS	National Academy of Science
NMBM&MR	New Mexico Bureau of Mines and Mineral Resources
NMEMD	New Mexico Energy and Minerals Department
NMEMNRD	New Mexico Energy, Minerals, & Natural Resources Department
NMOCD	New Mexico Oil Conservation Division
NMPM	New Mexico Principal Meridian
OCD	New Mexico Oil Conservation Division
PA	Performance Assessment
PCs	Personal computers

LIST OF ACRONYMS (continued)

PSI	Pounds per square inch
RCRA	Resource Conservation and Recovery Act
SAR	Safety Analysis Report
SC&A	Sanford Cohen and Associates
SNL	Sandia National Laboratories
SWD	Salt water disposal
SRIC	Southwest Research and Information Center
TA	Temporarily Abandoned
TRU	Transuranic
USCA	United States Code Annotated
U.S. EPA	U.S. Environmental Protection Agency
U.S.G.S	U.S. Geological Survey
U.S. GAO	U.S. Government Accounting Office
VOC	Volatile organic compound
WIPP	Waste Isolation Pilot Plant

6. LIST OF WORKSHOP ATTENDEES

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