CARD

Citizens For Alternatives To Radioactive Dumping

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Included here are CARD's comments on the Department of Energy's Compliance Criteria Application. These comments consists of nine papers:

1. ***Comments on the Department of Energy's Compliance Criteria Application, 1996 for the Waste Isolation Pilot Plant, New Mexico*** (David T. Snow, Ph.D., P.E.) provides an overview of some problems at the WIPP site and addresses subjects related to failure of seals and engineered barriers, discharge from the undisturbed and disturbed repository via paths to the surface or to Rustler aquifers caused by hydrofracturing around borehole seals or shafts or through the overburden strata. Secondly, groundwater flow and transport incident to concentrated discharge in fractures and dissolution conduits of the Rustler and younger formations is discussed, suggesting that those barriers are compromised.

2. **Conceptual Errors in the Department of Energy's Model of Groundwater Flow in the Rustler Formation** (Richard Hayes Phillips, Ph.D.) describes the Rustler as, among other things, a fractured aquifer with three-dimensional flow and karst features. This differs greatly from DOE's model which describes the same aquifer as porous, homogenous and confined with horizontal flow. Problems with DOE's descriptions of matrix diffusion, clay sorption and other processes are addressed.

3. **Cavernous Zones at the WIPP Site** (Richard Hayes Phillips, Ph.D.) presents detailed evidence of karst at the WIPP site.

4. **Rainwater Recharge at the WIPP Site** (Richard Hayes Phillips, Ph.D.) presents detailed evidence of rainwater recharge at the WIPP site.

5. **Potential Flow Paths From the WIPP Site to the Accessible Environment** (Richard H. Phillips Ph.D. and David T. Snow Ph.D., P.E.) describes how flow paths from the WIPP site are directed along karst channels and enlarged fractures ,allowing rapid transport to the accessible environment. Flow paths from the site to Nash Draw are identified.

6. **Breach Scenarios at the WIPP Site** (Richard H. Phillips Ph.D. and David K. Mitchell, P.E.) describes how the WIPP site is vulnerable to human intrusion because of the abundance of natural resources above, below and near the site. Breach scenarios involving the pressurized brine reservoir beneath the site and nearby fluid injection wells are detailed as well as DOE's lack of demonstration of shaft sealing technology in the field.

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7. Nuclear Transmutation as a Means of Reducing the Menace of Plutonium and Radioactive Waste (Harold M. Frost IV) describes Accelerator Transmutation of Waste as a promising technology which could power itself and be an alternative to deep geological disposal of wastes.

8. WIPP Waste Storage Concerns at Los Alamos National Laboratory (LANL) (Deborah Reade) describes LANL's current storage and disposal of transuranic and low level waste and presents information that it is old disposal practices as well as past and current laboratory operations which are the most likely sources of offsite contamination. Choosing to spend limited waste management money to prepare waste for WIPP disposal has kept LANL from being able to put retrievably buried transuranic waste into inspectable storage.

9. Human Error and the Department of Energy (Deborah Reade) describes why human error must be included as a separate factor in all of DOE's compliance calculations. Some problems of risk assessment and human error in the DOE system are presented. Human error that led to the 1987 waste hoist accident at the WIPP site are also described.

More detailed executive summaries and the papers themselves follow.

Executive Summaries of CARD's Comments on DOE's Compliance Criteria Application

Comments on DOE's Compliance Certification Application, 1996
For the Waste Isolation Pilot Plant, New Mexico

David T. Snow, Ph.D.., P.E.

The complex but untested design of a proposed permanent underground storage facility for the nation's low-to-intermediate military nuclear waste deserves, but is not getting, the highly conservative treatment the public should expect. Flawed from the outset by brine in the salt beds and by the mechanical squeeze the plastic salt will inevitably impose on the waste drums, it is a certainty that any mobile radioactivity, such as brine may obtain by dissolving some of the plutonium, will ultimately be extruded upwards into shallow aquifers or to the surface. No conceivable seal design can withstand the extrusion, since fluid at pressures equal or more than the pressure of the rocks will fracture upwards along the boundaries of the seals, or along abandoned boreholes to the repository level. Otherwise, if defects in the salt strata prove weaker, fractures will break upwards to the aquifers. Similarly, hydraulic fracturing could occur to and drive brine through the repository in the event that oil-field pressure stimulation is continued in the vicinity, or if our progeny inadvertently sink exploration drill holes through the repository, intercepting highly-pressured brines that predictably underlie the repository.

DOE has relied upon the apparent properties of the Culebra dolomite, a likely path for travel from the repository site to the accessible environment (distant about 5 km) in calculating total radionuclide releases that do not exceed the limits of 40CFR191 in the first 10,000 years. While tests in 30-odd boreholes span four orders of magnitude of hydraulic conductivity (on which speed of travel depends), none

of the tests reveal the worst that is likely to exist. Evidence gathered at the surface (such as sinkholes into which storm-waters disappear, and more), as well as subsurface drill data largely obscured by low-technology coring techniques used in the past 30 years, support conservative opinions shared by many geologists that large solution conduits exist at shallow depths. Unlike the slow paths envisioned by DOE, the evident dissolution pathways typical of cavernous regions imply rapid groundwater movements from the region of the WIPP site to nearby Nash Draw. Consequently, the Culebra is not reliably characterized as a barrier to rapid flow or excessive radionuclide releases.

Failing to demonstrate in its application either that the underground repository can retain the rad-waste by effective sealing, or by reason of the integrity of overlying strata to contain or delay it, DOE must rely wholly upon engineered barriers in the repository. While one chemical component has been proposed (MgO) as a partial backfill that will minimize plutonium solubility, DOE has not proposed other barriers that could absorb the brines to immobilize the potential effluent. In view of the above, the application should be rejected.

Conceptual Errors in the DOE Model of Groundwater Flow in the Rustler Formation

Richard Hayes Phillips, Ph.D.

The DOE model of groundwater flow in the Rustler Formation is a misrepresentation of reality. The Rustler is a fractured, karstic, anisotropic, artesian aquifer with three-dimensional flow. It should not be modeled as a porous, homogeneous, isotropic, confined aquifer with horizontal flow. The processes of matrix diffusion and clay sorption have not been demonstrated in the field; the values assumed for rock hydraulic properties are at variance with observed lithology and measured transmissivity; and the values assumed for rainwater recharge are unreasonable.

Cavernous Zones at the WIPP Site

Richard Hayes Phillips, Ph.D.

Evidence of karst at the WIPP site is gathered and presented. Zones of unconsolidated or cavernous rock in Rustler mudstone, in both the Forty-Niner and the lower unnamed members, are correlated stratigraphically across the WIPP site; a zone of dissolution in Tamarisk gypsum is identified; encounters of caverns in the Dewey Lake Redbeds are reported; and karst sinkholes at H-7, WIPP-33 and WIPP-14 are described in detail.

Rainwater Recharge at the WIPP Site

Richard Hayes Phillips, Ph.D.

Evidence of rainwater recharge at the WIPP site is gathered and presented. Mescalero caliche, Gatuña sandstone, and the Dewey Lake Redbeds are shown to be transmissive to rainwater recharge. Water in the Dewey Lake Redbeds is commonplace and potable; recharge tends to occur where the Santa Rosa

Sandstone is not present. Groundwater and karst features are found in all members of the Rustler Formation. Water in the Culebra Dolomite is everywhere unsaturated, in places potable, and freshest where recharge is greatest.

Potential Flow Paths From the WIPP Site to the Accessible Environment

Richard H. Phillips, Ph.D.
and David T. Snow, Ph.D.

Flow paths from the WIPP site are primarily directed along karst channels and fracture system enlargements, allowing rapid transport to the accessible environment. Potential flow paths from the WIPP site to Nash Draw are identified, consistent with geophysical logs, lithologic descriptions, washouts during drilling, loss of core, loss of circulation of drilling fluid, caverns identified by drilling, multi-well pump tests, high transmissivity, hydraulic heads, groundwater geochemistry, dissolution of halite, distribution of salinity, karst geomorphology, air photo interpretation, sinkholes identified by augering, field observations of rainwater recharge at WIPP-33, field observations of groundwater discharge at Laguna Grande de la Sal, and the regional water balance.

Breach Scenarios at the WIPP Site

Richard H. Phillips, Ph.D.
and David K. Mitchell, P.E.

The WIPP site is vulnerable to human intrusion. It should not have been located in a mineral district. The existence of oil, natural gas, and potash resources was known before the site was selected. In the future, an oil or gas drillhole could penetrate the waste panels and tap into geopressurized brine beneath the repository. Even today, any oil injection well within two miles of the site could force pressurized brine into the repository. Waste containment at WIPP depends upon the ability to seal the WIPP shafts, perfectly, forever, but such technology has not been demonstrated in the field.

Nuclear Transmutation as a Means of Reducing the Menace of Plutonium and Radioactive Wastes.

Harold M. Frost IV

Transmuting radioactive isotopes into stable isotopes and isotopes with shorter half-lives is an alternative to burying radioactive waste and would produce more energy than it consumes. An intense beam of protons would bombard target material which then would produce a shower of neutrons. The intense flux of neutrons causes the transmutation reaction in plutonium or other wastes. A runaway chain reaction could not occur and after radioactive waste is all transmuted, the system could be run to produce energy with thorium or uranium. The technology of *Accelerator Transmutation of Waste (ATW)* is not difficult and much of the technology is developed or being developed. ATW could eliminate the possibility of future mining of waste repositories for plutonium since waste would not have to be buried.

WIPP Waste Storage Concerns at LANL

Deborah Reade

Los Alamos National Laboratories (LANL) has the 4th largest volume of transuranic waste of the Department of Energy (DOE) system. This waste is planned to be shipped to WIPP. Transuranic (TRU) waste is retrievably stored in several ways at LANL's Area G. contact-handled TRU waste is in above-ground fabric domes where it is inspectable, in above-ground bermed storage, and buried in pits and trenches. Remote-handled TRU waste is buried in lined or unlined shafts. Pre-1971 generated TRU waste is non-retrievably buried and is not planned to be sent to WIPP. The Pantex Plant and Sandia National Laboratories expect to send TRU waste to LANL for characterization and storage.

DOE has said waste can safely be stored onsite for 100 or even 140 years, but people living near LANL are concerned that air, soil, and water will be contaminated by stored TRU waste. Radioactive contamination has already been found offsite. WIPP waste is one of the least likely candidates as the source of this contamination, however. Legacy waste and past and current laboratory practices like exploding depleted uranium, mercury, lead, and beryllium on mesa tops are more likely sources. Older retrievably buried WIPP waste is of some concern, but cannot be dug up and placed in inspectable storage for at least 10 years because money is being used to get ready for shipment to WIPP instead.

DOE has identified around 2000 potentially contaminated sites on and near LANL. Runoff from storms and snow melt washes contaminants into canyons that end up at the Rio Grande. Even if stored WIPP waste were gone, LANL would still be a major disposal site. It has the 3rd largest inventory and generation of low-level waste (LLW) and disposes of 24,000 drums of LLW at area G yearly. This waste is also a more likely source of contaminants than above-ground retrievably stored WIPP waste.

Potential storage problems for WIPP waste are tornado-like winds, earthquakes or fires. Volatile Organic Compound exposure of workers is also of concern. Better storage containment would give us more security while actively pursuing appropriate technologies for permanent solutions to our waste problems.

Human Error and the Department of Energy

Deborah Reade

Human error must be included as a separate factor in all of DOE's compliance calculations. Some human and organizational risk factors–both general and specific to the DOE–are described. The 1987 waste hoist accident at the WIPP site is described as an example of poor risk analysis that did not include the human error factor. Uncertainties about waste characterization and interactions, site hydrology and seal performance must be reduced or eliminated.

Abstract of

Comments on doe's Compliance Certification Application, 1996
For the Waste Isolation Pilot Plant, New Mexico

David T. Snow, Ph.D., P.E.

The complex but untested design of a proposed permanent underground storage facility for the nation's low-to-intermediate military nuclear waste deserves, but is not getting, the highly conservative treatment the public should expect. Flawed from the outset by brine in the salt beds and by the mechanical squeeze the plastic salt will inevitably impose on the waste drums, it is a certainty that any mobile radioactivity, such as brine may obtain by dissolving some of the plutonium, will ultimately be extruded upwards into shallow aquifers or to the surface. No conceivable seal design can withstand the extrusion, since fluid at pressures equal or more than the pressure of the rocks will fracture upwards along the boundaries of the seals, or along abandoned boreholes to the repository level. Otherwise, if defects in the salt strata prove weaker, fractures will break upwards to the aquifers. Similarly, hydraulic fracturing could occur to and drive brine through the repository in the event that oil-field pressure stimulation is continued in the vicinity, or if our progeny inadvertently sink exploration drill holes through the repository, intercepting highly-pressured brines that predictably underlie the repository.

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Failing to demonstrate in its application either that the underground repository can retain the rad-waste by effective sealing, or by reason of the integrity of overlying strata to contain or delay it, DoE must rely wholly upon engineered barriers *in* the repository. While one chemical component has been proposed (MgO) as a partial backfill that will minimize plutonium solubility, Doe has not proposed other barriers that could absorb the brines to immobilize the potential effluent. In view of the above, the application should be rejected.

Comments on DoE's Compliance Certification Application, 1996
For the Waste Isolation Pilot Plant, New Mexico

David T. Snow, Ph.D., P.E.

Introduction

Disposal of radioactive waste is a virgin industry, the product of 50 years' labor to conceive safe resting places for the legacy of bombs and power plants. Not one prototype has been built anywhere on earth to test the many solutions proposed by the thousands of involved technologists of many pursuasions and countries. The nuclear waste disposal industry is in about the same state that dam-building occupied when (in the 1930's) we suffered in America the failures of the St. Francis Dam, the Fort Peck Dam, the Hales Bar Dam and others. Failures are predictable for prototypes dependent upon geology, an inexact science replete with surprises, usually because exploration provides only a fraction of the necessary data. Since WIPP is the guinea pig, we must treat the ground with the respect experience should have taught us. The wishful thinking, the false confidence detectable in a thousand topics the DoE proposal entails is cause for uncommon conservatism, remembering that the proponent, all its contractors and even reviewers have a positive bias. There is a comfortable interdependency among a diversity of "experts", none of whom have built a successful repository, nor put their names to their findings. Who are the professional engineers the public has licenced, who can be trusted with this complex paper edifice?

I wish to express a healthy skepticism about some untested expectations of repository containment, and upon the best-case assumptions used to predict transport in groundwater. I submit my qualifications (see website www.mallmerchant.com/dr-snow) to express views drawn from abundant hydro-geotechnical experience, much of it with repository siting.

Apropos of responsibility, the EPA has imposed the common-sense restriction, based on RCRA prohibitions on land disposal of toxic waste (present in some TRU containers) that the waste must be retrievable. EPA only requires that the retrieval be possible, not that it be easy or economic (CCA 7.6.1). It is clear that future generations will find it infeasible, practically precluding retrieval from this site. That effectively leaves no slack for inevitable mistakes in concept, data validity or interpretation, or the design of the many vital parts such as those intended to minimize the mobility of dissolvable actinides, to isolate the repository contents from shallow strata or to limit radionuclide transport in aquifers carrying water to the accessible environment. DoE claims (CCA 7.6) that waste retrieval is possible and it has been demonstrated. Were the simulated waste containers in place in time to be crushed by a roof collapse, then retrieved ? Assuming that actual retrieval would be attempted after repository performance proves unsatisfactory, the real conditions would entail crushed drums and wooden boxes under tons of fallen salt, part of whose radioactivity has escaped in liquid form and dispersed throughout cracks of the disturbed rock zone (DRZ) beneath the heaved floor, or as salt backfill impregnations. The total contaminated volume might be five to ten times the original volume, a mechanically-heterogeneous mix of salt, metal and

plastic, poorly suited for machine excavation, diluted but radiologically as variable as its source. The problems of safe handling, as well as of packaging, transport and of disposal would be more monumental and uncertain than the present, near-impossible task of safe siting. The economic burdens would be so great that stop-gap options of surface protection or land abandonment would be far more feasible and likely. A present mistaken decision to store the waste is not permissible because creep closure and its consequences make waste retrieval impractical. If any miner says it can be done, it is because he expects never to be so required.

DoE has been eager to solve the national problem of too many inadequate TRU waste storage facilities around the country, by concentrating it all at WIPP. It has lead to a premature solution. The proposal is elaborate and seemingly conceived carefully, yet it retains unsolved some fundamental problems. Neglect of these has produced a project the public should view as irresponsible, thus not allowable.

At the outset, there were established some wise geological criteria for site selection (CCA 2.1, p.2-6). Some of these have not been satisfied for the WIPP site. Contrary to DoE's claims, 1) the plastic nature of the salt host-rock does not have the ability to encapsulate the waste under all conditions, since fractures of the DRZ around the rooms developed in the stiff anhydrite interbeds provide egress of fluid waste components and collected brines through hydrofractures, and 2) the consequences of karstic dissolution of the Rustler and Dewey Lake Red Beds are unknown in character, though some features of karst exist at and near the site. 5) future exploitation of known resources is neither predictable nor necessarily minimal.

Containment

It is clear that radionuclide releases from WIPP to the accessible environment in excess of the limitations of 40 CFR 191 can occur only if three factors are met:

1. A sufficient fraction of the actinide inventory must be mobilized in dissolved or colloidal form.
2. The engineered containment within and adjacent to the repository must be breached and capable of discharging brine, and
3. The intervening geologic environment and man-made features within it facilitate effective transport to the compliance boundary.

As long as poor definition characterizes the nature of the waste (such as the amount, size distribution and solubility of plutonium particles) and other parameters are ill-defined, such as the amount of reacting brine and numerous other components still being investigated in the actinide source term (AST) project, DoE cannot eliminate the first factor unequivocably. The CCA relies heavily on elimination of factors 2. and 3. Among the various claims being disputed by interveners to this application, the writer addresses some limited but vital subjects related to failure of seals and engineered barriers, discharge from the undisturbed and disturbed repository via paths to the surface or to Rustler aquifers caused by hydrofracturing around borehole seals or shafts or through the overburden strata. Secondly, groundwater flow and transport incident to concentrated discharge in fractures and dissolution conduits of the Rustler and younger formations is discussed, suggesting that those barriers are compromised.

Shaft Seals

The intended hydraulic function of shaft seals (CCA 3.3.1.2) is to "restrict groundwater flow" and "limit radionuclides", not to eliminate them. There is neither a proven, field-tested technology of sealing (especially in salt), nor an irrefutable conceptual design to assure us that those objectives will be met. Shaft seals in mining applications have histories of such frequent failures as to make a prudent engineer treat the proposed seals with cautious skepticism, even if their design is apparently good, innovative, well-studied and reviewed.

I examine, first, the mechanical behavior of some seal components in relation to each other, during the period of shaft closure before significant repository air pressures are imposed. I examine, second, the propensity for seal failure by pneumatic hydrofracture, a potential mechanism for development of a conduit for concentrated, rapid egress of air and brine, contaminated or otherwise, from the repository to the Rustler aquifers or the surface. It is evident that the seal designers may have given insufficient credence to the hydrofracture mechanism along the seals, or into the strata above the repository, competing avenues for release of the pressures that will build upon compression of the air and gasses that will develop in the repository.

Concrete plugs with asphalt water-stops have recently been redesigned. Such "chemical" seals in mine-shaft use have a checkered history of failure by displacement. Asphalt is a viscous liquid, so when subjected to shear, it is more readily deformed than is salt. The intended function of the asphalt, filling not only a shaft segment, but also filling a tapered kerf (slot) excavated all-around one radius into the shaft wall, is to intercept the DRZ, believed to be the most likely path for fluid bypassing the impermeable seal materials that will fill the shaft. The radial extension of the DRZ around the tip of the kerf has been modeled (CCA 7.6.1) to conceptualize its development and subsequent crack closure when the asphalt and adjoining concrete plugs take on load from the convergence of salt. One cannot tell from the text whether or not the modeling is realistic in conceptualizing the closure consequences.

The asphalt will shrink slightly during cooling (days), after the upper concrete plug has set (hours). Presumably, the concrete plug will support itself in shear without salt damage as the concrete gains strength (months). Ensuing creep deformation of the walls (years) will load the asphalt and concrete. According to reported structural calculations (SEAL 7.4.4.2), the radial stresses for upper, middle and lower seals in asphalt will be only 1.8, 2.5 and 3.2 MPa at 100 years, and in concrete (SEAL 7.4.1.2), only 2.5, 4.5 and 5.5 MPa at 50 years. They claim that such modest backpressures will heal the DRZ, even while creep continues to close the shaft. The geometry of the kerf will speed its closure, relative to the radial closure around cylindrical concrete elements, thus modeling should show vertical components of salt movement towards the kerf. As stated (CCA 7.6.1, Para 2), after 20 years the DRZ is localized, 2 m deep, at the asphalt/concrete contact, where such shear of salt against concrete must be maximum.

The designer's concern should be that more rapid closure of the kerf will raise the asphalt pressure more rapidly than the salt/concrete contact pressure, so that asphalt may prise and penetrate upwards along that contact. Whenever a fluid of density less than the surrounding rock rises to higher levels, the propagation of the hydrofracture is unstable. There is nothing to prevent

the extrusion of the asphalt until the water-stop is replaced (centuries) by salt, and the asphalt is displaced along the contact of the overlying clay seal segment. Apparently we cannot count on the interception of potential seepage paths along the shaft DRZ by placement of asphalt water-stops, because they may not be permanent.

The asphalt column at the top of the Salado (element 6 of Fig. 3-4) is to be composed of asphaltic aggregate. It will be lightly loaded and will have some shear strength, so will have limited or no mobility past its upper plug of concrete placed against anhydrite of the Unnamed member of the Rustler.

Other parts of the seal system should compact without discharge or distortion.

Repository Pressure and Discharge

Waste emplacement design includes a backfill of sacks of MgO placed to buffer acidity as CO_2 evolves from decomposing organics in the waste. Hydration to $Mg(OH)_2$ will sequester water beneficially, but release it as CO_2 combines with the hydroxide. Besides maintaining low actinide solubility, it is evident that the MgO will reduce the rate of gas pressure build-up and diminish the liquid filling repository voids.

Castile brine occurrences pressurized by biogenic H_2S (such as ERDA-6, 1981) are analogues for the evolution of repository contents, wherein decomposition of cellulose, plastics, rubber and steel will generate CO_2 and H_2. DoE's concepts of the nature of these Castile brine reservoirs is found in CCA 6.4.8, but there is no recognition that primitive pressures must be lithostatic as a limit, that the extent, interconnectedness and discharge processes must be tied to the stress state of salt. The Castile fluids are stored in rather stiff fractures in the anhydrite. The pressure has developed by microbial reduction made possible by methane or petroleum in the presence of anhydrite. Its threshold for dissipation by hydrofracture along weak contact partings is the lithostatic pressure of salt adjoining such fractures, not the steep fractures interior to the anhydrite beds. Upon tapping such a reservoir with a drill hole, its head is initially thousands of feet above land surface, but as it flows, friction drops the pressure rapidly. It would flow freely until anhydrite fracture closure attains hydrostatic pressure for the brine.

How much of the H_2S is dissolved or gaseous in the Castile is unknown, but it is probably dissolved because none of the drill intersections have produced gas only, followed by brine. In addition to elastic closure of fractures and expansion of brine, evolving gas in the column drives the well discharge. Remote parts of a reservoir become isolated as diminishing pressure causes closure of hydraulic fractures at salt contacts.

In the repository, compaction begins with air only, and ends with air, decomposition gasses and brine from inflows, all at lithostatic pressure. The greatest factor of uncertainty is the amount of brine that will enter during the long room closure period while pressure is below lithostatic. The National Academy review (NAS, 1996, App. C) summarized the competing theories, indicating cumulative inflows in the range of 500 to 800 l/m of drift. It appears that none of those computations were coupled to backpressure computations. Like the Castile anhydrite beds, some

areas of which contain abundant brine, there is probably a variation of brine content in fractures of Salado interbeds, and variations in size and continuity between reservoir areas. Hydrofractures may or may not join various steep-fracture reservoirs, depending upon their pressure histories. So the calculated cumulative brine flows may err by large amounts, and a conservative inflow may total more than 1000 l/m.

The choice of backfilling materials in the rooms provides the only control over final void volumes, since the waste can sustain only so much residual void space when compacted to lithostatic total stress. Ideally, since waste voids will probably become saturated, residual porosity should be maximized, to limit the amount that can otherwise be expelled from the repository after the gas has escaped. The MgO backfill will absorb water into the hydroxide, then yield it as the carbonate is formed.The amount of MgO is said to exceed the gas expected to evolve, so a net water absorption will function to inhibit corrosion, just as will pH control. But unlike salt backfill, MgO will not sequester air; the $Mg(OH)_2$ will saturate and consolidate as it continues to take load. Compressed air in fractures and contacts and within the collapsed drums will all communicate to hydrofractures that can form as pressure attains lithostatic in the repository. It doesn't seem conservative to assume that the backfill and residual voids will retain all the remaining brine, since gas will continue to evolve. I am unaware of any DoE claim that brine will be unavailable for transport of radionuclide contaminants away from the repository, nor would it be prudent to so assume.

A possible safety measure rejected by DoE is the option of completing the backfilling around the waste and MgO packages with dry compressed or adobe bricks of clay. It is well-known that clays of the montmorillonite family have extremely high cation exchange capacities and can exert high swelling pressures. Reduction of the initial air volume and prompt backpressure would shorten the time to cessation of closure. Diminished inflow and enhanced absorption of brine would ameliorate corrosion. Perhaps an absence of free brine could be guaranteed, limiting the actinide source to the fluids already in the waste, less the actinides which can be absorbed by the clay. In absence of incontrovertible geologic containment and retardation, such engineered barriers may be the only way to get certified.

It is safe to say that a diminished rate of decomposition of the waste does not eliminate the prospect of continued pressure build-up to hydrostatic. As proposed, the large initial voids ratio of the repository (as seen in Fig. 3-8) probably implies that the air cannot be contained at less than lithostatic pressure in the residual voids of the waste containers, some of which will be brine-filled. Continued gas generation, at any rate, will ultimately raise pneumatic pressure to lithostatic in spaces communicating with the DRZ in the marker beds. The compressed air and gasses are available to form and drive hydrofracture either along the seals or through the overburden rocks. The energy available for propagation and friction is in excess of 2.5×10^{12} joules, if the original void volume of about 460,000 m^3 (SEAL 8.3.2), plus any generated gas is compressed to about 1/146 th of that volume.

Seal Failure. In shafts and boreholes, the pre-existing contacts between wall rocks and seal materials are likely paths of hydrofracture, and the vertical aspect enhances instability (runaway propagation to up-hole regions of decreasing rock stress). There is nothing to stop it except

whatever tensile strength may exist in the least-healed discontinuity, such as dust coatings on original walls. It may propagate readily between air-filled voids of the compacted salt fill, and certainly along fluid films in the clay seals. Asphalt deforms to pass air at contacts, and salt will yield to form a parting against concrete. Likewise, boreholes sealed with concrete will not sustain much beyond lithostatic fluid pressures before parting at contacts. The DRZ fractures, even healed ones in salt, are candidates for hydrofracture. One might design end-constraints for a salt column to exceed lithostatic radial pressure, but it would not be permanent. It is easy enough to design effective seals for fluid pressures below lithostatic, but not above.

The computations in SEAL 8., the hydrologic evaluation of seal performance. are perhaps valid, but the assumptions of homogeneous, intergranular or continuous fractured-media properties do not apply under all conditions, such as at high pressures. Seals and DRZ rocks behave as continuous media during early phases of repository closure, but under lithostatic or higher pressures, fluids will travel along singular pathways not envisioned by the modelers. During compaction of clay and perhaps of salt, air can be expelled along contacts of the seals. During any subsequent consolidation phase, water can be expelled along those same pathways. Either fluid will take the path of least resistance, usually by forming a conduit at the rock/seal contact, persistently maintaining that opening as flow occurs or preserving a path susceptible to re-opening and concentrated flow when pressure is raised. Seals can be breached to the Rustler aquifers or to the surface via the unsaturated zone. If engineered barriers in the repository preclude free brine, it would be harmless air and gas discharge. Otherwise, the undisturbed scenario has a potential for radionuclide releases to Rustler aquifers by way of shafts or boreholes.

Hydrofracture through the Salado. If the shaft seals are as good as they can be made, then hydrofracture will occur elsewhere instead. In essence, no fluid phase can be long contained by seals or geologic media when the fluids exceed lithostatic pressure; the best that can be done is to assess the relative weaknesses of competing paths of egress. Mindful that roof slabbing (even presently occurring in the experimental rooms) exposes one or more weak partings, at anhydrites "a", "b" or the clay at the base of MB 138, subsequent closure will cause those members to bend and decline towards the center of the room. Air will remain in the anhydrite fractures even as rock stress attains lithostatic over rooms as well as pillars (the unmined salt between rooms). During roof deformation, shear displacements produce microscopic openings along several such stacked partings that extend towards the centerline of the pillar. Coalescence of the DRZ from room to room can occur by hydrofracture across the pillar regions, completing the continuity of the entire repository, even if there are room or panel seals in place. DoE has chosen to neglect the NAS recommendation (1996, p. 145) for generous, long room entry seals, that would diminish the continuity of the repository. All rooms should dead-end in salt for isolation. Canadian potash mines safely excavate 2000 ft rooms with only one entry. The concrete seals to be emplaced for RCRA compliance (CCA 3.3.2) are not being relied upon for compartmentation to isolate nuclear waste products. Therefore, the energy of air compression and gas generation stored in the entire repository is available to drive a single hydrofracture to great distances.

I anticipate a counter-argument that lithostatic pressure cannot build because the slightly-permeable anhydrite beds would continually bleed air from the repository, especially from the up-dip extremities, while brine continues to drain into the down-dip extremities. The fallacy of that argument is the erroneous belief that brine in the marker beds is at no more than 12.5 MPa (Beauheim, et.al., 1993), when measurement itself disturbs the pressure. Virgin pressure must be lithostatic to prevent salt closure of the fractures. Therefore, it is doubtful that appreciable air losses can occur through the marker beds until that formation pore pressure is exceeded at the repository end, even if it takes centuries to attain it.

In the far-field, remote from any stress perturbations the excavations may impose, it is safe to assume that creep of salt maintains lithostatic, all-around rock pressure equal to the overburden load. In such circumstances, the presence of structural weaknesses will govern the nature of a hydrofracture forming in response to fluids exceeding lithostatic. Clay partings along contacts between salt and marker beds, and some clay lamina within salt beds are candidate horizons. These may be interrupted at infrequent local breaks in stratigraphy formed during Permian deposition by channels that crossed the shallow salt-flats. They have been observed in the experimental area of the repository (D. Borns and R. Patchett, personal communication, 1995). The effect of such an interruption of a bedding-plane hydrofracture is to force the opening to propagate elsewhere. It is known also that hydrofractures tend to jump up to higher levels in the strata, where load is less. In homogeneous rock, hydrofractures become dish-shaped. Such behavior in the Delaware Basin has been demonstrated. In 1991, the Bates #2 Well encountered brine with 1000 psi shut-in pressure while drilling at 2240 feet. It flowed about 840 gpm for 5.5 days. Responsible for the brine was a Texaco Co. well injecting (oil-field waterflood operations) at 3000 ft depth, about 760 ft lower than the Bates well intersection and about two miles away. It is consistent with that incident to predict that when pneumatic pressure in the repository approaches the fracture gradient of 0.966 psi/ft depth, it will either hydrofrac a seal or produce a single, elongated hydrofracture along a succession of overlying partings of the Salado, ultimately breaching the Rustler aquifers. As EEG (1996, p. 2-4) point out, the Rustler/Salado contact is also a potential pathway. Alternatively, an extensive hydrofracture may intersect a borehole inadequately sealed to sustain the pressures from deeper horizons.

The importance of borehole sealing, at sites both on and off the land withdrawal area, is evident from the Bates #2 Well experience, and from other water-flood hydrofractures encountered in recent years. DoE has chosen to accept the condition of numerous abandonned wells in the region, presuming them to be well sealed in accordance with state regulations. But the imperfection of casing cement jobs and the corrosion that destroys casings in evaporite environments point to predictable vertical paths open to the surface now or in the foreseeable future via the many abandoned and active oil wells. The possibility that waterflood operations in the neighborhood may propagate hydrofracture to the repository, saturate and pressurize it, then hydrofrac an outlet to the surface is very real.

Discharge of air and gasses is innocuous, insofar as TRU waste is not expected to generate appreciable radioactive gas to contaminate the repository air. The significance of pneumatic hydrofracture is that it prepares and maintains an open path for escape of liquids to follow after the available vapor-phase has discharged from the repository. The energy of any remaining room

closure is available to expel fluids of density below that of salt. Only if engineered barriers have been emplaced in the rooms can sufficient brine sequestration be envisioned to preclude eventual brine discharge along hydrofracture conduits, and DoE has not maximized use of such barriers.

Disturbed-case scenarios. Whereas the above considerations leading to pneumatic hydrofracture apply to the undisturbed repository, they should also be applied to the single borehole E1 or E2 case or the E1E2 case that would, at least, discharge accumulated gasses and air from the repository. After hydrofracture, repository pressure may not normally attain lithostatic again without a connection to the Castile brines or waterflood brines. If the drilling occurs subsequent to undisturbed hydrofracturing, pressures may become elevated when a Castile brine reservoir is intercepted, the E1 scenario (CCA, 6.3.2.2.2).

In the event of potash mining in the McNutt member of the Solado overlying the repository, the consequences would be far more extensive than merely the enhancement of Culebra transmissibility (Corbet and Knupp, 1996). In addition to shaft penetrations, the overburden between the mine and the surface would be disrupted by numerous steep subsidence fractures. Many traversing salt may reheal while mining proceeds, but typically, potash mines flood via fractures carrying water from overlying aquifers, as occur in the Rustler. Thus, a mine overlying the WIPP repository can provide different connections to the accessible environment, depending upon the time of repository breaching relative to the time of mining. The mining level, about 75m above the repository, would retain lateral continuity for centuries before it seals itself. Thus, it would provide continuity from the repository to the surface, via the shafts, boreholes old and new, and especially via hydrofractures, the mine and Rustler aquifers. Several of these are potentially more likely than the simple M scenario envisioned by DoE.

The E2 scenario (CCA 6.3.2.2.1) , a drill hole inadvertently penetrating the repository would discharge any accumulated air and gas, but if it occurs after venting by undisturbed hydrofracture, the rooms may have closed to a state of near-saturation, facilitating brine discharge to the borehole, driven by expansion of the remaining gas and elastic expansions. The repercussions would depend upon the state of the repository, thus the timing of events. Diversion to the Culebra aquifer would result from successful blowout prevention at the collar of the hole.

A drill hole through a partially vented repository room, a closed access drift or the DRZ of any part of the system could conceivably be drilled deeper for resource exploration, whereupon a pressurized brine reservoir in the Castile could be encountered (E1 scenario, CCA 6.3.2.2.2), producing brine flow. Because no mechanically effective backfill or room seals are to be employed, direct circulation to a point of hydrofracture egress is likely to sweep any mobile contents out of a panel or perhaps two panels, but the panel closures would protect other panels from direct flushing. However, any blowout preventer restraining direct brine discharge up the hole would result in hydrofracture from room to room, to any shaft, borehole or hydrofracture to the Rustler, since the Castile brine is generally at lithostatic pressure for its deep level, thus much higher than lithostatic for shallower levels. The path depicted in Fig. 6-11 represents only one of those possible, and probably not the worst.

Many potential paths are possible with the E1E2 scenario, as described in CCA 6.3.2.2.3, conceivably sweeping as many as two panels of their mobile wastes. It seems unlikely that the DRZ would have greater conductivity than would paths through rooms, but in the event that panel closures function effectively, brine flowing through any salt-bounded fracture could readily enlarge it to concentrate flow, bypassing much of the waste. It is not convincing to say that the E1E2 scenario is the worst case, that it is to be minimized because the compound probability of two such penetrations is low. The E1 drill hole in combination with prior breaching paths seems more likely and dangerous. The event of exploration well penetration of the repository seems unlikely to contaminate the Culebra because such wells would be new and cased through the Culebra. Thus the claimed retardation due to Culebra transport processes might not provide a barrier when needed most.

Rustler Hydrology

It has long been DoE's position that flow through the Culebra dolomite provides a final barrier to excessive releases to the accessible environment. While shorter, more concentrated discharges, in place and time, to the immediate surface are likely to result from exploration boreholes or sealed boreholes, shafts, subsidence fractures or hydrofractures, it is worthwhile to evaluate the conceptual hydrogeology of the Culebra, implemented in so many studies contributing to Performance Assessment (PA).

The case for obtaining a comprehensive set of data to characterize the structure of the Culebra has been made before (Ferrall and Gibbons, 1978; Snow, 1995; NAS, 1996 and others), so that modeling for transport calculations can more correctly represent the true conditions. The reasons have to be reiterated here.

Fractures and stratigraphic features would become secondary in importance if it were realized that the Rustler contains significant solution conduits within the WIPP site and within the range of potential hydrofractures and boreholes that may communicate with the repository. Then, fractures would no longer be the key elements in governing transport. Upon demonstrating karst features within the model domain, it may be so evident that travel times are brief (say, 5 to 250 years) that the Rustler must be discounted as a barrier to transport to the accessible environment.

Fracture System in the Culebra

DoE's hydrologists are among the world's foremost modelers, but the data DoE has collected to facilitate appropriate conceptual aspects and the details of the models themselves do not reflect the state of the art of geotechnical engineering, in view of the hydrostratigraphy, the fracture system geometry or the suspect dissolution features of the rocks overlying the Salado. Consider, first, the lack of fracture data and its adverse influences.

It was one of the Carlsbad area potash mining companies that convinced ERDA to examine that area; to store TRU waste seemed a great end-use for a spent mine, and when that was rejected, the government got some help in drilling to prove the resource of space could be found beneath the mining horizon. The coring of drill holes has been with the same equipment and of the quality

appropriate to the potash industry, probably by the same "experienced" drillers. For potash exploration, only the chemistry of the ore matters; the quality of core recovery is unimportant. Consequently, any attempt to learn much from the cores in storage, such as structural details, is a frustrating exercise because the core looks like crushed road aggregate, for the most part. Frequently, recoveries are less than 50% of the length of hole, and the weakest parts, such as seams, solution zones and fractured intervals are missing from the hundreds of boxes representing millions of dollars worth of drilling. One hole of the H-11 pad site reflects superior care in obtaining good recovery, though it would still be considered abysmal by engineering geologists trained for damsite exploration work. Instead of the traditional single-tube core barrel used in potash programs, it is reported that the H-19 pad holes of 1995 were drilled, at last, with a triple-tube core barrel, obtaining about 98% recovery. In my view, 30 years of exploration effort before 1995 were squandered in inept technology. Even the 1995 core misses the objective of fracture system characterization because DoE has continued to refuse (DoE letter to EEG, August 17, 1995) to execute slant-hole coring, without which near-vertical fractures cannot be intercepted with sufficient frequency. Outcrop evidence and common knowledge would tell them that flat-lying sediments abound in vertical fractures, as must be the case in the Culebra. A reasonably-representative data-set can and still must be obtained at WIPP by applying well-established directional drilling technology perfected in the last decade by oil companies for the task of intercepting steep producing fractures. It is reported that directional drilling costs about 15% more than vertical drilling, so economics are no impediment.

The need for fracture system data to model the flow and transport of contaminants in the Culebra has been detailed recently (Snow, 1995) and reinforced by reviewers (NAS, 1995), such as Dr. Konikow. The role of matrix diffusion, hydrodynamic dispersion and sorption depend upon parameters that can only be estimated crudely by in-situ tracer tests. The interpretation of tests depends upon models that cannot be well-conceived in absence of data on the fracture system geometry and stratigraphic details .

Indirect inferences of fracture system geometry at the site have to depend upon remote observations, such as the outcrops at Culebra Bluffs along the Pecos River, SW of Nash Draw. According to personal observations preserved in photographs, there are two steep orthogonal sets of fractures, NE and NW in strike, with long traces seen on bedding surfaces and spacings about 1-2m. These are consistent with regionally-pervasive tectonic patterns visible in the Capitan Reef and elsewhere in the Basin (Swift, 1992). Superimposed on the orthogonal tectonic joint pattern are more numerous, randomly-oriented fractures, sometimes abutting in polygons.

Judging by a similar distinction between joints above versus below a dissolved evaporite sequence in Manitoba, I believe that the random set at Culebra Bluffs results from dissolution of underlying evaporites, which occurs differentially over space and time to impose strains in various directions. Horizontal partings at clay lamina in the Culebra probably shear and open by the same differential subsidence mechanism.

At the WIPP site, there has been variable removal of salt from the uppermost Salado rocks and the Unnamed Anhydrite unit of the Rustler, perhaps increasing in magnitude of removal from east to west across the site. Since the demarcation is not abrupt, neither is the distribution of Culebra

fracture types predictable. Only a well-conceived and executed slant-hole drill-coring program could resolve the changes of pattern to be expected across the site. The nature, apertures and spacings of each type are needed, augmented by length parameters from outcrop studies. Core data should facilitate interpretation of fracture system anisotropy and the effective porosity, all in the interests of better PA modeling than is possible with currently oversimplified geometry (such as horizontal fractures only) and the absence of data.

Further objectives should be to include fracture system distinctions across the dissolution-transition zone coincident with the WIPP site, and especially to characterize dissolution channeling effects evident by erosion of fracture fillings and the opening of vugular strata. Fracture conduits traversing the Dewey Lake Red Beds and the several Rustler members are needed, since the assumption made by DoE that the Culebra is confined by impermeable beds is clearly unjustified (see below).

It is appropriate to caution against exploration expenditures for fracture system characterization to the exclusion of dissolution-feature characterization.

Karst Hydrology

If DoE cannot be induced by the reasoning of many to evaluate and employ knowledge of fracture hydrology, preferring to labor handicapped without such knowledge, then what is the efficacy of recommending explorations to obtain knowledge of karst hydrology at WIPP, data even more vital to establishment of transport properties of the Rustler ? Fear of failure, having spent $2 billion on studies already seems to have driven completion-oriented managers to deny the existence of karst features (CCA 2.1.3.5.2). Ultimate failure, still a very real possibility, would be to have a repository filled with TRU waste that has to be retrieved later at astronomical costs when our progeny, perhaps ten generations from now, discover shafts, drill holes or springs discharging radioactive brine to the Pecos River. It has been an unspoken hope that slant-hole coring for fractures could accidentally disclose solution cavities in the Dewey Lake and Rustler formations, features already obvious to a field-oriented geologist, re-iterated as evidence of karst by a procession of competent but largely discounted scientists (Olive, 1957; Vine, 1963; Bachman, 1974; Anderson, 1978 and 1994; Barrows, 1982; Chaturvedi and Channel, 1985; Phillips, 1987; Snow, 1995; EEG, 1996).

Claiming reliance on retardation during actinide transport through the idealized Culebra towards the accessible environment (5 km distant), the E1E2 scenario is by no means the worst case, but even it cannot approach 40 CFR 191 standards if short travel times implied by karst hydrology are correct in magnitude.The field evidence presented in Phillips' (1987) dissertation on WIPP site geomorphology is so potentially damaging to the project that DoE has suppressed it, not even listing it in the CCA bibliography. That is inexcusable, when the work constitutes the most exhaustive exploration of surface features, including 1000 auger holes and many backhoe trenches investigating sinkholes and solution trenches on the Mescalero Plain. His evidence is clear that there are local windows through the Mescalero caliche horizon and that there are many aligned sinkholes with alluvial infillings. These are evident, even though dune sands mantle much of the plain, free of surface drainage channels. He recorded observations of storm runoff disappearing

down one such sinkhole, the WIPP-33 drill site where five nested caverns were drilled to the depth of the Culebra. Water-balance methods, based on reasonable evaporation rates from Laguna Grande de la Sal, versus stream-gaging data from Malaga Bend seem to indicate that Nash Draw is the discharge point for nine-tenths of the recharge. This implies shorter paths from WIPP via cavernous channel features reasonably deduced from the geomorphology and geochemistry.

In current comments to the CCA, Phillips (1997) has summarized surface and near-surface hydrological evidence to conclude that the karst solution features on and near the WIPP site are subject to modern infiltration events. The Dewey Lake Red Beds have several regions of sufficient transmissibility and potable water that it constitutes a subsurface drinking water supply. He further documents the occurrence of karst features in the Rustler units: the Forty-Niner, Magenta, Tamarisk and Culebra, including sites within the WIPP boundaries. There are places of apparently continuous dissolution extending from Dewey Lake downwards to the Culebra. Salinities in Culebra water samples decrease along the preferred path, to Malaga Bend, according to DoE, as well as along other potential paths to Nash Draw.Their finding is inconsistent with confined flow in the Culebra, but is consistent with fresh-water recharge through sinks, especially west and southwest of WIPP. Portions of the Culebra carry potable water, making it a candidate for drinking water supplies, rather than a "brine unsuitable even for stock-watering".

The importance of these findings is that the WIPP site is established as a recharge area for a dissolution-enhanced aquifer on and west of WIPP that spans the Dewey Lake and most of the Rustler to at least the Culebra. That is contrary to DoE's modeling of the thin dolomite as a confined aquifer. DoE has modeled the Culebra with transmissibilities computed on the faulty assumption of continuously-varying values. The T-field computations are invalid for fractured media, much less for karstic channels traversing tighter rocks. Typically, exploration drilling on a random pattern cannot be expected to intercept nor measure the high-conductivity solution channels as must exist to carry storm runoff such as flowed into the WIPP-33 sinkhole on September 18-19, 1985, or as observed in other karst regions of the world. Travel time from the site to Nash Draw is speculative, but if it accords with experience in other karst regions, it may be less than 100 years

The current regional groundwater model (MASS 14.2) errs significantly by neglect of concentrated, intermittent recharge across strata via sinkholes, at least in large parts of the domain. The continuity of Darcy's Law models with properties averaged over large regions cannot represent the transient, channelized flows that occur rarely in karst, giving the medium effective porosities that are orders of magnitude smaller than intergranular media would suggest. Recharge estimates of 0.2 to 2.0mm per year were based on small transmissibilities (seemingly neglecting some of the extreme-valued tests) in the Culebra, none that represent vertical flows. This range is at odds with Phillips' estimated recharge of 0.75 inch/year (1987, p. 224), a more reasonable figure for 15 inches of rainfall that form no surface drainage channels. Phillips' estimate was based on evaporation from the original surface area of Laguna de la Sal before mine process water was ever discharged there. Sinkholes must connect to highly-conductive channels in the subsurface, features that are believed to develop by headward extension, probably from the discharge points in Nash Draw. The surface morphology suggests that channels must extend onto the WIPP site itself, since sinkholes are present there. As reason to believe that Nash Draw is the terminus of the

shortest, fastest paths from WIPP via the Rustler, there is the significant excess of computed net evaporation at Laguna Grande over the gain of streamflow at Malaga Bend. Flow paths to Nash Draw are shorter than DoE's expected paths to Malaga Bend. Whereas pluvial-period groundwater flow may have been most responsible for karst development, the established paths during today's dry climatic conditions are probably also southwestward into Nash Draw.

Average transport properties would be very different for a Rustler aquifer dominated by even occasional periods of rapid, karstic channel flow. The speed with which organic contamination shows up in karst terrain is suggestive of the behavior to expect of actinide transport. Little specific surface can be active for sorption or matrix diffusion. If efforts to characterize the formations are to continue, then testing of rare solution conduits has to be done. Usually, dye-tracing is employed to establish travel times. The location of drill holes seeking direct evidence of conduits can be guided by the negative gravity anomalies (Barrows, et.al, 1983), by surface morphology, by the distribution of salinities and fracture fillings in the Culebra (Beauheim and Holt, 1990), and by following apparent trends of high transmissibilities deduced from interference testing.

It should be as transparent as the emperor's new clothes that the Culebra and overlying strata are inadequate to the belabored task of providing a barrier to excessive cumulative releases at the compliance boundaries. But if proof must be obtained that transport would be swift and conservative in the Rustler, then perhaps explorations must proceed step-wise, in order to be wholly convincing. Regulatory agencies should require completion of a geophysical and subsurface drilling program to obtain statistically relevant data characterizing fracture system geometry and karst-conduit geometry. Regional efforts in the realm of conventional surface hydrology are needed to confirm suspected partitioning of the recharge between the Malaga bend and Nash Draw discharge areas.

Summary Statement

Two of the three major barriers have been shown to be unreliable: neither repository containment nor transport processes guarantee satisfaction of the cumulative release limits of 40 CFR 191. DoE should rely solely on a favorable actinide source term that is brought about by incorporating optimum engineered barriers within the repository (but not in transport) to show compliance. Furthermore, retrieval of the waste after decades of loading is infeasible. Establishment of an alternative site and method of disposal may be necessary. The expense and delay, though burdensome, would serve the public interests better than failed emplacement at WIPP. A monitored retrievable storage facility, safely above the water table in stable rock openings is suggested. There are well-drained candidate sites in fractured tuffs or carbonates in other desert mountain ranges within government nuclear reservations.

References Cited

Anderson, R.Y., 1978, Report to Sandia Laboratories on deep dissolution of salt, northern Delaware Basin, New Mexico.

Anderson, R.Y., "Deep Hydrology" issues: Comments on CSR, DoE/WIPP 94-019, 14 July, 1994

Bachman, G.O., 1974, Geologic processes and Cenozoic history related to salt dissolution in southeastern New Mexico: U.S. Geol. Survey Open-file report 74-194.

Barrows, L., 1982, WIPP geohydrology--the implications of karst: memo to W.D. Weart, Sandia Nat'l Labs, reprinted in EEG-32, 1985, App. A.

Barrows, L.J., S.E. Shaffer, W.B. Miller and J.D. Fett, 1983, Waste Isolation Pilot Plant (WIPP) site gravity survey and interpretation: SAND82-2922

Beauheim, R.L. and R.M. Holt, 1990, Hydrology of the WIPP site. In Geological and hydrological studies of evaporites in the northern Delaware Basin for the Waste Isolation Pilot Plant (WIPP), New Mexico: Geol. Soc. Amer. 1990 Ann'l Mtg. Trip #14 Guidebook, pp.131-179

Beauheim, R.L., R.M. Roberts, T.F. Dale, M.D. Fort and W.A. Stensrud, 1993, Hydraulic testing of Salado Formation evaporites at the Waste Isolation Pilot Plant site: Second interpretive report. SAND92-0533

Chaturvedi, L. and J.K. Channel, The Rustler Formation as a transport medium for contaminated groundwater: EEG-32

Corbet, T.F. and P.M. Knupp, 1996, The role of regional groundwarter flow in the hydrogeology of the Culebra Member of the Rustler Formation at the Waste Isolation Pilot Plant (WIPP), southestern New Mexico: SAND96-2133.

Dept. of Energy, ltr. to R.H. Neill, EEG, dtd. Aug. 17, 1995

Environmental Evaluation Group, 1996, Review of WIPP draft application to show compliance with the EPA transuranic waste disposal standards: EEG-61.

Ferrall, C.C. and J.F. Gibbons, 1979, Core study of the Rustler Formation over the WIPP site: Civil Systems, Inc., for Sandia Nat'l Labs, CSI-2055-03

National Academy of Sciences, 1996, The Waste Isolation Pilot Plant, a potential solution for the disposal of transuranic waste, 167 p.

Olive, W.W., 1957, Solution-subsidence troughs in the Castile Formation of Gypsum Plain, Texas and New Mexico: Geol. Soc. Am. Bull., v. 68, p 351-358.

Phillips, R.H., 1987, The prospects for regional groundwater contamination due to karst landforms in Mescalero caliche at the WIPP site near Carlsbad, New Mexico: unpubl. Ph.D. thesis, Univ. of Oregon, 316 p.

Phillips, R.H., 1997, Rainwater recharge at the WIPP site: Comments to DoE Compliance Certification Application, 1996: this submission.

Powers, D.W., S.J. Lambert, S.E. Shaffer, L.R. Hill, W.D. Weart, eds., Geological characterization report, Waste Isolation Pilot Plant (WIPP) site, southeastern New Mexico: Sand 78-1596, vol. I.

Snow, D.T., Review of transport in the fractured Culebra dolomite: report to EEG, transmitted to DoE June 20, 1995.

Swift, P., Fracture orientations in outcrops of the Rustler Formation and Dewey Lake Red Beds, WIPP area: Tech Reps., Inc. report to distribution, April 24, 1992, 23 p.

Vine, J.D., 1963, Surface geology of the Nash Draw Quadrangle, Eddy County, New Mexico: U.S. Geol. Survey Bull. 1141-B

CONCEPTUAL ERRORS IN THE DOE MODEL OF GROUNDWATER FLOW IN THE RUSTLER FORMATION

by Richard Hayes Phillips, Ph.D.

Konikow (1996) identified the three most common sources of error in modeling of groundwater flow: (1) conceptual errors; (2) uncertainties in the model; and (3) uncertanties in the data.

These are conceptual errors in DOE's model of groundwater flow in the Rustler Formation at the WIPP site and vicinity:

(1) Darcy's Law should not be applied to a karstland, because groundwater velocity is not proportional to the potentiometric gradient (Barrows, 1982).

In permeable rocks other than those giving rise to karst, the water table parallels the land surface, with somewhat less relief. The potentiometric surface is the level to which groundwater will rise in a cased well. These water levels can be mapped, relative to sea level; and contour lines can be drawn, in accordance with the slope of the water table. Groundwater will flow across the contour lines, generally perpendicular to them; and the more closely spaced the contour lines, the faster the groundwater flows. Velocity is proportional to the permeability times the potentiometric gradient. This is expressed as Darcy's Law, the general hydrogeologic equation (Jennings, 1971).

A water table such as occurs in porous rocks like sandstone does not exist in karst. Wells close together often reach water at very different levels (Sweeting, 1973; Jennings, 1971). Trying to map contour lines is futile. Potentiometric contour lines are not a reliable indicator of groundwater velocity or direction.

(2) The Culebra should not be modeled as a porous homogeneous medium with continuously varying properties (Snow, 1995).

Karstified rocks are not porous homogeneous media (Milanovic, 1976). Primary permeability, which depends on the size and degree of interconnection of the original pore spaces in the rock matrix, is uncommon in karst; secondary permeability, consisting of flow through joints, fractures, solution conduits, caverns, and cave sediments, is much more representative (LeGrand, 1983; Milanovic, 1981). DOE admits that "flow velocities are usually orders of magnitude higher in the fractures than in the matrix" (SEIS, 1996, p. H-24). That is precisely the point. According to Rehfeldt (EEG-27, 1984): "The groundwater travel time in open fractures is very short in comparison to travel time in porous media. Open fractures exist in Nash Draw, at H-6, and are likely present elsewhere at and near the WIPP site." Konikow (1995) regards open fractures in the Culebra as "the most likely fatal flaw in site integrity."

(3) The fracture model should not assume "continuous, isotropic, radial flow in cubically fractured medium." (Lovejoy, 1995)

This is an attempt to model a fractured medium as a homogeneous medium. Fractures are an extreme example of heterogeneity. Fractures are preferential flow paths for water (Konikow, 1996).

Flow in the Culebra is highly anisotropic (varies with direction, has preferred orientation). In the northwest corner of the WIPP site is the H-6 hydro pad, which consists of three wells forming an equilateral triangle, 100 feet on a side. The wells are labeled H6a, H6b, and H6c; a line connecting H6a and H6c is oriented east-west. A convergent tracer test was performed in the Culebra by pumping well H6c and simultaneously introducing tracers into wells H6a and H6b. As reported by Rehfeldt (EEG-27, 1984), "the peak concentration of the H6b tracers arrived 30 times faster and at a concentration 10 times greater than the H6a tracers. Flow in the H6b-H6c direction (150° or 330°) is probably through discrete channels whereas flow in the H6a-H6c direction (90° or 270°) was through the dolomite matrix or through a very tortuous system of fractures."

Dissolution of gypsum filling has opened some fractures in the Rustler Formation, creating "anisotropic fracture permeabilities at least an order of magnitude greater than matrix permeability. ... Throughout the site, flows are concentrated in any such fractures ... Large-aperture solution channels may transect regions of fracture-dominated dolomite (and perhaps anhydrite) devoid of mineral fillings." (Snow, 1995).

The Magenta and Culebra dolomites have been fractured since shortly after their deposition. The impact of this fracture pattern on WIPP geohydrology depends upon the size, angle, length, orientation, spacing and extent of the fractures, the degree and type of fracture filling by groundwater, and the amount of fracture enlargement by solution. The most reliable means of evaluating the fracture pattern would be to collect core samples from a slant drilling program. If angled 45° with respect to the horizontal, and oriented perpendicular to the predicted trends of dominant fracture sets, a three-dimensional record could be obtained (Gibbons and Ferrall, 1980).

(4) DOE should not use "a two-dimensional model where significant flow or transport occurs in the third dimension." (Konikow, 1996)

Traditional "layer-cake" hydrogeology represents aquifers as continuous porous media separated by continuous aquitards or aquicludes (Snow, 1995). "There has been too little accounting for the three-dimensional nature of ground-water flow and consequent leakage through confining layers." The Culebra is one part of a three-dimensional flow system (Konikow, 1996). The Rustler is best characterized as one aquifer with five members.

(5) Borehole data should not be assumed to be representative of hydraulic conditions beyond the immediate vicinity.

In karst, the hydraulic conductivity along solution-enlarged fractures may be three orders of magnitude greater than that of the adjacent unaltered rock (Fetter, 1980). Because the active solution conduits comprise a small part of the total area of the watershed, most boreholes will miss them, and will show values for hydraulic conductivity which are not representative of karst conditions (Bloom, 1978; Barrows, 1982). Borehole measurements may reflect aquifer properties only within the immediate vicinity of the borehole (Konikow, 1995). The technique of interpolation between data points, although useful in porous, homogenous media, should not be applied to a karstland (LeGrand, 1973).

(6) Matrix diffusion in the Culebra dolomite is not a reliable mechanism for the retardation of radionuclide migration.

In rocks with dual porosity, groundwater flows mainly through open fractures in the rock, while some groundwater is diffused through smaller fractures into the rock matrix. This process, known as matrix diffusion, is capable of retarding the migration of radionuclides in groundwater (SEIS, 1996). In karst, however, water flowing through fractures in soluble rocks will enlarge the fractures as it does so. The more permeable the groundwater pathways, the more rapidly they will become enlarged (Barrows, 1982). More and more groundwater flows through fewer and fewer solution conduits (Fetter, 1980), with less and less diffusion of groundwater into the rock matrix. The end result is a regional network of primary solution channels and stagnant secondary pathways (Barrows, 1982), with little or no matrix diffusion.

(7) Distribution coefficients used for the Culebra dolomite are not representative of field conditions.

The distribution coefficient (Kd), or sorption coefficient, is a measurement of the proportion of radionuclides that are retarded during migration of groundwater. The magnitude of retardation is proportional to the surface area in the host rock encountered by flowing water and therefore available for sorption. The higher the Kd value, the greater the retardation of radionuclide migration. The Kd values used in WIPP performance assessment were determined in the laboratory from single measurements upon Culebra dolomite samples which were crushed to a powder, thus providing much greater surface area per volume of rock than actually occurs in the field. The results, preferred by DOE, give a Kd value as high as 7300 for Culebra dolomite, compared to a Kd value of 19 for tablets of solid rock, which is more representative of fracture flow in the Culebra dolomite. The greater the aperture (diameter) of the groundwater channels, the lower the Kd value. Under karst conditions, the conservative assumption is that Kd equals zero, that some radionuclides will

travel at the speed of water. The only way to obtain reliable distribution coefficients is to perform sorbing tracer tests in the field (GCR, 1978; EEG-61, 1996; SEIS, 1996).

(8) There is no evidence that clay linings on fractures in the Culebra dolomite will affect radionuclide migration.

The WIPP performance assessment takes credit for radionuclide retardation due to clay linings on fractures in the Culebra dolomite. The claim is based on experiments that were performed not upon fractures in the Culebra, which contain only small amounts of clay, but upon corrensite clay taken from a black shale layer in the lower unnamed member of the Rustler. Clay fillings are most likely to exist in secondary pathways, where groundwater movement is infrequent enough to allow the clay to settle out of the water; here the clay could block the movement of water into the rock matrix, thus preventing matrix diffusion. The WIPP performance assessment takes "double credit" for a mechanism that may not exist, by claiming significant radionuclide retardation in primary pathways in the Culebra, while denying that clay fillings in secondary pathways would inhibit matrix diffusion (EEG-61, 1996; SEIS, 1996).

One of the problems with analyzing DOE's Compliance Certification Application (DOE/CAO-1996-2184) is its incompleteness. Materials are continually being added to the docket, and to criticize the Application now is like shooting at a moving target. By the time the EPA certifies that the Application is complete, the public comment period will be over, and DOE will be at liberty to assail its critics without fear of response, using materials which were unavailable during the public comment period. Therefore, instead of analyzing the WIPP performance assessment as it now stands, it is more reasonable to analyze a completed report, trusting that the public will be given another chance to analyze the Compliance Certification Application when EPA deems it complete.

One recent addition to the docket is a Sandia Report by Corbet and Knupp (SAND 96-2133), received by the New Mexico Attorney General on January 15, 1997, midway through the public comment period. The report, which models regional groundwater flow in the Rustler Formation, is said to have bounded the hydrologic effects of karst, potash mining, and climatic change, simply by analyzing the effects of a three order of magnitude increase in hydraulic conductivity in the Culebra dolomite. Unfortunately, the report begins with conceptual errors and misrepresentative data, and the difference is always favorable to DOE.

The use of "geologic data to infer hydraulic conductivity values for areas in which conductivity measurements were not available" is inexcusable. DOE has had 20 years to collect the necessary data. There is no substitute for field work. The interpretation should be drawn from the data, not the other way around.

These values for rock hydraulic properties, said to be inferred from geologic observations, are not always consistent with borehole data in the vicinity. Examples are given below.

Figure 2-6: The "eastern limit of Salado dissolution" is placed at Livingston Ridge, which is not correct. Seven boreholes east of Livingston Ridge (P-6, P-12, P-13, P-14, H-3, H-6 and WIPP-33) encountered dissolution residue at the top of the Salado.

Figure 2-7: In Zone I, the fracturing and disruption of Rustler strata in Nash Draw is attributed to dissolution of the upper Salado, rather than to karst processes in the Rustler. This zone includes borehole WIPP-25, where the Tamarisk and lower unnamed members consist almost entirely of mudstone breccia and gypsum.

Figure 2-7: In Zone II, Rustler strata is said to be fractured but not disrupted. This zone includes borehole H-7, where 24.3 feet of Culebra dolomite was broken into six sections separated by five cavities totalling 21.7 feet; this was underlain by 6.2 feet of mud, beneath which there was no core for 80.8 feet.

Figure 2-9: The zone assumed to have hydraulic conductivity of 1×10^{-11} m/sec (2.8×10^{-6} ft/day) in Rustler anhydrite includes borehole WIPP-33, where all of the anhydrite has been converted to gypsum, some of the gypsum has been removed by dissolution, and two gypsum caves were encountered in the Forty-Niner member.

Figure 2-10: The zone assumed to have hydraulic conductivity of 1×10^{-9} m/sec (2.8×10^{-4} ft/day) in Rustler mudstone includes borehole WIPP-14, where 71.4 feet of mud, with anhydrite and gypsum fragments, was encountered beneath the Culebra dolomite.

Figure 2-11: The Dewey Lake Redbeds are assumed to have hydraulic conductivity of 2×10^{-7} m/s (.028 ft/day) everywhere east of Livingston Ridge. This is a wild guess. I am unaware of any measurements of hydraulic conductivity in the Dewey Lake Redbeds. However, at test wells H-11 and WQSP-6, inflow from the Dewey Lake Redbeds was measured at 25 to 30 gallons per minute.

The "assumed values for hydraulic conductivity" in the Culebra dolomite are at variance with measured data. In Figure 2-8, the zone assumed to have hydraulic conductivity of $1 \times 10^{-7.5}$ m/sec (.009 ft/day) includes test wells H-3, DOE-1 and H-11, where hydraulic conductivity is 0.86 ft/day, 1.5 ft/day, and 1.7 ft/day, respectively. The zone assumed to have hydraulic conductivity of 1×10^{-6} m/sec (0.28 ft/day) includes test wells DOE-2, WIPP-13, H-6 and P-14, where hydraulic conductivity is 4.0 ft/day, 3.0 ft/day, 3.2 ft/day, and 10.6 ft/day, respectively. The zone assumed to have hydraulic conductivity of 1×10^{-5} m/sec (2.8 ft/day) includes test well H-7, where hydraulic conductivity is at least 31.0 ft/day. Hydraulic conductivity (in ft/day) is here calculated as transmissivity (in ft^2/day) divided by the

thickness of the aquifer (in feet). It is true that hydraulic conductivity at these eight test wells is anomalously high, but that is exactly the point. To disregard the highest measurements of hydraulic conductivity is to throw out the evidence for karst.

Potential recharge, defined as "the maximum amount of moisture available to recharge the saturated zone," is assumed to be 0.2 to 2.0 mm/yr. These values are claimed by Corbet and Knupp to be "certainly reasonable." In fact, precipitation for the last ten years at the Carlsbad airport has averaged slightly over 15 inches per year, or 40 cm/yr. Corbet and Knupp are saying that annual recharge equals 0.05% to 0.5% of annual precipitation, which is to say that evapotranspiration equals 99.5% to 99.95% of precipitation. From this they conclude that the travel time for vertical leakage to reach the Culebra is "probably thousands or tens of thousands of years." These estimates of recharge are too low. Geohydrology Associates (1978) and Barrows (1982) estimated 96% evapotranspiration and 4% recharge. Phillips (1987) estimated 94% evapotranspiration and 6% recharge.

"Vertical leakage may contribute as little as 5% or more than 50% of the total inflow" to the Culebra at WIPP. This statement is an open admission that DOE does not even know the <u>order of magnitude</u> of rainwater recharge to the Culebra. The truth is that vertical leakage contributes nearly 100% of recharge to the Culebra; the alternative explanation, that the Culebra contains "fossil water" left over from the Ice Ages, is not supported by geochemical data showing Culebra water to be far from saturated.

The conclusion that the Culebra is "poorly connected to the source of recharge" is entirely unsubstantiated. DOE does not even claim to know where the recharge area is located. It is said not to be "feasible" to measure, in the field, the vertical conductivity of the "confining layers" because it would take longer than "several months" to do so. This is a poor excuse. DOE has already had 20 years to study rainwater recharge.

Regarding the hydrologic effects of climatic change, the computer simulations employed by Corbet and Knupp "covered the time period from late in the Pleistocene (14,000 years ago) to 10,000 years in the future." The full-glacial maximum (generally considered to have been 23,000 to 17,000 years ago), and the climate and hydrology associated with it, were not considered. Indeed, Corbet and Knupp assume that the climate over the next 10,000 years will be no different than the last 8,000 years. As for potential recharge, Corbet and Knupp assume that 2.0 mm/yr was realized during the late Pleistocene (14,000 years ago), and that maximum recharge during the Holocene was 0.6 mm/yr. Recharge at 8,000 years ago is assumed to have been <u>zero</u>, although Corbet and Knupp do admit that this value is "somewhat arbitrary."

Glacial advances are cyclical. The Holocene is properly viewed not as an epoch distinct from the Pleistocene, but as the latest interglacial interval. Due primarily to a decrease in obliquity (the tilt of the earth's axis), the amount of incoming solar radiation received during the summer at the Arctic Circle (and throughout most of the northern hemisphere) will decrease during the next 9000 years. The polar ice cap will not be able to melt back during the summer, and a glacial advance is predictable.

During the last full-glacial maximum, summers were at least 10°C (18°F) colder in south-central New Mexico, and the evaporation rate was 40% to 50% of the present rate. The combined amount of precipitation and runoff into the local lake basins of the Texas panhandle was about 50% greater than at present; this would be sufficient to cause Laguna Grande de la Sal (the discharge point for contaminated water from the WIPP site) to overflow into the Pecos River. Climatic transitions can be rapid; temperature drops of up to 5°C (9°F) have been identified. For a fuller discussion of climatic change, see Phillips (1987, Chapter 9).

All the studies cited by Corbet and Knupp relate to groundwater flow through porous, homogeneous media. Not a single report on karst hydrology is referenced. Corbet and Knupp acknowledge that they are using equations for flow in porous media, based on Darcy's law. The idealized cross-sections of groundwater basins (Figure 2-1) are representative of porous, homogeneous media. They bear no resemblance to karst hydrology at the WIPP site.

"Differences in the elevation of the water table" are said to "provide the driving force for groundwater flow." This is not necessarily true. In karst, the driving force for groundwater flow is the flushing of underground caverns by fresh water recharge after major rainstorms. Groundwater will flow through preferential pathways, through channels of high transmissivity, even if the flow path is not directly downgradient.

"All of the outflow" from the Culebra at WIPP is attributed to "lateral flow. Therefore, contaminants introduced into the Culebra will travel toward the accessible environment along the Culebra rather than by migrating upward or downward into other units." This statement is in direct conflict with measured data. DOE's data set for hydraulic heads, incomplete though it is, shows that water in the Culebra can and does flow <u>upward</u> to the Magenta at test wells H-6 and WIPP-25. The Culebra is not a confined aquifer, and DOE's attempt to model it as such is a misrepresentation of reality. If it is simply too difficult, for purposes of performance assessment, to model the Rustler as one complex artesian aquifer with five units, with water flowing up, down, and sideways, as it does in the real world, then the proper response is not to oversimplify the actual conditions of Rustler groundwater flow to the point of science fiction, but to abandon the attempt to obtain EPA certification to open WIPP.

CAVERNOUS ZONES AT THE WIPP SITE

by Richard Hayes Phillips, Ph.D.

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is intended for the permanent disposal of radioactive waste from nuclear weapons production. The project is the brainchild of the United States Department of Energy (DOE). The waste is to be buried in steel drums and plywood boxes in direct contact with salt beds of the Salado Formation. The project lacks engineered barriers; it is the rocks themselves -- the Salado Formation and the aquifers of the overlying Rustler Formation and Dewey Lake Redbeds [shown in cross-section in Figure 1] -- which are intended to be the effective barriers to radionuclide migration.

The Culebra dolomite member of the Rustler Formation has long been recognized as the most likely pathway for contaminated water to travel from the WIPP site to the accessible environment. The Culebra dolomite is not a porous, homogeneous medium; groundwater does not move uniformly and predictably through interconnected pore spaces in the rocks. The Culebra, in most places, is highly fractured, and the effective groundwater flow paths are through the largest fractures, the paths of least resistance.

Dolomite is a soluble rock; it slowly dissolves when exposed to fresh water. As fractures become enlarged by solution, they become even more effective groundwater flow paths. Over time, more and more groundwater flows through fewer and fewer solution-enlarged fractures. Ultimately, these solution conduits become underground caverns, capable of carrying groundwater quite rapidly with little resistance. This type of groundwater hydrology is known by geologists, world-wide, as <u>karst</u>.

The problem with karst as a waste-disposal environment is that some radionuclides may travel unretarded, at the speed of water. The larger the aperture, or diameter, of the solution conduits, the less contact the radionuclides will have with the surrounding rock, and the less the amount of radionuclide retardation. The ability of the Rustler Formation to retard significantly the migration of radionuclides depends upon the absence of karst conditions, of channelized flow, at the WIPP site.

Recent pumping tests at hydrologic test wells in Culebra dolomite at the WIPP site (Beauheim, 1986; Beauheim, 1989) have resulted in unexpectedly short response times between certain test wells. For example, when water was pumped from test well DOE-2, there was a drop in water level within two hours at test well WIPP-13, which is 4835 feet from DOE-2. Test well H-6, which is 10,150 feet from DOE-2, responded within one day. Other test wells, no farther away (e.g. WIPP-12, WIPP-18 and H-5), showed no response at all. This indicates that DOE-2, WIPP-13 and H-6, in the

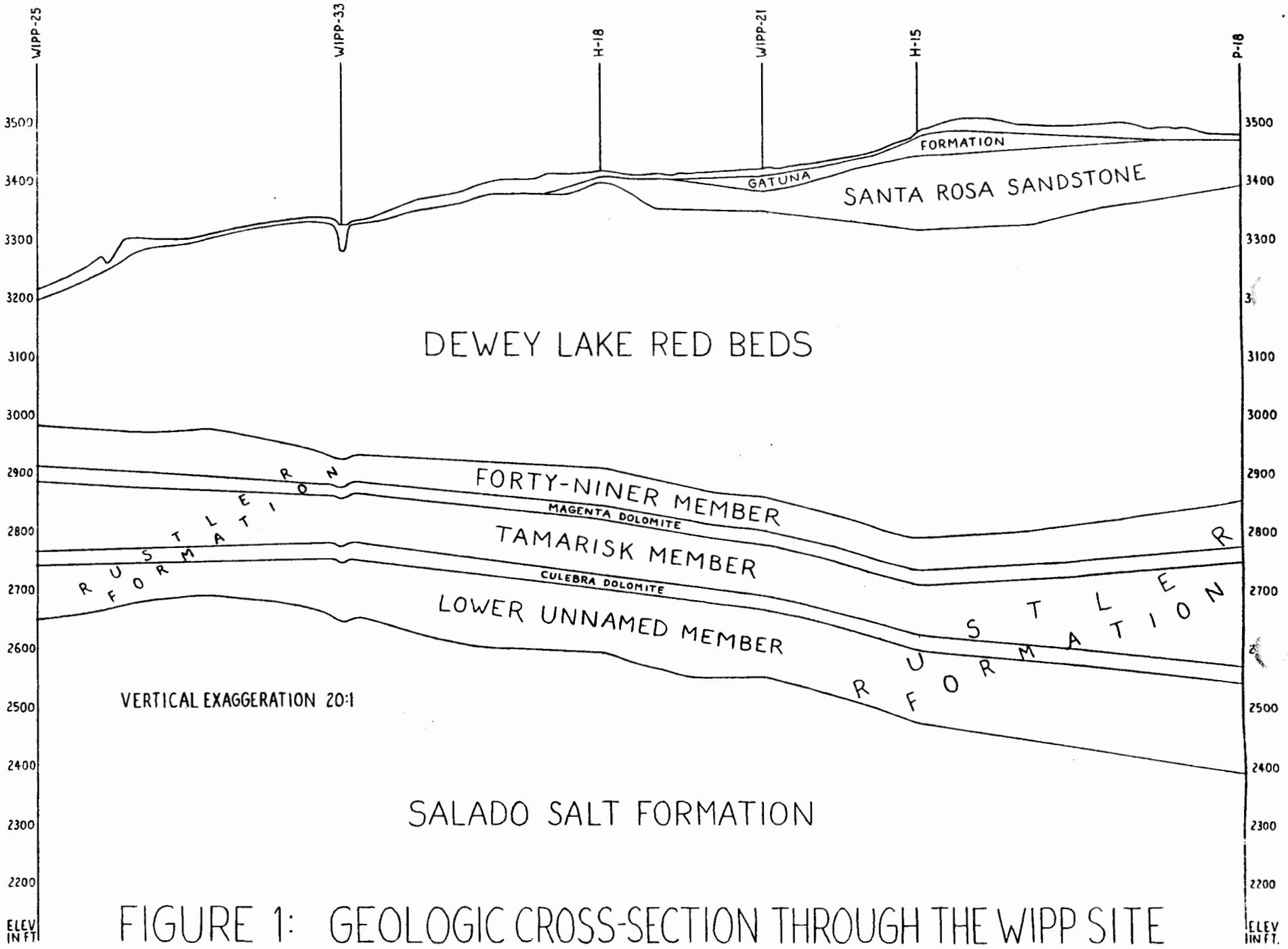


FIGURE 1: GEOLOGIC CROSS-SECTION THROUGH THE WIPP SITE

northern part of the WIPP site, are hydraulically connected by channelized flow in the Culebra dolomite. Similar results indicate a hydraulic connection between test wells H-3, DOE-1 and H-11 in the southeastern part of the WIPP site, with measurable response at test wells H-15, H-17, P-17 and Cabin Baby, and little or no response at test wells H-4, H-12, H-14, P-15 and P-18 [Figure 2]. These hydraulic connections are not necessarily fracture networks, as interpreted by Beauheim (1986, 1989); the response was so rapid that they could be karst channels.

Hydraulic conductivity is the velocity at which water moves through an aquifer. Transmissivity is the rate at which water is transmitted by the aquifer; it is equal to hydraulic conductivity times the thickness of the aquifer. The highest measured values for transmissivity and hydraulic conductivity in the Culebra dolomite aquifer at WIPP test wells are given in Table 1.

It has long been recognized that, in the Culebra dolomite, transmissivity varies by five orders of magnitude in the vicinity of the WIPP site, from 0.002 ft^2/day at test well P-18, located 4547.3 feet east of the WIPP site, to 233.0 ft^2/day at test well P-14, located 4664.2 feet west of the WIPP site (Haug et al., 1987). It is often represented that transmissivity in the Culebra dolomite increases steadily from east to west, but this is not the case. When measurements of transmissivity in the Culebra dolomite are plotted on a map [Figure 3], contour lines cannot be drawn, not even on a logarithmic scale. Rather, it becomes apparent that, among test wells within one mile of the WIPP site, seven test wells show anomalously high transmissivity in the Culebra dolomite, one to three orders of magnitude higher than in any others. These test wells include, besides P-14, the very six test wells shown by pumping tests to be hydraulically connected (DOE-2, WIPP-13, H-6; H-3, DOE-1 and H-11).

Anomalously high transmissivity in some boreholes is exactly what one would expect in a karstland. A borehole which misses one of the active solution conduits should show values which are much less than the average. This applies to almost all boreholes in a karstland because the area of active solution conduits is only a small part of the total area. It is possible, indeed likely, that none of the measured transmissivities within one mile of the WIPP site are representative of karst conditions in the Culebra dolomite, because none of these test wells were reported to have encountered cavernous zones in the Culebra.

However, cavernous zones were encountered at WIPP-33, a borehole located 2753.4 feet west of the WIPP site. There were five caverns in all: four in the Rustler Formation (two in Magenta dolomite, two in Forty-Niner gypsum), and one in the Dewey Lake Redbeds. The caverns were inferred by: (1) a precipitous drop of the drilling equipment (zero minutes per vertical foot); (2) a loss of circulation of drilling fluid; and (3) no core recovery.

FIGURE 2: RESULTS OF MULTI-WELL PUMP TESTS

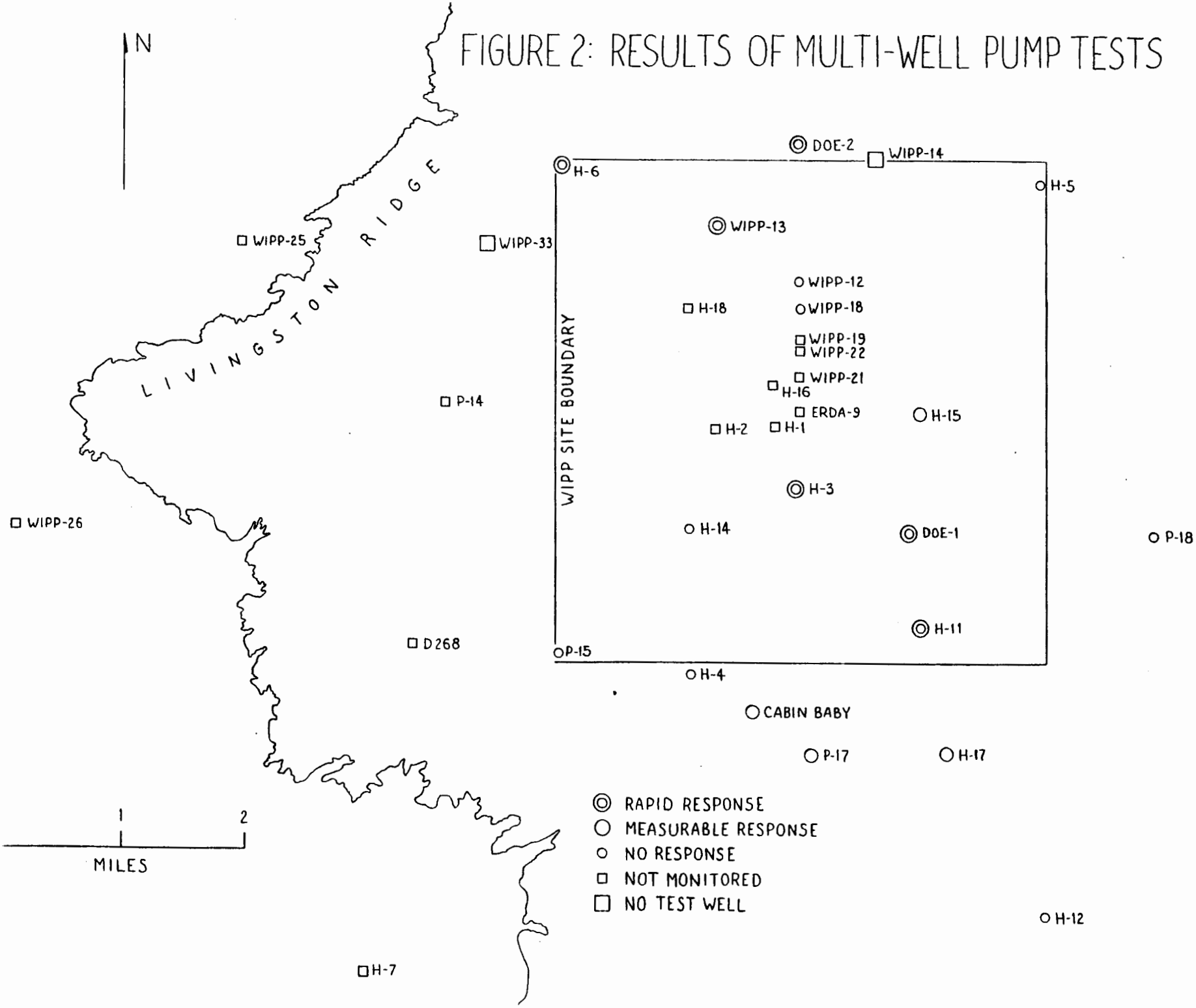
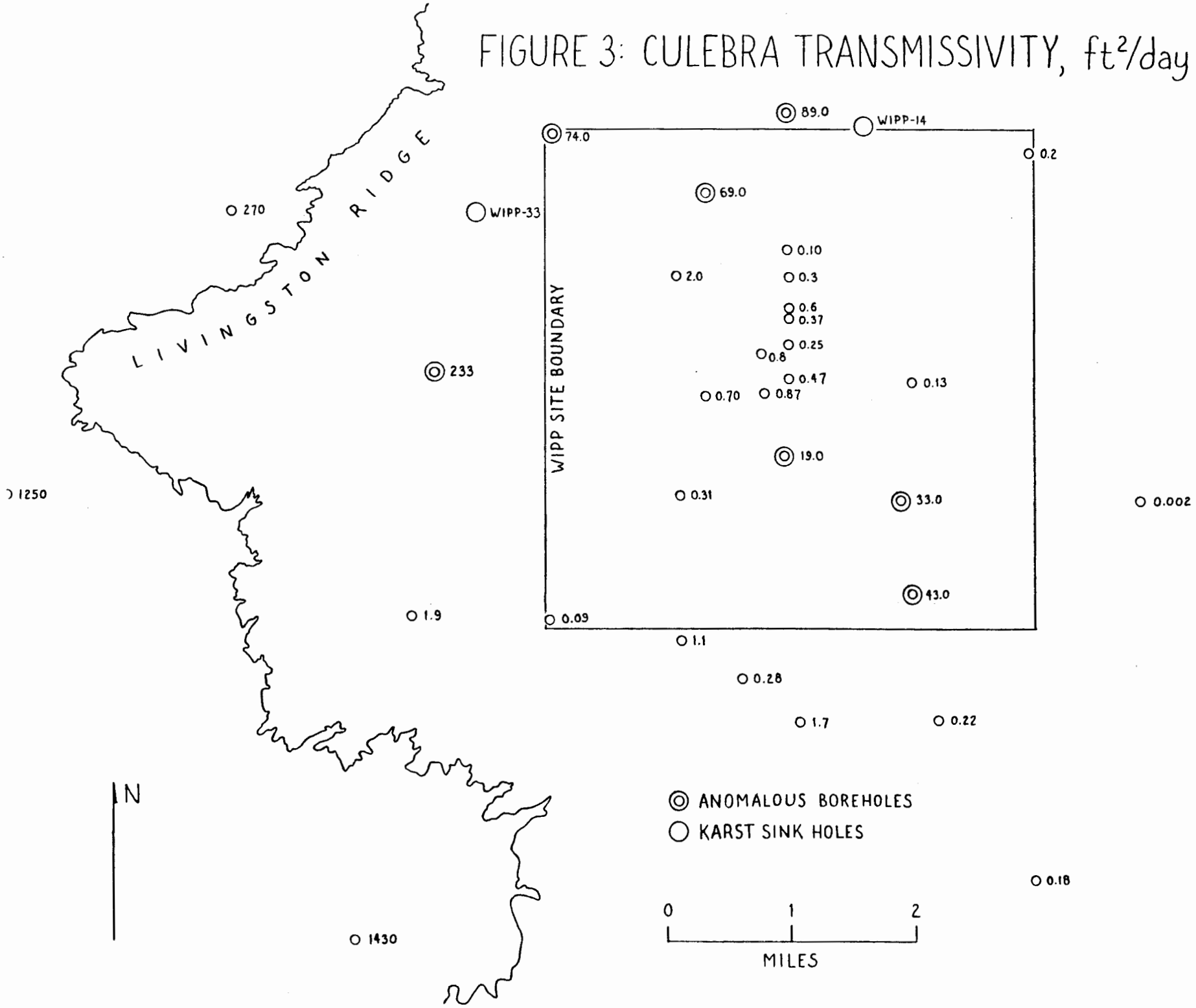


TABLE 1: HIGHEST MEASURED TRANSMISSIVITY (ft^2/day)
AND HYDRAULIC CONDUCTIVITY (ft/day)
IN CULEBRA DOLOMITE AT WIPP TEST WELLS

test well	transmis-sivity	hydraulic conductivity	source of data
* H-1	0.87	.038	LaVenue et al. (1989)
* H-2	0.70	.032	Beauheim (1989)
* H-3	19.0	0.86	Mercer (1983)
* H-4	1.1	.046	Haug et al. (1987)
* H-5	0.2	.009	Mercer (1983)
* H-6	74.0	3.2	LaVenue et al. (1988)
H-7	1430.0	31.0	LaVenue et al. (1989)
H-8	16.0	0.59	Mercer (1983)
H-9	231.0	7.7	Mercer (1983)
H-10	0.07	.002	Mercer (1983)
* H-11	43.0	1.7	Beauheim (1989)
H-12	0.18	.007	LaVenue et al. (1989)
* H-14	0.31	.013	LaVenue et al. (1988)
* H-15	0.13	.005	Beauheim (1987)
* H-16	0.80	.037	Beauheim (1987)
H-17	0.22	.009	Beauheim (1987)
* H-18	2.0	0.08	Beauheim (1987)
* P-14	233.0	10.6	Haug et al. (1987)
* P-15	0.09	.004	LaVenue et al. (1988)
* P-17	1.7	.074	Haug et al. (1987)
* P-18	0.002	.00007	Haug et al. (1987)
* WIPP-12	0.10	.004	Beauheim (1987)
* WIPP-13	69.0	3.1	LaVenue et al. (1988)
* WIPP-18	0.3	.014	LaVenue et al. (1988)
* WIPP-19	0.6	.026	LaVenue et al. (1988)
* WIPP-21	0.25	.010	LaVenue et al. (1988)
* WIPP-22	0.37	.017	LaVenue et al. (1988)
WIPP-25	270.0	11.0	Mercer (1983)
WIPP-26	1250.0	54.3	Mercer (1983)
WIPP-27	650.0	25.0	Mercer (1983)
WIPP-28	18.0	0.69	Mercer (1983)
WIPP-29	1000.0	33.3	Mercer (1983)
WIPP-30	0.3	.013	Mercer (1983)
AEC-7	0.26	.010	LaVenue et al. (1989)
* DOE-1	33.0	1.5	Haug et al. (1987)
* DOE-2	89.0	4.0	LaVenue et al. (1988)
* ERDA-9	0.47	.020	LaVenue et al. (1988)
D-268	1.9		LaVenue et al. (1989)
* Cabin Baby	0.28		LaVenue et al. (1988)
Engle	43.0		LaVenue et al. (1988)
USGS-1	515.0		LaVenue et al. (1988)

* Test wells located at or within one mile of the WIPP site.

FIGURE 3: CULEBRA TRANSMISSIVITY, ft²/day



A camera was then lowered into the borehole, which confirmed the presence of underground caverns. If cavernous zones are present in other WIPP boreholes, the same three criteria should apply. Unfortunately, an examination of the geophysical logs and lithologic descriptions for other WIPP boreholes reveals that the first two criteria -- drilling time and lost circulation -- are rarely noted. Nor can cavernous zones in the Culebra and Magenta dolomite members of the Rustler Formation be detected by a lack of core recovery alone, because the Culebra and Magenta are typically fractured, which makes core recovery difficult. However, a correlation of geophysical logs and lithologic descriptions does reveal a consistent lack of core recovery at two other stratigraphic horizons in the Rustler Formation:

(1) A zone of solution residue characterized by soft reddish-brown siltstone or mudstone with gypsum-filled voids and clasts of brecciated gypsum and anhydrite. This zone grades downward into a greenish claystone separated from the Magenta dolomite by 13.9 to 18.7 feet of anhydrite or gypsum. In the WIPP ventilation shaft this zone is 6.7 feet thick; it washed out 2.5 feet deep into the shaft wall; water seeps into the shaft at this level; and a ten-foot steel liner plate was installed to prevent further caving of the shaft wall.

(2) A zone of solution residue consisting of claystone or mudstone, gray to dark reddish-brown, with brecciated anhydrite clasts, gypsum crystals, and gypsum-filled fractures; poorly consolidated, and readily crumbled. The claystone grades upward into a layer of soft shale, black to dark gray, immediately beneath the Culebra dolomite. In the WIPP ventilation shaft this zone is 7.1 feet thick; it washed out into the shaft wall; water seeps into the shaft at this level; and a ten-foot steel liner plate was installed to prevent further caving of the shaft wall.

Note that the first zone is in the Forty-Niner member of the Rustler Formation; the second zone is in the lower unnamed member of the Rustler Formation; and both zones produce water, at least in the WIPP ventilation shaft. This is direct evidence that no member of the Rustler Formation is impermeable, that the Magenta dolomite and Culebra dolomite are not confined aquifers. This substantiates the findings of Ferrall and Gibbons (1980), who examined available cores of the Rustler Formation and observed high-angle to near-vertical fractures in each member.

If these zones appeared only in the WIPP ventilation shaft, or elsewhere but rarely, it might be reasonable to regard them as "washed out zones" attributable to drilling fluid. However, both of these zones can be correlated across the WIPP site, with a consistent lack of core recovery. Both zones are poorly consolidated, probably transmissive, and possibly cavernous.

In the zone above the Magenta dolomite there was loss of core, washout, and/or loss of circulation at H-17, H-11b3, H-3b3, H-1, WIPP-19, WIPP-12, DOE-2, WIPP-34, H-16, H-18, and WIPP-33. In the zone below the Culebra dolomite there was loss of core or cuttings at H-11b3, H-3b3, P-1, H-14, H-15, H-18, P-12, WIPP-13, WIPP-11, DOE-2, WIPP-34, and WIPP-14. Detailed summaries of these cavernous encounters, compiled almost entirely from geophysical logs and lithologic descriptions, with occasional reliance on Chaturvedi and Channell (EEG-32, 1985), are given in Tables 2 and 3. The boreholes are mapped in Figure 4.

Dissolution residue was reported in the Forty-Niner member, within 15 to 18 feet of the Magenta, but with no loss of core, at ERDA-9, WIPP-18, WIPP-19, WIPP-21, WIPP-22, and WIPP-13. Dissolution residue was reported in the lower unnamed member, within 2 to 4 feet of the Culebra, but with no loss of core, at ERDA-9, WIPP-18, WIPP-21, WIPP-22, H-6, and WIPP-33.

All the boreholes listed above are located at the WIPP site or within one mile of the WIPP site. In addition, at borehole H-7c, located 2.9 miles southwest of the WIPP site in Nash Draw, there was loss of core at 273.5 to 280.0 feet below the land surface, immediately below the Culebra dolomite. At borehole WIPP-25, located 2.5 miles west of the WIPP site in Nash Draw, there was lost circulation of drilling fluid at 522 to 526 feet below the land surface, within a 20.6-foot section of mud in the lower unnamed member of the Rustler Formation.

There is another dissolution zone in the Tamarisk member of the Rustler Formation. Four boreholes clustered near the center of the WIPP site have encountered washouts or loss of core in Tamarisk anhydrite: at H-1 (650.0-653.5 feet below land surface, 22.5 feet above Culebra); at H-2a (593.0-606.0 feet below land surface, 17.0 feet above Culebra); at H-3b3 (645.5-652.5 feet below land surface, 19.5 feet above Culebra); and at ERDA-9 (690.0-698.0 feet below land surface, 6.0 feet above Culebra). At the same horizon in the Tamarisk member, dissolution residue was encountered in the WIPP ventilation shaft and along two paths leading away from ERDA-9: northward at WIPP-21, WIPP-22, WIPP-19 and WIPP-18, and northwestward at H-18, WIPP-13 and H-6.

Caverns are known to occur in the Dewey Lake Redbeds as well. The lithologic log for borehole H-7c reports "boulders caving in" at 59 feet below the land surface. Lost circulation of drilling fluid in the Dewey Lake Redbeds has been reported at H-7c (24 feet above the Rustler), at WIPP-33 (37 feet above the Rustler), at WIPP-25 (124 to 154 feet above the Rustler), at P-1 (180 feet above the Rustler), and at DOE-2 (400 feet above the Rustler).

This correlation of cavernous zones raises two questions: (1) are karst conditions expressed at the land surface; and (2) if so, is WIPP hydrologic data representative of karst conditions?

TABLE 2: CORRELATED EVIDENCE OF CAVERNOUS ZONE, FORTY-NINER MEMBER, RUSTLER FORMATION

H-17:
"no recovery," 7.2 ft, claystone, 542.9-550.1 ft below surface, 13.9 ft above Magenta

H-11b3:
"no recovery," 6.2 ft, claystone, 595.7-601.9 ft below surface, 21.0 ft above Magenta

H-3b3:
"washed out zone," 2.5 ft, mudstone, on caliper log, 536.5-539.0 ft below surface, 20.0 ft above Magenta

H-1:
"washed out zone," 8.5 ft, mudstone, on caliper log, 538.5-547.0 ft below surface, 16.0 ft above Magenta; loss of circulation of drilling fluid

VENTILATION SHAFT:
"deep washout," 6.7 ft, mudstone, first liner plate, 569.2-575.9 ft below surface, 20.2 ft above Magenta

WIPP-19:
"no core," 2.1 ft, mudstone, 620.2-622.3 ft below surface, 25.5 ft above Magenta

WIPP-12:
"no core," 6.0 ft, clay, 678.7-684.7 ft below surface, 19.2 ft above Magenta

DOE-2:
"no core," 2.5 ft of 10.2 ft interval, mudstone/siltstone, 669.8-680.0 ft below surface, 18.6 ft above Magenta

WIPP-34:
"no core," 2.7 ft, mudstone, 691.0-693.7 ft below surface, 22.1 ft above Magenta

H-16:
"no recovery," 2.5 ft, clay, 566.8-569.3 ft below surface, 20.9 ft above Magenta

H-18:
"no recovery," 7.1 ft, clay, 542.2-549.3 ft below surface, 21.9 ft above Magenta

WIPP-33:

"cavity; determined by drop of drill string during drilling and through interpretation of caliper log," 9.5 ft, gypsum, 416.5-426.0 ft below surface, 23.0 ft above Magenta

"cavity; no core (drill string dropped), possible cavernous formation," 6.0 ft, gypsum, 430.0-436.0 ft below surface, 13.0 ft above Magenta

ALSO AT WIPP-33:

cavity, 7.0 ft, siltstone, in Dewey Lake Redbeds, (no core, 0.0 min/ft drilling time, lost circulation), 357.0-364.0 ft below surface

"cavity; no core (cavernous)," 2.0 ft, in Magenta dolomite, no circulation for 24 hours, 0.0 min/ft drilling time, 452.0-454.0 ft below surface

"cavity (drill string dropped)" 5.0 ft, in Magenta dolomite, no core, no circulation for 24 hour period, 462.0-467.0 ft below surface

TABLE 3: CORRELATED EVIDENCE OF CAVERNOUS ZONE, LOWER UNNAMED MEMBER, RUSTLER FORMATION

H-17:
"some rock washed away," core recovered, 0.8 ft, claystone 733.2-734.0 ft below surface, 1.8 ft below Culebra

H-11b3:
"no recovery (estimated zone of core loss)," 2.6 ft, clay, 765.9-768.3 ft below surface, 0.4 ft below Culebra

H-3b3:
"only 20% of the core was recovered," 5.5 ft, black shale and siltstone, appears on caliper log, 691.5-697.0 ft below surface, directly below Culebra

P-1:
"friable" (brittle, readily crumbled), 10.0 ft, mudstone, 580.0-590.0 ft below surface, 1.0 ft below Culebra

H-14:
"no recovery," 4.6 ft, claystone (?), 569.4-574.0 ft below surface, directly below Culebra

H-15:
"no recovery," 9.2 ft, mudstone, 890.8-900.0 ft below surface, 5.1 ft below Culebra

VENTILATION SHAFT:
"washed out zone," 7.1 ft, mudstone/claystone, third liner plate, 727.2-734.3 ft below surface, 0.3 ft below Culebra

H-16:
"washed out core," 4.0 ft, claystone, 725.1-729.1 ft below surface, 0.7 ft below Culebra

H-18:
"no recovery," 3.6 ft, clay and claystone, 713.8-717.4 ft below surface, 1.9 ft below Culebra

P-12:
"no sample," 5.0 ft, siltstone, 660.0-665.0 ft below surface, 4.0 ft below Culebra

WIPP-13:
"no core," 2.0 ft, mudstone, 727.0-729.0 ft below surface, 0.1 ft below Culebra

WIPP-11:
"no core," 4.5 ft, mudstone, 888.0-892.5 ft below surface, 8.0 ft below Culebra

DOE-2:
"no core," 1.4 ft, mudstone, 847.6-849.0 ft below surface, 1.6 ft below Culebra

WIPP-34:
"no core," 3.5 ft, mudstone, 860.8-864.3 ft below surface, directly below Culebra

WIPP-14:
"no core," 81.4 ft, mud with gypsum and anhydrite fragments (upper 71.4 ft), mud and siltstone (lower 10.0 ft), 836.2-917.6 ft below surface, directly below Culebra

ALSO AT WIPP-14:
"no core," 159.9 ft: siltstone and mudstone (10.7 ft) and gypsum (19.5 ft), lower 30.2 ft of Forty-Niner Member; entire 23.5 ft of Magenta dolomite; entire 87.2 ft of Tamarisk Member, siltstone, sandstone, anhydrite, clay, gypsum; entire 19.0 ft of Culebra dolomite; 676.3-836.2 ft below surface

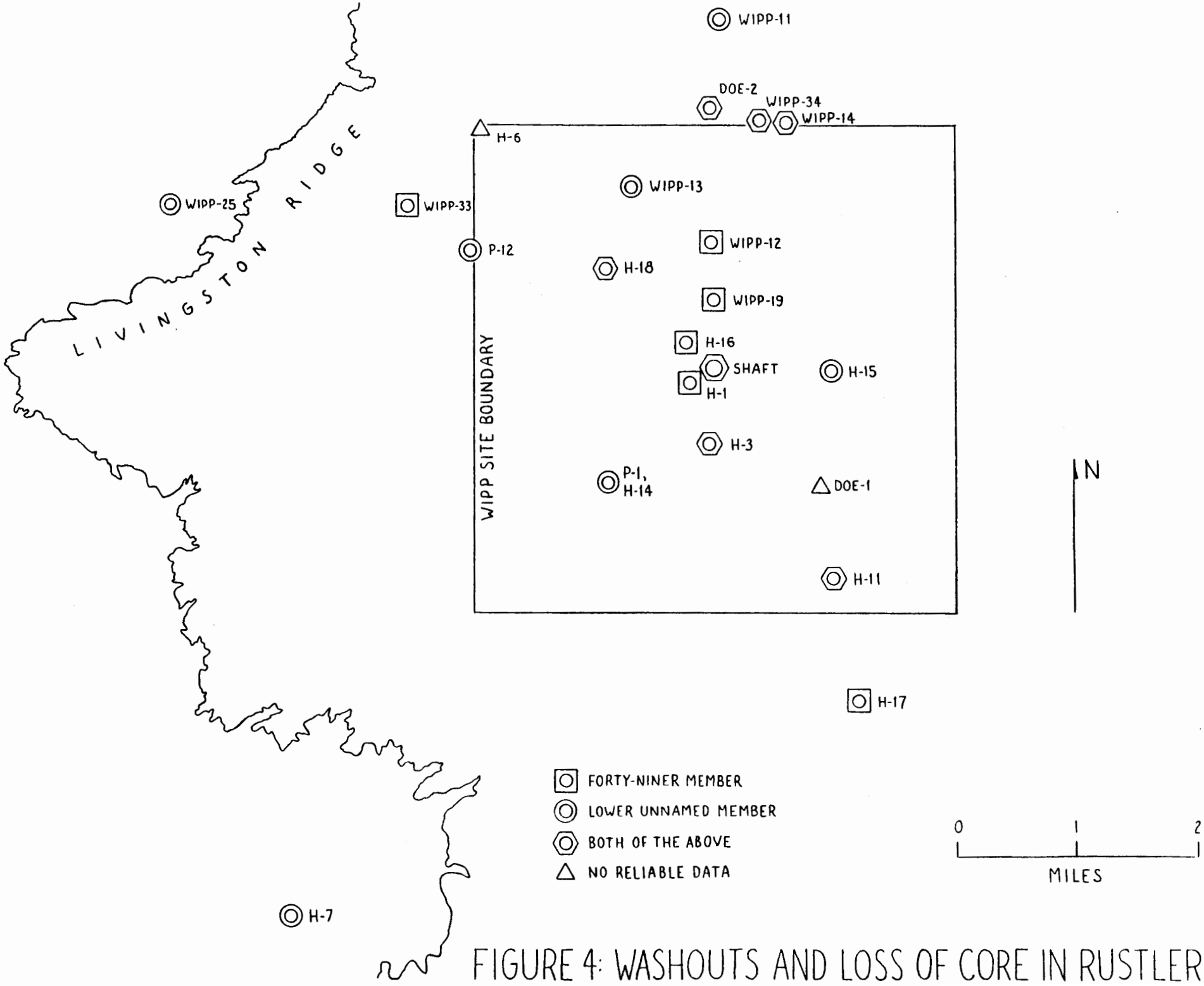


FIGURE 4: WASHOUTS AND LOSS OF CORE IN RUSTLER

Every karstland has sinkholes in the land surface. Two types of sinkholes are recognized: (1) collapse sinks, formed when surface rocks collapse abruptly into underground caverns, allowing surface runoff to be swallowed rapidly; and (2) alluvial dolines, or solution-subsidence dolines, formed when surface rocks subside slowly due to solution of underlying rocks; these are flooded after major rainstorms and become filled with alluvial sediments. Collapse sinks are more common where soluble rocks are exposed at the land surface; alluvial dolines are more common where soluble rocks are overlain by sandstones, as at the WIPP site.

West of the WIPP site is Nash Draw, one of the largest karst features with surface expression in the world. Nash Draw is a huge depression, 18 miles long and 10 miles wide, formed by the coalescence of thousands of sink holes. The H-7 test wells were drilled into one of the sinks in Nash Draw; it is located near the western end of an obvious karst valley, walled on both sides by high dunes, and plainly visible in the WIPP site air photos. There are ephemeral watercourses draining into the valley from the sides, but upon entering the valley these watercourses disappear underground. At borehole H-7c a cavern was encountered in the Dewey Lake Redbeds, with lost circulation of drilling fluid and "boulders caving in." The Culebra dolomite was broken into six sections totalling 24.3 feet, separated by five cavities totalling 21.7 feet; this was underlain by 6.2 feet of mud, beneath which there was no core for 80.8 feet. Transmissivity in the Culebra dolomite is 1430 ft^2/day, the highest measurement at any of the forty-one WIPP test wells.

The most obvious sinkhole in the WIPP site vicinity is WIPP-33, located in sec 13, T 22 S, R 30 E. It is a closed topographic depression about 700 feet in diameter and 30 feet deep. It is prominent on the WIPP site air photos, and is shown on the USGS topographic maps. One of the few small arroyos in the WIPP site vicinity drains into this depression. It is floored with matted leaves, organic matter and desiccated clay, indicating occasional flooding of the depression. Evidence of surface collapse can be seen in the caliche escarpment at its southeastern rim. Evidence of subsurface collapse was seen in backhoe trenches, where caliche breaks off abruptly, with near-vertical drops of four feet to the sandstone bedrock surface. Joint-controlled solution features were found in carbonate-cemented sandstone beneath the caliche. In the WIPP site gravity survey, a negative gravity anomaly of high amplitude was measured, originating no deeper than the Magenta dolomite. Borehole WIPP-33, drilled into this depression, encountered 44 feet of alluvial fill, and five underground caverns filled with water -- one in Dewey Lake siltstone, two in Forty-Niner gypsum, two in Magenta dolomite. In the Rustler Formation, all anhydrite has been converted to gypsum, and all halite has been dissolved and removed; salt dissolution has also affected the top of the Salado Formation.

Three other sinkholes form a chain trending west-southwestward, directly to WIPP-33, implying an underground flow path beneath them. All are visible in the WIPP site air photos, and all are underlain by structural depressions in the caliche surface. The westernmost sinkhole is 400 feet long, 200 feet wide, 2 to 4 feet deep, is floored by organic debris and desiccated clay, is saturated after rainstorms, contains at least 24 feet of alluvial fill, and swallows some of the water from the WIPP-33 arroyo. The second sinkhole is 300 feet long, 200 feet wide, 8 to 10 feet deep, and is not as well developed, being floored by sand with a weak clay pan and only partly filled with alluvial sediments, although non-incised watercourses are present on its slopes. The easternmost sinkhole is 300 feet long, 150 feet wide, 2 feet deep, is floored by organic debris and desiccated clay, is saturated after rainstorms, contains up to 20 feet of alluvial fill, and has an arroyo disappearing into it. This arroyo formed suddenly during the heavy rains of September 18-19, 1985, only to be swallowed by the sinkhole; this is direct evidence of active karst processes. This same rainstorm filled the WIPP-33 sinkhole with 5.0 feet of standing water, which infiltrated within days.

Another sinkhole in the WIPP site vicinity is WIPP-14, located in sec 9, T 22 S, R 31 E. It is 600 to 700 feet in diameter, 9 feet deep, and is shown on the USGS topographic maps. Draining into the WIPP-14 depression from the east are at least five ephemeral water courses. It is floored by windblown sand, organic debris, and desiccated clay. No collapse is evident at the surface, but such evidence could be obscured by 8 to 15 feet of dune sands that have accumulated on the crests of the depression. It is underlain by a structural depression in the caliche surface, 400 to 650 feet in diameter and 6 feet deep. Gleyed sediments were observed in trench exposures, indicating past ponding, when perched water accumulated in the depression and caliche became extremely leached and degraded, leaving only remnants pockmarked with solution features. Carbonate-filled fractures in Santa Rosa sandstone beneath the caliche are direct evidence of rainwater infiltration. The depression is underlain by a high-amplitude negative gravity anomaly. Borehole WIPP-14, drilled into this depression, encountered 15.4 feet of alluvial fill; there was 243.1 feet of lost core, including 71.4 feet of mud with gypsum and anhydrite fragments directly below the Culebra; halitic mudstone was found in the lower 3.7 feet of the Rustler Formation; all other halite has been dissolved and removed.

There are now 27 hydrologic test wells within one mile of the WIPP site. Six of them (DOE-2, WIPP-13, H-6, H-3, DOE-1, H-11) may be representative of fracture flow in the Culebra, but none are known to be representative of karst conditions. WIPP-33 is located one-half mile from the WIPP site, and WIPP-14 is located within 100 feet of the WIPP site. There is no excuse for not converting these existing boreholes into hydrologic test wells. The simplest explanation is that DOE is not interested in karst.

RAINWATER RECHARGE AT THE WIPP SITE

by Richard Hayes Phillips, Ph.D.

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is intended for the permanent disposal of radioactive waste from nuclear weapons production. The WIPP site was selected in 1974. It is now 1997, and the Department of Energy (DOE) still does not know where the groundwater aquifers are recharged. This, at a minimum, must be understood, or DOE's site characterization has no credibility (EEG-32, 1985; Anderson, 1994; Konikow, 1995; EEG-61, 1996; SEIS, 1996, Appendix H).

DOE's failure to grasp the fundamentals of WIPP site hydrology stems not from a lack of evidence, but from an unwillingness to face the truth: (1) the WIPP site is in karst; (2) the Dewey Lake Redbeds and the Rustler Formation are recharged by rainwater; and (3) groundwater flow at WIPP is three-dimensional.

The controversy over karst at the WIPP site dates to a paper by Larry Barrows entitled: "WIPP Geohydrology -- The Implications of Karst" (Barrows, 1982; reprinted in EEG-32, 1985, Appendix A). Barrows cites as evidence of karst geomorphology: (1) ample precipitation; (2) lack of surface runoff; (3) disappearing arroyos; (4) sink holes; and (5) underground caverns.

The WIPP site is located in one of the largest karstlands in the world. The Pecos River valley is famous for Santa Rosa Sinks, Bottomless Lakes, and Carlsbad Caverns. Within one mile of the northwest corner of the WIPP site is Nash Draw, a huge depression in the land surface, up to 18 miles long and 10 miles wide. Nash Draw was formed by the coalescence of thousands of sink holes caused by the abrupt collapse or gradual subsidence of overlying rocks into underground caverns beneath them.

Nash Draw is bounded on the east by Livingston Ridge, which is actually a rim, a 100-foot escarpment capped by Mescalero caliche. Livingston Ridge is not a geomorphic divide; it does not represent the eastern extent of karst conditions. It is the eastern extent of widespread collapse of surficial rocks into the voids caused by dissolution of evaporite rocks in the subsurface. Karst exists east of Livingston Ridge, but the karst landforms are not as widespread or as well developed as in Nash Draw.

The WIPP site has almost no surface runoff. This is not due to inadequate precipitation. Rainfall averages 14 inches per year, and 20 inches per year is not uncommon. Rather, the WIPP site is covered with windblown sand in the form of deflation basins and partially stabilized dunes. These sands are transmissive enough to allow infiltration of even the largest storms. "Instead of

running off, the precipitation collects in the small topographic depressions and rapidly soaks into the ground. The absence of surface runoff is characteristic of a karstland." (Barrows, 1982)

Most of the depressions are windblown. But some of the larger ones are sink holes, exemplified by WIPP-33 and WIPP-14, located 1.1 mile and 3.4 miles east of Nash Draw, respectively. WIPP-33 is a collapse sink with a disappearing arroyo, underlain by five caverns: one in Dewey Lake siltstone, two in Forty-Niner gypsum, and two in Magenta dolomite. WIPP-14 is a solution-subsidence doline which has held water in the geologic past; now the Culebra dolomite is underlain by 70 feet of mud with gypsum and anhydrite fragments, here interpreted as cave sediments. The cavernous zones at WIPP-33 and WIPP-14 are direct evidence of karst. These zones can be correlated stratigraphically with washouts and loss of core in seventeen other WIPP boreholes and in the WIPP ventilation shaft. The question is not whether karst exists at the WIPP site, but whether karst hydrology is active today.

The Rustler Formation is the most transmissive aquifer and the principal karst horizon at the WIPP site. If karst hydrology is active today, then the Rustler Formation must be recharged by rainwater. A likely process, according to Barrows (1982), is downward infiltration of fresh water through feeders in the overlying Dewey Lake Redbeds to karst channels in the Rustler Formation. Conversely, if karst hydrology is <u>not</u> active today, then the Rustler Formation must <u>not</u> be recharged by rainwater. This would require a continuous impermeable layer, acting as a barrier to rainwater infiltration, somewhere in the stratigraphic column above the Rustler Formation. Bachman (1985) argued that Mescalero caliche forms such a barrier, preventing infiltration and recharge of the Dewey Lake Redbeds and the Rustler Formation.

Caliche is a layer of calcium carbonate that forms in desert soils at the depth of soil water penetration. Where soil cover is thin, the caliche horizon may become plugged and indurated, forming a "hardpan" resistant to erosion and impervious to rainwater. But where soil cover is thick, infiltrating soil water may migrate along the caliche surface until it finds a fracture that allows downward drainage, or a hole where a plant root has penetrated the caliche; or it may collect in a small depression in the caliche surface and begin to dissolve a new hole in the caliche. In the southwestern part of the WIPP site (SW/4 sec 30, T 22 S, R 31 E), where Mescalero caliche is in direct contact with the Dewey Lake Redbeds, trench exposures revealed fifteen solution pipes, 1 to 14 feet in diameter, right through the caliche. Here the Dewey Lake Redbeds are recharged directly by rainwater. These trenches were located in a karst valley, a broad swale one mile long, ten feet deep, trending east-west, and narrowing from 900 feet in the east to 200 feet in the west, where thick groves of mesquite bushes are impenetrable.

Other smaller topographic depressions, visible in the WIPP site air photos, shown on USGS topographic maps, lead directly to the deepest fluvial incisions in Livingston Ridge. The air photos reveal ephemeral or near-surface drainage courses expressed at the land surface as vegetation in dendritic patterns.

The Gatuna Formation, consisting of light reddish-brown, poorly consolidated sandstone, is alluvial fill material deposited in ancient sinks and topographic lows by westward-flowing streams. It was exposed in trenches on the slopes of WIPP-33, below the caliche escarpment. The Gatuna sandstone is commonly fractured, jointed, and broken into blocks. As soil water dissolves the carbonate cement, these openings become enlarged by solution, forming solution pans or tinajitas, and solution grooves or slots. The Gatuna is not a barrier to rainwater infiltration.

The Santa Rosa Formation consists of pale orange, coarse-grained sandstone, cemented by dolomite, interbedded with conglomerate lenses containing dolomite, chert, and quartz pebbles. The Santa Rosa has been eroded from the western part of the WIPP site; to the east, where it remains, it protects the underlying Dewey Lake Redbeds from erosion. At WIPP-14, the Santa Rosa was exposed in trenches beneath a leached and degraded caliche profile. The Santa Rosa exhibited carbonate-filled fractures, direct evidence of rainwater infiltration. The Santa Rosa retards, but does not prevent, rainwater recharge to the underlying Dewey Lake Redbeds.

Water has been encountered in the Dewey Lake Redbeds in eleven test wells within one mile of the WIPP site. All are listed in Table 1. According to the neutron log for H3-b4, a down-hole camera recorded "water streaming from fracture." The water level was 466.85 feet below the surface. Water was also observed in the Dewey Lake Redbeds in the air intake shaft near the center of the WIPP site (EEG-61, 1996, p. 2-6), at WIPP-33 (SAND 80-2011, p. 11), and in three private wells within 2.5 miles of the WIPP site (Ranch, Barn, and Unger). All are shown in Figure 1.

Table 1 reveals a strong correlation between encounters of water in the Dewey Lake Redbeds and absence of the overlying Santa Rosa sandstone. At least nine of the thirteen test wells where the Santa Rosa is <u>not</u> present produced water in the Dewey Lake Redbeds. It is not certain that the other four (H-6, P-14, WQSP-5, and Cabin Baby) did not produce water in the Dewey Lake Redbeds, because the actual neutron logs for these test wells are unavailable. However, the "abridged drill-hole histories" for P-13 (located 224 feet from the H-6 hydropad) and P-14 do not report water in the Dewey Lake Redbeds. Only two of the twenty test wells where the Santa Rosa <u>is</u> present produced water in the Dewey Lake Redbeds. At these test wells (H-11 and H-16) the Santa Rosa is only 54 feet and 15 feet thick, respectively. This is further evidence that the Santa Rosa retards, but does not prevent, rainwater recharge to the underlying Dewey Lake Redbeds.

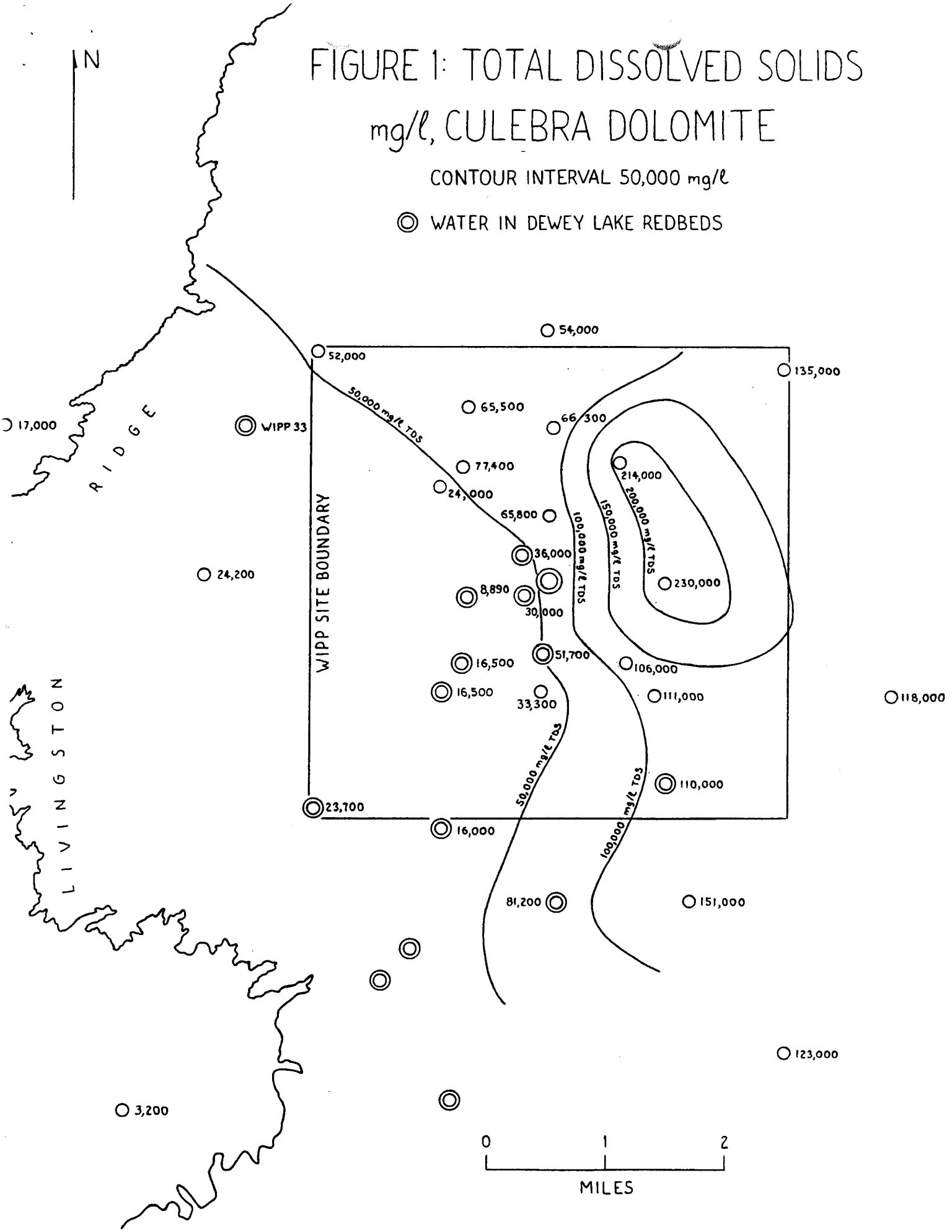


FIGURE 1: TOTAL DISSOLVED SOLIDS
mg/ℓ, CULEBRA DOLOMITE
CONTOUR INTERVAL 50,000 mg/ℓ
WATER IN DEWEY LAKE REDBEDS
N
RIDGE
LIVINGSTON
WIPP SITE BOUNDARY
50,000 mg/ℓ TDS
100,000 mg/ℓ TDS
150,000 mg/ℓ TDS
200,000 mg/ℓ TDS
54,000
52,000
135,000
17,000
WIPP 33
65,500
66,300
77,400
24,000
214,000
65,800
36,000
230,000
24,200
8,890
30,000
51,700
16,500
106,000
16,500
33,300
111,000
118,000
110,000
23,700
16,000
81,200
151,000
123,000
3,200
0
1
2
MILES

TABLE 1: THICKNESS OF SANTA ROSA SANDSTONE, MEASURED IN FEET, CORRELATED WITH ENCOUNTERS OF WATER IN DEWEY LAKE REDBEDS, AT WIPP TEST WELLS

test well	Santa Rosa	water in Dewey Lake
H-1	N.P.	*
H-2	N.P.	*
H-3	N.P.	*
H-4	N.P.	*
H-5	217	
H-6	N.P.	?
H-11	54	*
H-14	N.P.	*
H-15	126	
H-16	15	*
H-17	34	
H-18	12	
P-14	N.P.	?
P-15	N.P.	*
P-17	N.P.	*
P-18	78	
WIPP-12	138	
WIPP-13	53	
WIPP-18	129	
WIPP-19	82	
WIPP-21	34	
WIPP-22	68	
DOE-1	87	
DOE-2	120	
ERDA-9	9	
Cabin Baby	N.P.	?
WQSP-1		
WQSP-2		
WQSP-3		
WQSP-4		
WQSP-5	N.P.	?
WQSP-6	N.P.	*
WQSP-6a	N.P.	*

Note: WQSP-6 and WQSP-6a are shown as one well in Figures 5 and 6.

Sources: DOE/CAO 1996-2184, pp. 2-131, USDW-25; SAND 88-0157, p. 81; SAND 80-2011, pp. 8, 11, 15, C-3; and EEG-61, p. 2-6.

Figure 2 graphically displays the relationship between the western edge of the Santa Rosa sandstone and the locations of wells that produce water in the Dewey Lake Redbeds. Simply stated, the recharge area for the Dewey Lake Redbeds is everywhere that the Santa Rosa Formation is not present.

The water in the Dewey Lake Redbeds is potable. Environmental Protection Agency (EPA) criteria for drinking water are twofold: (1) less than 10,000 milligrams per liter (mg/l) total dissolved solids (TDS); and (2) more than 5 gallons per minute (gpm) of water produced by the well. Water quality data for the Dewey Lake Redbeds are given in Table 2. Five private wells within eight miles of the WIPP site produce water of potable quality in the Dewey Lake Redbeds, but the quantity has never been measured. Three WIPP test wells produce water in sufficient quantity from the Dewey Lake Redbeds, but the quality has never been tested. At seven WIPP test wells, (and also at WIPP-33), water produced by the Dewey Lake Redbeds has never been tested for quality or quantity. At only one test well, WQSP-6a, has both the quality and quantity of water from the Dewey Lake Redbeds been tested, and it was found to meet both criteria for drinking water (3,920 to 4,238 mg/l TDS, 12 gpm). DOE claims (DOE/CAO 1996-2184, Appendix USDW, Table USDW-4) that test well WQSP-6a is not subject to EPA standards (40 CFR 191, Subpart C) because WQSP-6a is located on-site -- one mile southwest of the center of the WIPP site, 0.3 miles southwest of the waste emplacement panels (DOE/CAO 1996-2184, Figure 3-9). DOE says it is "possible" that other test wells are subject to EPA standards (DOE/CAO 1996-2184, Appendix USDW, Table USDW-4). DOE does not know because DOE has not done the necessary testing. P-17 is 3908 feet outside the WIPP site. WIPP-33 is 2854 feet outside the WIPP site. H-4c is 446 feet outside the WIPP site. All the private wells are outside the WIPP site. Until these wells are properly tested, it cannot be claimed that the Dewey Lake aquifer does not qualify as an underground source of drinking water under 40 CFR 191, Subpart C. Absence of evidence is not evidence of absence.

Directly underlying the Dewey Lake Redbeds is the Rustler Formation. In WIPP boreholes, outside of Nash Draw, the Rustler ranges in thickness from 276 feet at WIPP-33, a collapse sink, to 462 feet at P-18, considered to be a complete Rustler section. The Rustler is divided into five members, here described in descending order: (1) the Forty-Niner member consists of 48 to 78 feet of broken and slumped gypsum with a bed of massive siltstone near the base; (2) the Magenta dolomite, 19 to 28 feet thick, is a highly fractured aquifer; (3) the Tamarisk member consists of 80 to 179 feet of anhydrite or gypsum with clay seams; (4) the Culebra dolomite, 21 to 31 feet thick, also highly fractured, is the most transmissive of the Rustler aquifers; and (5) the lower unnamed member consists of 72 to 150 feet of siltstone and very fine-grained sandstone, with interbedded gypsum or anhydrite.

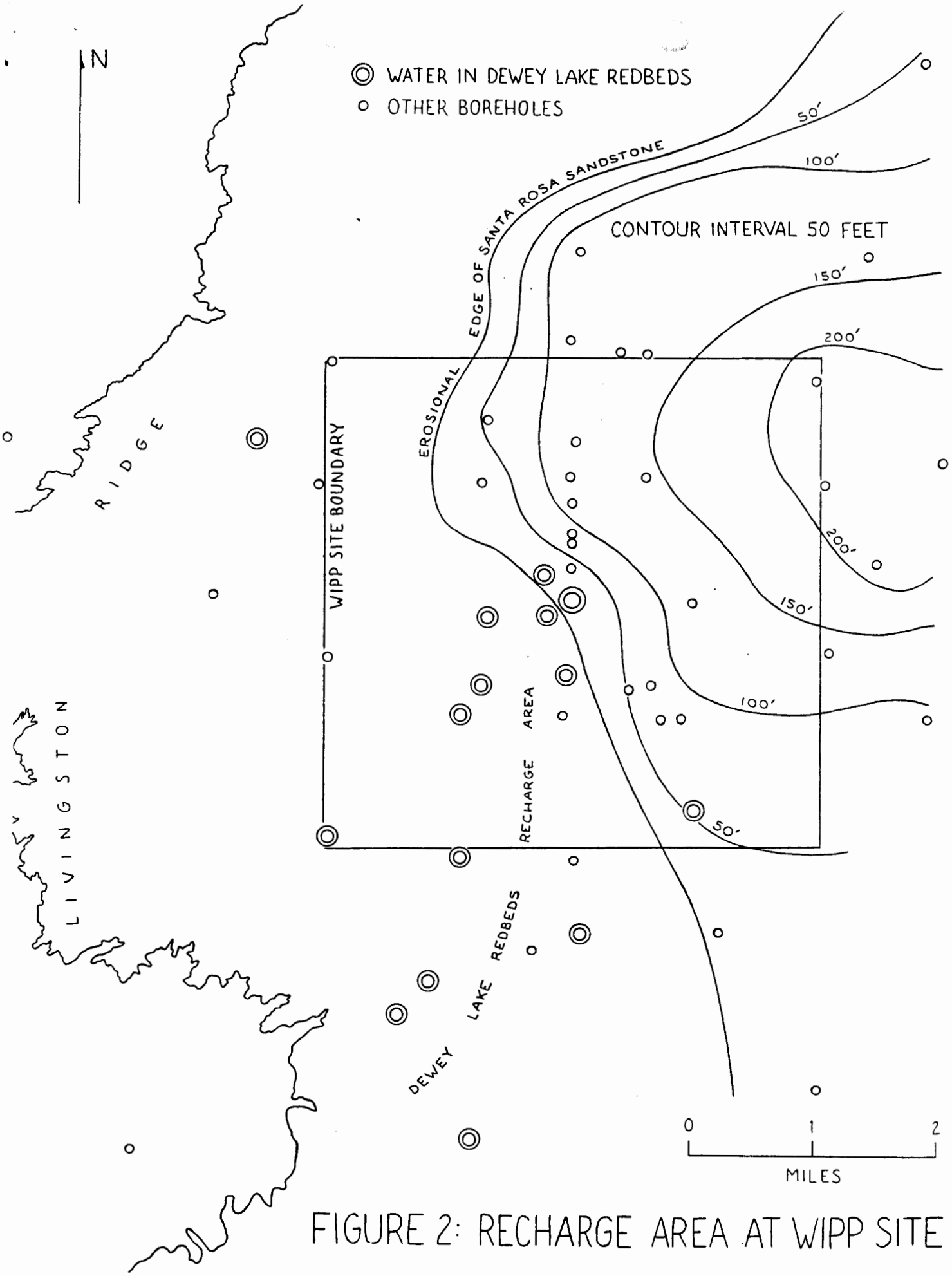


FIGURE 2: RECHARGE AREA AT WIPP SITE

TABLE 2: WATER IN THE DEWEY LAKE REDBEDS, GALLONS PER MINUTE, TOTAL DISSOLVED SOLIDS

well	gpm	TDS (mg/l)	date
H-1	not tested	not tested	
H-2	not tested	not tested	
H-3	not tested	not tested	
H-14	not tested	not tested	
H-16	not tested	not tested	
P-15	not tested	not tested	
P-17	not tested	not tested	
WIPP-33	not tested	not tested	
P-9	25	not tested	
H-4c	12-15	not tested	
H-11	25-30	not tested	
WQSP-6	25-30	not tested	
WQSP-6a	12	4,238	07/13/95
		3,920	03/28/96
Barn Well	not tested	670	11/04/87
		720	04/20/88
		630	07/27/89
		650	06/21/90
Ranch Well	not tested	3,300	06/18/86
		3,200	12/20/87
		2,900	04/20/88
		2,800	07/27/89
		3,000	06/20/90
Twin Wells	not tested	400	01/30/86
		390	08/03/88
		400	10/20/89
		410	05/30/90
Fairview Well	not tested	3,400	11/16/87
		3,300	07/06/88
Unger Well	not tested	3,300	11/18/87
		3,200	07/06/88

Notes: WIPP-33 encountered 7.0-foot cavity in Dewey Lake Redbeds; fluid level during logging was 274 feet below land surface.

Criteria for drinking water: < 10,000 mg/l TDS <u>and</u> > 5 gpm.

Sources: DOE/CAO 1996-2184, pp. 2-131, USDW-25; SAND 88-0157, p. 81; SAND 80-2011, pp. 8, 11, 15, C-3; EEG-61, p. 2-6; and USGS Open-file Report 78-592.

The Culebra and Magenta dolomite members are persistent marker beds and reliable aquifers. In forty-one WIPP test wells, the Culebra was always saturated; the Magenta was dry at H-7 and WIPP-26, and is absent at WIPP-29, all in Nash Draw (Mercer, 1983, Table 8). But water is sometimes found in the other members of the Rustler, even near the center of the WIPP site. Water was observed seeping into the WIPP ventilation shaft from a zone of solution residue in the Forty-Niner member, 17.7 to 30.2 feet above the Magenta; test well H-1 yielded as much water in the Tamarisk member as in the Culebra or Magenta; and test well H-3 yielded as much water in the lower unnamed member as in the Culebra or Magenta (EEG-32, 1985, pp. 37, 39). Potash test holes P-4, P-12, P-13 and P-17 hit water in the lower unnamed member.

Karst features have been observed in Dewey Lake siltstone, Forty-Niner gypsum, Magenta dolomite, Tamarisk anhydrite, and Culebra dolomite. Lost circulation of drilling fluid has been reported in the Dewey Lake Redbeds at H-7c, P-1, DOE-2, WIPP-25 and WIPP-33; in Forty-Niner gypsum at H-1 and WIPP-33; and in Magenta dolomite at WIPP-33. Four boreholes clustered near the center of the WIPP site have encountered washouts or loss of core in Tamarisk anhydrite (H-1, H-2, H-3 and ERDA-9). Five cavernous zones were encountered in Culebra dolomite at H-7c. Just three miles from the WIPP site in Nash Draw, at the Gnome Site turnoff, a surface exposure of Forty-Niner gypsum features a striking display of grikes, tunnels, caves, and collapse sinks; at least one of the caves is large enough to enter. These caves supply fresh water to deeper Rustler aquifers (EEG-39, 1988).

Thus it is shown that rainwater recharge to the Rustler Formation is possible, that no impermeable barrier exists above the Culebra dolomite. The question is whether or not rainwater recharge is actually occurring. This question can be answered by looking at the geochemistry of groundwater in the Culebra dolomite.

Total dissolved solids (TDS) in Culebra groundwater has been measured in 38 WIPP test wells [Table 3]. In some cases there have been multiple samplings at the same test well; in these cases the lowest measured values are presented in Table 3, as they are the most likely to represent mixing of groundwater with fresh water, and the least likely to represent contamination by brine from nearby injection wells. Table 3 reveals that TDS in Culebra groundwater in WIPP test wells vary by nearly two orders of magnitude, from 239,000 mg/l at WIPP-29 to 2,710 mg/l at H-8. When the wells are plotted on a map [Figure 1], it is shown that even within the WIPP site, TDS in Culebra groundwater vary by a factor of 25 -- from 230,000 mg/l at H-15 to 8,890 mg/l at H-2b. These two test wells are less than 8,750 feet (1.66 miles) apart.

Figure 1 shows contour lines of TDS at a contour interval of 50,000 mg/l. The contour lines display a zone of high TDS in the northeastern part of the WIPP site, where the Santa Rosa

TABLE 3: LOWEST RELIABLE MEASUREMENTS,
TOTAL DISSOLVED SOLIDS, CULEBRA DOLOMITE

Well	TDS (mg/l)
H-1	30,000
H-2	8,890
H-3	51,700
H-4	16,000
H-5	135,000
H-6	52,000
H-7	3,200
H-8	2,710
H-9	3,040
H-10	66,000
H-11	110,000
H-12	123,000
H-14	16,500
H-15	230,000
H-16	36,000
H-17	151,000
H-18	24,000
P-14	24,200
P-15	23,700
P-17	81,200
P-18	118,000
WIPP-13	65,500
WIPP-19	65,800
WIPP-25	17,000
WIPP-26	16,000
WIPP-27	126,000
WIPP-28	56,000
WIPP-29	239,000
WIPP-30	109,000
DOE-1	111,000
DOE-2	54,000
ENGLE	3,000
WQSP-1	77,400
WQSP-2	66,300
WQSP-3	214,000
WQSP-4	106,000
WQSP-5	33,300
WQSP-6	16,500

Sources: Mercer, 1983 (USGS-WRI 83-4016, Table 8); Ramey, 1985 (EEG-31); Chapman, 1988 (EEG-39); Lappin et al., 1989 (SAND 89-0462, Table 3-12); DOE/CAO 1996-2184, Appendix USDW, Table USDW-2; Annual Site Environmental Reports, 1992-1995.

sandstone is present, with TDS steadily decreasing to the southwest, where the Santa Rosa is absent. This is consistent with the interpretation that Culebra groundwater becomes mixed with increasing amounts of fresh water as it approaches Nash Draw, because the hydrologic regime is increasingly karstic.

A similar observation was made by Chapman (EEG-39, 1988). She concluded (p. 35) that "the only plausible mechanism" for an order of magnitude decrease in TDS as Culebra groundwater moves along its flow path "is the influx of a large quantity of low TDS water. As no fresh-water aquifers are located in the WIPP area, the source of the fresh water must be surface water recharge."

Test wells known to have produced water in the Dewey Lake Redbeds are depicted as bull's eyes in Figure 1. At ten of these wells, TDS in the Culebra dolomite were measured; and in seven of these, the lowest measurement was 36,000 mg/l or less (H-16 was measured only once). According to Ramey (EEG-31, 1985): "Waters with greater than 35,000 mg/l of total dissolved solids are classified as brines." Thus, Culebra water in the recharge area, where the Santa Rosa is absent, is fresh enough not to be classified as brine. In fact, Culebra water at H-2b is potable (8,890 mg/l TDS). H-2b is <u>on-site.</u> DOE has tested the <u>quality,</u> but not the <u>quantity,</u> of Culebra water at H-2b. Five private wells within ten miles of the WIPP site produce water of potable <u>quality</u> in the Culebra dolomite, but the <u>quantity</u> has never been measured. Three test wells <u>outside</u> the WIPP site -- H-7b1, H-8b and H-9b -- produce water of sufficient quality <u>and</u> quantity (less than 10,000 mg/l TDS <u>and</u> more than 5 gpm) to meet EPA criteria and establish the Culebra as an underground source of drinking water under 40 CFR 191, Subpart C. Test well H-7b1 is located only 2.9 miles from the WIPP site, in Nash Draw, along a potential groundwater flow path from WIPP to the accessible environment. Water quality data for the Culebra dolomite are given in Table 4. Thirteen wells which produced potable water are shown in Figure 3.

Conclusions: (1) karst landforms exist at the WIPP site, and karst hydrology is active at the WIPP site today; (2) rainwater infiltrates through solution pipes in Mescalero caliche, solution features in Gatuna sandstone, and fractures in the Dewey Lake Redbeds; (3) cavernous zones have been found, in WIPP boreholes, in Dewey Lake siltstone and in every member of the Rustler Formation -- in Forty-Niner gypsum, Magenta dolomite, Tamarisk anhydrite, Culebra dolomite, and mudstone of the lower unnamed member; (4) water has been found at the WIPP site in the Dewey Lake Redbeds and in every member of the Rustler Formation; (5) the Dewey Lake Redbeds and the Culebra dolomite contain potable water at and near the WIPP site, which can only be explained by rainwater recharge; (6) the recharge area for the Dewey Lake Redbeds and the Rustler Formation is at and near the WIPP site, everywhere that the Santa Rosa sandstone is not present; and (7) groundwater flow in the Rustler Formation is three-dimensional.

TABLE 4: POTABLE WATER IN CULEBRA DOLOMITE

well	TDS (mg/l)	date	gpm
H-2b	8,890	02/22/77	not tested
H-7b1	3,400	03/27/86	5-6
	3,500	02/25/87	
	3,400	04/25/88	
	3,500	05/19/89	
	3,500	11/09/90	
H-8b	3,100	01/22/86	6
	3,100	02/11/87	
	2,900	06/08/88	
H-9b	3,300	11/14/85	9.6-10.5
	3,300	01/28/87	
	3,100	06/21/88	
	3,300	01/19/90	
Engle	3,450	03/04/85	not tested
	4,000	12/08/87	
	3,600	01/31/90	
Poker Trap	2,200	07/07/88	not tested
Mobley Well	3,800	04/14/88	not tested
USGS-1	2,100	04/12/88	not tested
	4,000	07/07/88	
James Brothers	3,940	04/30/50	not tested

Criteria for drinking water: < 10,000 mg/l TDS <u>and</u> > 5 gpm.
Source: DOE/CAO 1996-2184, Appendix USDW, pp. 19, 20, 22.

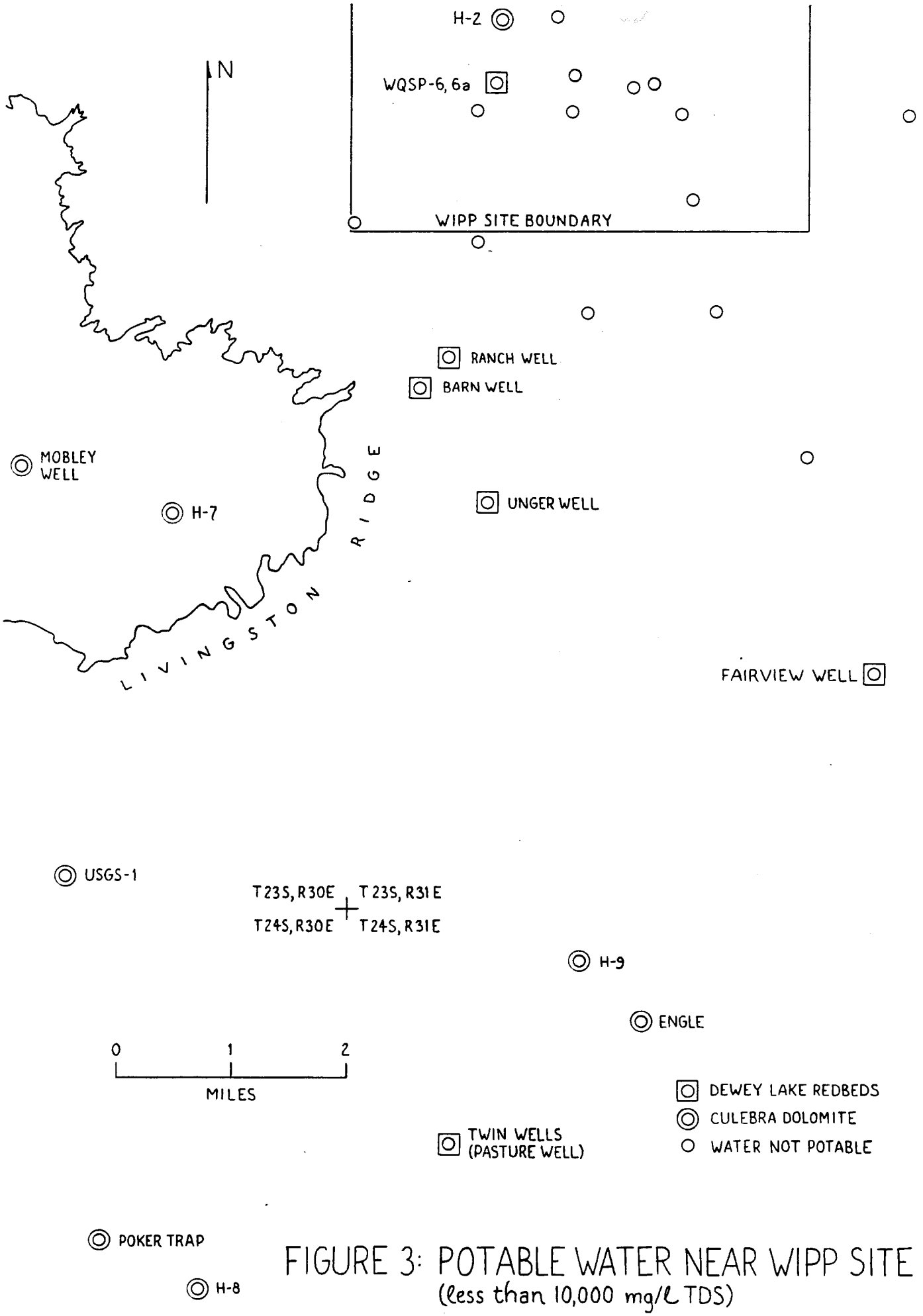


FIGURE 3: POTABLE WATER NEAR WIPP SITE
(less than 10,000 mg/ℓ TDS)

POTENTIAL FLOW PATHS FROM THE WIPP SITE TO THE ACCESSIBLE ENVIRONMENT

by Richard H. Phillips, Ph.D.
and David T. Snow, Ph.D.

The Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, is intended for the permanent disposal of radioactive waste from nuclear weapons production. The WIPP site was selected in 1974. It is now 1997, and the Department of Energy (DOE) still does not know the position of the water table, the flow paths of Rustler groundwater, or where the Rustler groundwater discharges. Without an understanding of such basic hydrologic parameters, "knowledge about the site is incomplete." (EEG-61, 1996). If completed early in the WIPP investigations, a study of near-surface hydrology would have revealed vital information.

The water table represents the top of the saturated zone. At the WIPP site, the water table "is believed to be in the Dewey Lake Redbeds" (EEG-61, 1996, p. 2-6). DOE has collected data on the hydraulic heads of Culebra groundwater from 35 test wells at the WIPP site and vicinity. According to DOE, contour maps of these water levels "suggest" that Culebra groundwater at WIPP flows to the south (SEIS, 1996, p. 4-20). DOE concludes that groundwater flow in Nash Draw "is unrelated to groundwater at WIPP," (SEIS, 1996, p. 4-18), and "that the Culebra probably discharges into the Pecos River" at Malaga Bend (EEG-61, 1996, p. 2-7). If the position of the water table is "believed," and the groundwater flow path is "suggested," and the groundwater discharge point is "probable," then little is known for certain, and all the risk assessments based upon modeling of radionuclide migration through an assumed groundwater flow path are without foundation.

Groundwater flows occur in a conduit, such as an aquifer, according to its hydraulic conductivity and the gradient of hydraulic potential (heads) acting in that conduit. Since heads in an aquifer can be measured readily by measuring the water surface in cased wells penetrating an aquifer, the gradient is commonly determined from the spacing of contours drawn to describe the potentiometric surface from a number of such piezometers. Such has been the work done for 30 years, in attempts to understand flow in the Culebra dolomite.

If the Culebra aquifer were isolated, above and below, by impervious aquicludes, and the water were supplied and discharged at its edges, the piezometric work might have been adequate for predicting flow paths. It has been recognized (Corbet and Knupp, 1996) that recharge occurs by infiltration through overlying strata, but flow models have assumed uniform areal recharge and smoothly-varying hydraulic conductivity for lateral flow in the aquifer. Had some work been done to assess local variation of

such recharge, more effective understanding of localized flow controls in the Culebra, as well as the Dewey Lake Redbeds, would have ensued. DOE chose to neglect warnings that the system does not vary smoothly. Because the Rustler and Dewey Lake are karstic, the flows are probably dominated by a small number of very conductive horizontal and vertical conduits.

One type of piezometric surface is the water table, depicted as the surface of uppermost saturated rock, having atmospheric pressure. If the piezometric surface for a buried aquifer, like the Culebra, lies below the water table for rocks above it, such as the Dewey Lake, a gradient exists across the strata tending to develop recharge. If they coincide, there is either no recharge since there is no gradient, or there may be great recharge if the interval has such high hydraulic conductivity in the vertical direction that vertical flows take place with a minimal vertical gradient. Such distinctions need to be made at the WIPP site, but because the hydrology of units overlying the Culebra has been neglected, there is no detailed knowledge of the shallow water table nor the heterogeneities of the Dewey Lake and other units.

At a sinkhole, such as WIPP-33, the water table (first water encountered in a drill hole) must coincide with the Culebra piezometric surface. At WIPP-33 a nested sequence of five caverns, one in Dewey Lake siltstone, two in Forty-Niner gypsum, and two in Magenta dolomite, was found during drilling. Rapid surface inflow during the rainstorm of September 18-19, 1985 proved the existence of a vertical conduit connecting these caverns, of such dimensions as to provide rapid, concentrated recharge to the Rustler aquifer. If adjacent Dewey Lake rocks are undissolved, a well located there might disclose a water table higher than the Culebra piezometric surface, the difference implying that a gradient is required to produce slow recharge because of low vertical conductivity. It is still important to the WIPP project that a comprehensive program be undertaken to study the shallow water table, the heterogeneities of vertical conductivity, and the implications for Rustler flow.

WIPP is a disturbed site. Previously existing exploratory boreholes for oil, gas and potash, and the WIPP boreholes and test wells themselves, all requiring casings through the Rustler, have affected hydraulic head distribution in the Rustler. WIPP monitoring wells have experienced sharp rises in water levels. Between 1988 and 1993, water levels in the Culebra dolomite generally rose from 4 to 30 feet (EEG-62, 1996). These water level rises "were strongly correlated with a nearby salt water disposal well operated by the oil and gas industry." (EEG-61, 1996). Subsequent measurements are unreliable, as graphically illustrated by DOE's annual mapping of the changing Culebra potentiometric surface (ASER, 1992-1995, Figure 7-3). For purposes of long-term prediction, what is needed is a record of the primitive conditions (Snow, 1994).

The best record we have of the Rustler potentiometric surface prior to disturbance by WIPP shafts and boreholes is given in Mercer and Orr (1977, Figure 23). This map shows a southwesterly gradient from Forty-Niner Ridge to the Salt Lake (Laguna Grande de la Sal) at the lower end of Nash Draw. Hunter (1985) also produced maps of the Rustler potentiometric surface. These maps also show a southwesterly gradient through Nash Draw to Laguna Grande de la Sal (Phillips, 1987, Figure 75).

One of the most compelling arguments for prevalent flow paths to Nash Draw, as opposed to Malaga Bend, is the water balance. The surface area of Laguna Grande de la Sal is so large (2,120 acres, or 9.23×10^7 ft^2 in natural extent), and net evaporation rates are so high (6.32 ft/yr), that the Rustler flow discharging to Laguna Grande and evaporated by the lake must be an order of magnitude greater (5.83×10^8 ft^3/year) than the incremental flow discharging to the Malaga Bend reach of the Pecos River (6.53×10^7 ft^3/yr) (Phillips, 1987, pp. 219-222, 232-235). Further, the Malaga Bend brine springs have geochemistry more consistent with the "brine aquifer" at the top the Salado, while Laguna Pequena, which flows into Laguna Grande, has geochemistry more consistent with the gypsum and dolomite aquifers of the Rustler (Phillips, 1987, pp. 242-248). Laguna Pequena is the single, most copious discharging point for the Rustler (Phillips, 1987, pp. 227-231), and most flow paths must be directed there from WIPP, as from elsewhere in the watershed.

The DOE assumes a southerly flow path from the WIPP site to the brine springs at Malaga Bend on the Pecos River, bypassing Laguna Grande. This flow path would have obvious advantages for the DOE: it is 20 miles from the WIPP site boundary to Malaga Bend along this path, compared to 12.5 miles as the crow flies; it runs through areas of low Culebra conductivity for up to 7.85 miles from the WIPP site boundary; and it bypasses Nash Draw.

DATA FOR DOE FLOW PATH FROM WIPP SITE TO MALAGA BEND

test well	dist. (mi)	conduct. (ft/day)	head (ft)	TDS (mg/l)	NaCl (mg/l)	CaSO4 (mg/l)
H-11		1.7	2995	110000	92650	7620
H-17	0.79	.009	2995	151000	N.D.	N.D.
H-12	3.00	.007	2998	123000	112100	8030
H-9	7.85	7.7	2975	3040	345	2460
H-8	12.27	0.59	2991	2710	85	2420

The geochemistry of Culebra water is inconsistent with southerly flow from the WIPP site. Dissolved halite (sodium and chloride) decreases by a factor of 1300 along the assumed flow path, and the principal mineral constituents change to gypsum (calcium and

sulfate). More importantly, the geochemistry is inconsistent with the concept of the Culebra dolomite as a confined aquifer, bounded above and below by impermeable layers, and containing only fossil water left over from the Ice Ages. Siegel and Anderholm (1994) state that "no plausible geochemical process has been identified that would cause this transformation in a hydrologically confined unit." According to Chapman (1989), the only plausible mechanism is rainwater recharge. DOE has yet to present a flow path that is consistent with the geochemistry.

Dissolved sodium and chloride in Culebra groundwater are given in Table 1. When these levels are plotted on a map [Figure 1], and contour lines are drawn, it is shown that the concentration of dissolved halite in Culebra groundwater decreases steadily from east to west across the WIPP site. This should demonstrate that Rustler groundwater is not old, and that fresh water recharge is occurring. Water saturated with halite, incapable of dissolving significantly more halite, contains approximately 318,000 mg/l of dissolved sodium and chloride (EEG-31, 1985). Within one mile of the WIPP site, the highest reliable measurements of dissolved halite in Culebra groundwater, at test well H-5b, range from 124,100 to 139,000 mg/l, well below saturation.

In the Rustler Formation, there has been extensive dissolution of halite across the WIPP site. This interpretation is supported by Powers et al. (1978), Gibbons and Ferrall (1980), Barrows (1982), Borns et al. (1983), Barrows et al. (1983), Mercer (1983), Lambert (1983), Chaturvedi and Rehfeldt (1984), Bachman (1984), Snyder (1985), Chaturvedi and Channell (1985), Lowenstein (1987), Chapman (1988), Brinster (1991), and Anderson (1994). An isopach map of the Rustler Formation (Borns et al., 1983, Figure 2-25) shows a westward thinning of the Rustler from 460 feet at P-18, 0.86 miles east of the WIPP site, to 277 feet at WIPP-33, 0.54 miles west of the WIPP site. Borehole data show a downward and westward drop in the position of uppermost halite remaining in the Rustler Formation. This is attributed to downward and eastward progression of dissolution in the Rustler (Barrows, 1982), first and most extensively from the Forty-Niner member, then from the Tamarisk member, and finally from the lower unnamed member only in the west. The Magenta and Culebra dolomite members are disrupted and fractured as halite is removed from beneath them; as a result they become more transmissive to groundwater, which in turn accelerates the process of dissolution. The process "feeds upon itself." (Snyder, 1985)

When the progression of halite dissolution is plotted on a map, along with the distribution of salinity in Culebra groundwater [Figure 2], it is shown that some test wells contain dissolved halite in Culebra groundwater where there is no halite in the Rustler. These wells (e.g. H-6, P-14, WIPP-25, WIPP-26) are located west of the Rustler "dissolution front." If groundwater is supposed to be flowing from north to south, as DOE contends,

TABLE 1: LOWEST RELIABLE MEASUREMENTS
OF MINERAL CONSTITUENTS
IN CULEBRA GROUNDWATER

Well	TDS	NaCl	CaSO4
H-1	30,000	21,400	8,180
H-2	8,890	4,835	3,303
H-3	51,700	39,700	5,960
H-4	18,200	11,860	4,180
H-5	135,000	124,100	1,170
H-6	52,000	45,300	4,620
H-7	3,200	560	2,490
H-8	2,710	85	2,420
H-9	3,040	345	2,460
H-10	66,000	57,000	7,200
H-11	110,000	92,650	7,620
H-12	123,000	112,100	8,030
H-14	18,100	12,005	3,240
H-16	36,000	28,000	7,590
H-18	24,000	18,800	4,680
P-14	24,200	18,100	4,500
P-15	23,700	17,900	3,970
P-17	81,200	71,400	6,700
P-18	118,000	89,200	6,580
WIPP-13	65,500	57,500	6,400
WIPP-19	65,800	57,750	8,030
WIPP-25	17,000	13,400	3,320
WIPP-26	16,000	11,800	3,500
WIPP-27	126,000	116,000	7,000
WIPP-28	56,000	51,000	4,400
WIPP-29	239,000	219,000	13,810
WIPP-30	109,000	101,000	6,150
DOE-1	111,000	101,900	7,260
DOE-2	57,800	50,200	6,210
Engle	3,000	357	2,450

Sources: Mercer, 1983 (USGS-WRI 83-4016, Table 8); Ramey, 1985 (EEG-31); Chapman, 1988 (EEG-39); Lappin et al., 1989 (SAND 89-0462, Table 3-12); DOE/CAO 1996-2184, Appendix USDW, Table USDW-2; Annual Site Environmental Reports, 1992-1995.

FIGURE 1: DISSOLVED HALITE IN CULEBRA (mg/ℓ)

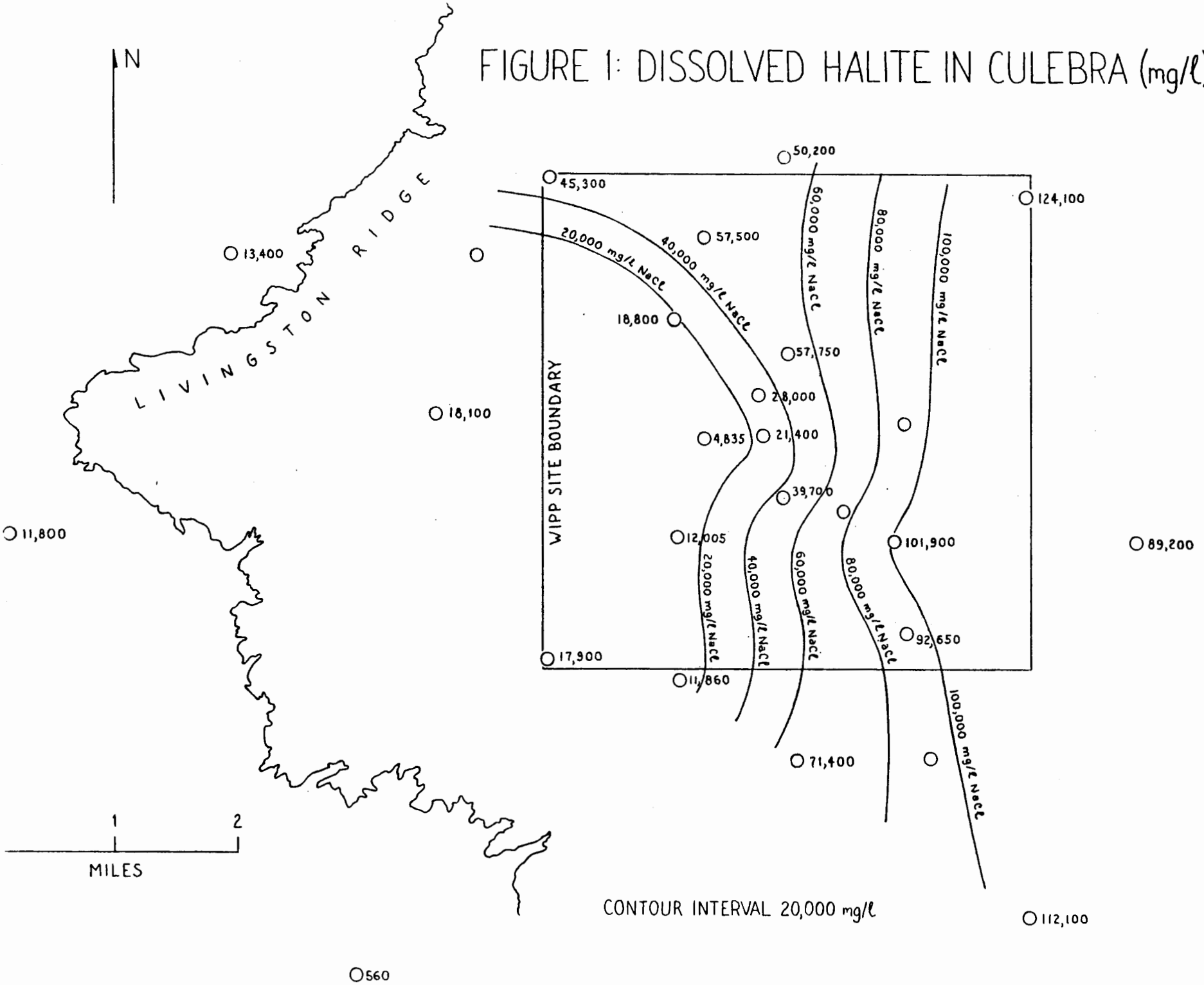
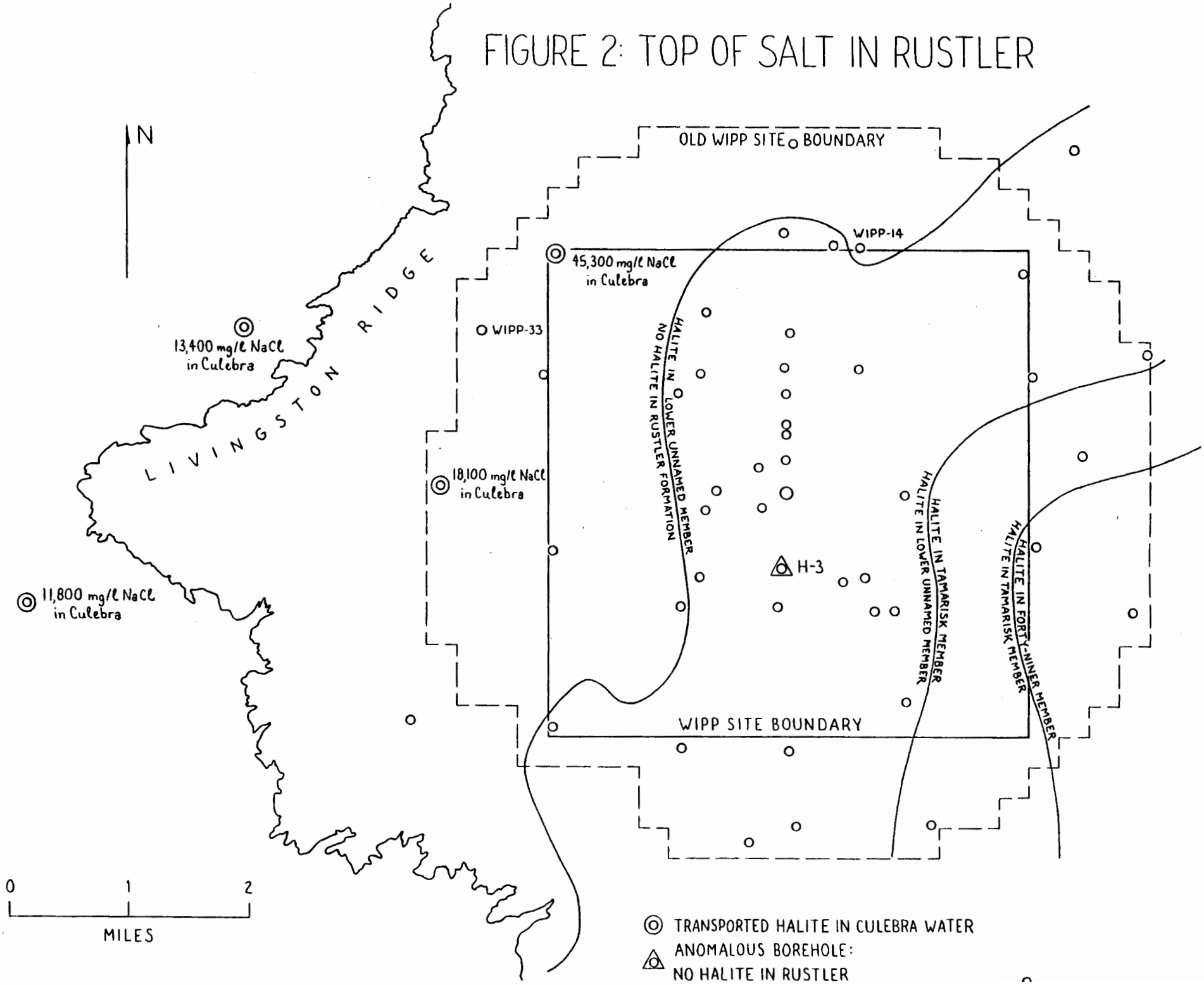


FIGURE 2: TOP OF SALT IN RUSTLER



how then did dissolved halite appear in these test wells? It could not have come from the brine aquifer at the top of the Salado salt formation, because its hydraulic head is less than that of the Culebra at all four of these wells [Table 2]. There is no halite in the Rustler to the north and west of these wells. There is halite in the Rustler only to the east, which requires a westerly component to groundwater flow.

The actual groundwater flow paths from the WIPP site to the environment are governed by three processes: (1) Water follows the path of least resistance, consistent with the gradient. Because dissolution proceeds fastest where velocities are greatest and salinities are lowest, open channels have been observed to form near discharge areas of a groundwater flow system, connecting to sinkholes, and eroding upgradient to places of greatest recharge. (2) The flow path must be consistent with groundwater geochemistry, taking three-dimensional flow into account. (3) Water flows downgradient in isotropic (unfractured) regions of the Culebra, but may flow at an increasingly acute angle to the contours in anisotropic (fractured to channeled) regions. Only if the geometry of the fractures or solution channels is known, can the flow direction be deduced from the gradient.

In karst, the paths of least resistance are solution-enlarged fractures and underground caverns. At WIPP, such paths are suggested by multi-well pump tests which showed some test wells to be interconnected by networks of open fractures, and by caliper logs and lithological descriptions which showed unconsolidated or cavernous zones in the Rustler Formation.

The most useful indicators of groundwater flow direction are measurements of hydraulic head (the level to which water rises in a cased well). In porous isotropic rocks like sandstone, water flows uniformly or radially downgradient, from higher to lower hydraulic heads. In soluble anisotropic rocks like gypsum and dolomite, water flows preferentially through discrete underground channels, rather than through the surrounding undissolved rock. However, if karst groundwater flow paths can be identified, say by dye-tracing or morphology, then the hydraulic heads will confirm which direction the groundwater flows along these paths.

Groundwater geochemistry is an indicator of the sense of the flow direction but not the flow path. The flow path must be consistent with groundwater geochemistry. The changes in geochemistry along the flow path must be explainable.

At WIPP, hydraulic heads were measured for the Culebra dolomite at 32 test wells, and for the Magenta dolomite at 16 test wells. Hydraulic heads were measured for the brine aquifer at the top of the Salado Formation at 11 test wells, and for the Forty-Niner

TABLE 2. COMPARISON OF FRESH WATER HYDRAULIC HEADS, MEASURED IN FEET ABOVE SEA LEVEL

Well	Salado	Culebra	Magenta	49er
H-1		3024	3159	
H-2	> 3129	3031	3152	
H-3		3008	3152 *	3126
H-4		2995	3146	
H-5		3064	3162	
H-6	3001	3057 *	3057	
H-7	2972	2995		
H-8	3014	2991	3027	
H-9		2975	3126	
H-10		3021	3214	
H-11		2995		
H-12		2998		
H-14		3001	< 3168 *	3109
H-15		3011		
H-16	< 3152	3005	3116 *	3106
H-17		2995		
P-14	3011	3041		
P-15		3005		
P-17		2995		
WIPP-12		3057		
WIPP-13		3064		
WIPP-18		3050		
WIPP-25	> 3008	3054 *	3054	
WIPP-26	> 2962	3011		
WIPP-27		3077	3080	
WIPP-28	3096	3077	3149	
WIPP-29	2962-2975	2968		
WIPP-30	3008	3067	3126	
DOE-1		3001		
DOE-2		3067	<< 3182 *	< 3162
USGS-1		2982		
Cabin Baby		2988		

Source: Lappin et al., 1989 (SAND 89-0462), Tables 3-6, 3-8, 3-10, 3-11.

Notes: Magenta was dry at H-7, WIPP-26, WIPP-28; not present at WIPP-29 (Mercer, 1983, Table 7).

Note: Synoptic data is difficult to assemble from the various sources of data presented in the Application.

member of the Rustler Formation at 4 test wells; measurements for the other members of the Rustler are nonexistent [Table 2]. However, a partial data set is better than none.

The data show that, in most places, water from the Magenta dolomite is able to infiltrate downward into the Culebra dolomite. This is possible when the hydraulic head for the Magenta is higher than the hydraulic head for the Culebra. In some places (e.g. H-6, WIPP-25), water from the Culebra is able to rise into the Magenta, due to higher heads. [These instances are denoted with asterisks in Table 2]. The data also show that water from the Magenta is able to rise into the Forty-Niner everywhere that hydraulic head in the Forty-Niner was measured.

It has been known for years that the Magenta and the Culebra are hydraulically connected (equal heads) at test well H-6, in the northwest corner of the WIPP site, "and thus the water flowing into Laguna Grande de la Sal and the Pecos River may not be identified as belonging to a particular zone of the Rustler Formation." In the absence of data, it is not known where the Magenta and the Culebra lose their hydrologic isolation from each other (EEG-32, 1985; EEG-61, 1996).

At test wells H-1, H-2 and H-3, clustered near the center of the WIPP site, the Magenta and the Culebra are separate hydrologic units; the hydraulic heads indicate that rainwater is able to infiltrate downward from the Magenta to the Culebra. This is consistent with low total dissolved solids (TDS) at H-2, where Culebra water is potable (8890 mg/l TDS), and with washouts or loss of core in Tamarisk gypsum, between the Magenta and Culebra, at H-1, H-2, H-3 and ERDA-9. This is within the recharge area for the Dewey Lake Redbeds and the Rustler Formation.

DATA FOR DEWEY LAKE AND RUSTLER RECHARGE AREA

test well	conduct. (ft/day)	head Cul.	head Mag.	TDS (mg/l)	NaCl (mg/l)	CaSO4 (mg/l)
H-2	.032	3031	3152	8890	4835	3303
H-1	.038	3024	3159	30000	21400	8180
H-3	0.86	3008	3152	51700	39700	5960

From H-3 there is a southeastward direction of superior hydraulic connection, through DOE-1 and H-11. These three test wells were shown by multi-well pump tests to be hydraulically connected, perhaps through a network of open fractures in the Culebra (Beauheim, 1989). These could be karst channels in the Rustler. It is a zone of anomalously high hydraulic conductivity in the Culebra (0.86 ft/day at H-3, 1.5 ft/day at DOE-1, 1.7 ft/day at H-11). As the first manifestation of dissolution in the Culebra

is probably the removal of gypsum from the fractures, the areal distribution of transmissibility may be directly related to removal of such fillings. Directional properties may be due to preferential dissolution along one set of fractures versus another set of different orientation. Alternatively, the directional feature may be a karst channel, adjacent to which the fracture fillings are more fully removed. Suggestive of karst development, there were washouts and loss of core at H-3 and H-11 in the Forty-Niner and the lower unnamed members. The lithologic description for DOE-1 is unreliable, with the Culebra 100 feet out of place; however, at potash test hole P-4, located 880 feet west of DOE-1, water was encountered in the lower unnamed member, 48 feet below the Culebra. A flow path along this trend would be consistent with hydraulic heads in the Culebra, which drop steadily from H-3 (3008 ft) to DOE-1 (3001 ft) to H-11 (2995 ft).

West of H-11 there is a linear surface depression with sinkholes and disrupted drainage patterns, strikingly similar to those in Nash Draw. The depression is four miles long and up to 7000 feet wide, and is plainly visible in the WIPP site air photos. Its southern margin follows Livingston Ridge from the Gnome site turnoff to the WIPP site turnoff, extends alongside the James Ranch dune field, and reaches within 2000 feet of test well P-17, where water was encountered in the lower unnamed member, 17 feet below the Culebra. When this east-west trending depression first approaches Livingston Ridge, at a point 2.1 miles west of P-17, it connects to Nash Draw through a northeast-southwest karst trench, 0.5 miles long, walled by high dunes, that is plainly visible in the WIPP site air photos. Within Nash Draw, a north-south trench follows the base of Livingston Ridge for 0.8 miles. Here it joins an east-west trench, 1.2 miles long, that connects with test well H-7; drilled into a sink, H-7 encountered one cave in the Dewey Lake Redbeds and five caves in the Culebra dolomite. This karst trench is generally 100 to 300 feet wide. If such a surficial trench, having three segments of differing orientation, is indicative of one or more subsurface solution channels, it may connect, through courses unknown, to Laguna Grande de la Sal.

Until groundwater flow reaches H-7, it passes through an area where there is residual halite in the Rustler, at least in the lower unnamed member. This would account for the large amounts of sodium and chloride upgradient, especially at DOE-1 and H-11. Hydraulic conductivity at P-17 is not high (.074 ft/day), but this test well probably missed the active solution conduits; hydraulic conductivity at H-7 is very high (at least 31.0 ft/day), and represents karst conditions. At H-7 the Culebra sequence is 46.0 ft thick (24.3 ft of dolomite, 21.7 ft of caverns); the transmissivity is 1430 ft^2/day, the highest of any WIPP test well. The hydraulic heads at H-11, P-17 and H-7 are equal (2995 ft), implying a region of such high transmissibility that a high gradient is not needed to drive groundwater flow.

Northward from the recharge area there may be a trend of preferential flow that extends through the ventilation shaft, thence to H-16, H-18, and WIPP-13. There were washouts and loss of core at all three test wells; in the ventilation shaft there were five washouts where steel liner plates were installed to prevent further caving of the shaft wall. At H-16, heads in the Culebra (3005 ft) and Magenta (3116 ft) are lower than in the recharge area. At H-18, head measurements are not available. A solution channel must underlie WIPP-13, where the hydraulic head in the Culebra is 3064 feet above sea level and the Culebra is hydraulically connected to the Magenta; (hydraulic heads in the Magenta should confirm this, but the data are not available).

A chain of topographic depressions suggestive of an underlying flow channel can be seen in the WIPP site air photos, snaking through the WIPP-14 sinkhole, where 71.4 feet of mud with gypsum and anhydrite fragments was found below the Culebra. This path may continue westward to WIPP-34 and DOE-2; there was loss of core in the Forty-Niner and lower unnamed members in both boreholes, and loss of circulation of drilling fluid in the Dewey Lake Redbeds at DOE-2. Here, at DOE-2, the path would intercept a network of open fractures which were shown by multi-well pump tests to be hydraulically connected to WIPP-13 and H-6 (Beauheim, 1986). These could be karst channels in the Rustler. This is a zone of high hydraulic conductivity (4.0 ft/day at DOE-2, 3.1 ft/day at WIPP-13, 3.2 ft/day at H-6). Both of these trends which may merge at WIPP-13 pass through areas where there is residual halite in the Rustler Formation; this is consistent with the elevated levels of dissolved halite at WIPP-13.

Multi-well pump testing revealed that WIPP-13 is hydraulically connected to H-6, where the hydraulic heads for the Magenta and the Culebra are equal. Thus, the Rustler aquifer may include both of these dolomites as one. From H-6 at the northwest corner of the WIPP site, it takes little imagination to see a connection to WIPP-33, 0.84 miles to the southwest. The most likely flow path lies beneath an east-west trend of three smaller sinkholes, two of which have swallowed surface water carried by arroyos (Phillips, 1987, pp. 82-86). At WIPP-33, five nested caverns, all filled with water, were found within a 110-foot section of Dewey Lake siltstone, Forty-Niner gypsum, and Magenta dolomite, indicating the thickness of the karst aquifer there. The flow may continue from WIPP-33 to the vicinity of WIPP-25, 2.0 miles west of WIPP-33 in Nash Draw, where gypsum spring deposits at the surface are evidence of groundwater discharge in the geologic past, when the water table was higher (Bachman, 1985). Water in this karst aquifer would continue to Laguna Grande de la Sal.

A flow path from WIPP-13 to WIPP-25 would be consistent with hydraulic heads in the Rustler, which drop steadily from WIPP-13 (3064 ft) to H-6 (3057 ft) to WIPP-25 (3054 ft). No hydrologic

data were taken at WIPP-33. Between WIPP-13 and H-6 the flow path enters the region where no halite remains in the Rustler; this is a possible explanation for the steadily decreasing levels of dissolved salt from WIPP-13 to WIPP-25. The evident recharge of fresh water through sinkholes is also sufficient explanation.

DATA FOR POSSIBLE GROUNDWATER FLOW PATHS

test well	conduct. (ft/day)	head Cul.	head Mag.	TDS (mg/l)	NaCl (mg/l)	CaSO4 (mg/l)
H-3	0.86	3008	3152	51700	39700	5960
DOE-1	1.5	3001	N.D.	111000	101900	7260
H-11	1.7	2995	N.D.	110000	92650	7620
P-17	.074	2995	N.D.	81200	71400	6700
H-7	31.0	2995	N.D.	3200	560	2490
DOE-2	4.0	3067	3182	57800	50200	6210
WIPP-13	3.1	3064	N.D.	65500	57500	6400
H-6	3.2	3057	3057	52000	45300	4620
WIPP-25	11.0	3054	3054	17000	13400	3320

In a semiarid karst such as Los Medanos (where the WIPP site is located), where 14 to 15 inches of annual precipitation may occur during a few large storms separated by many dry months, the groundwater hydraulics may be wildly transient. In Dalmatia, the classic karst region of Yugoslavia, rapid recharge is known to raise the water table as much as 200 feet, and tracer tests reveal velocities of kilometers per week. In New Mexico, lower episodic rainfall may also produce transients, during which most of the discharge occurs. During the longer periods between storm-flows, the gradients vanish in the major channels, while low-permeability rocks outside the channels drain into them. The task of interpretive non-synoptic piezometry from wells tapping domains of different transient behavior, none of which record the behavior of the major channels, may not be very rewarding, nor can it support realistic models of flow or transport.

In every hydrologic system, groundwater moves inexorably toward regional base level, the lowest point in the watershed. In Nash Draw, the lowest point is Salt Lake, or Laguna Grande de la Sal. Salt lakes are in closed drainage basins, with no outlet at the surface or underground. They lose water only by evaporation, which precipitates salt. At Laguna Grande, groundwater seeps upward into the lake (Robinson and Lang, 1938); this is confirmed at test well WIPP-29, near Laguna Grande, where water from the lower unnamed member is able to rise into the Culebra [Table 2]. Laguna Grande has no outlet, at the surface or underground.

A low, but discernible topographic divide exists between Laguna Grande and Malaga Bend of the Pecos River. This topographic divide is now partly breached by an irrigation canal at an elevation of 2960 feet above sea level. The evaporite crust of Laguna Grande has killed all vegetation up to the same elevation, indicating that 2960 feet above sea level is the high-water mark for Laguna Grande. In times of major flooding, Laguna Grande overflows to the Pecos River (Phillips, 1987, pp. 216-217)

The evidence supports a conclusion that flow paths from the WIPP site are predominantly directed to Nash Draw along karst channels or fracture system enlargements. These observations indicate that the Rustler is not a barrier to rapid transport from the WIPP site to the accessible environment.

BREACH SCENARIOS AT THE WIPP SITE

by Richard H. Phillips, Ph.D.
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The WIPP site is located in a known mineral district. Potash resources, including sylvite [KCl] and langbeinite [$K_2Mg_2(SO_4)_3$], in the McNutt member of the Salado Formation, extend directly above the WIPP repository (FEIS, 1980, Figures 8-5, 9-1, 9-2). Oil and gas resources in the Delaware Mountain Group (and lower formations) extend directly underneath the WIPP repository (FEIS, 1980, Figure 8-6; EEG-62, 1996, Figure 2.2-6). This has been known since before the WIPP site was selected.

Under the original WIPP site selection criteria, only "areas more than <u>two miles</u> from deep drill holes" were considered (GCR, 1978, Figure 2-3). When a test hole called ERDA-6, drilled at the original WIPP site, encountered a pressurized brine reservoir in the upper anhydrite of the Castile Formation, between the Salado Formation and the Delaware Mountain Group, the site had to be abandoned. Because no other potentially suitable sites in the Delaware Basin could be found, a new map was drawn indicating "areas more than <u>one mile</u> from deep drill holes." (GCR, 1978, Figure 2-8) On this basis, the current WIPP site was selected.

Two test holes, ERDA-9 and WIPP-12, were drilled at the current WIPP site, penetrating 53 feet and 47 feet deep, respectively, into the Castile Formation, stopping short of any pressurized brine reservoir. Thus the FEIS concluded that brine reservoirs "are extremely unlikely near the repository." A Stipulated Agreement was later signed between DOE and the State of New Mexico requiring that borehole WIPP-12 be deepened. (WIPP-12 is located one mile north of the center of the WIPP site).

On November 22, 1981, pressurized brine associated with hydrogen sulfide gas was encountered at WIPP-12 in the upper Castile anhydrite, 240 feet below the Salado Formation. The brine flowed to the land surface at a rate of 45 gallons per minute (1540 barrels per day) for forty days. Total brine outflow was 60,000 barrels, or about 2.5 million gallons (DOE, 1982, TME 3148). Thus a geologic mechanism exists which is capable of flooding the WIPP repository, corroding the steel drums, dissolving the waste, and carrying contaminated water up the WIPP shafts to overlying aquifers or to the land surface (EEG-6, 1980, pp. 47-48).

The total volume of the WIPP-12 brine reservoir was later estimated at between 17 millon gallons (EEG-23, 1983, p. 29) and 30 million gallons (EEG-22, 1983, p. 79). By comparison, about 63 million gallons would be necessary to completely fill the WIPP repository (EEG-16, 1982, p. 45). It is likely that the WIPP-12 brine reservoir extends directly underneath the WIPP waste

emplacement panels (EEG-23, 1983, p. 31; Phillips, 1987, Figure 76; EEG-61, 1996, p. 2-3) Borehole ERDA-9 (located 320 feet from the center of the WIPP site) was never deepened; but less than 200 feet of vertically fractured anhydrite is all that separates the pressurized brine reservoir from ERDA-9, an existing pathway to the WIPP repository. The plan is to plug ERDA-9, but there is no proven technology for plugging boreholes in salt formations, and CARD doubts that it can be done successfully.

In 1983 the boundaries of the WIPP site were reduced, from an approximation of a circle with a three-mile radius (18,960 acres) to a perfect square, four miles on each side (10,240 acres). The DOE thereby relinquished control of 8,720 acres in what had been designated as Zone IV (EEG-23, 1983, Figure 26), within which DOE had intended to prevent secondary methods of oil recovery such as waterflooding or hydrofracturing, to prevent solution mining for potash, and to oversee the eventual plugging of oil and gas drill holes (FEIS, 1980, p. 8-4). The rationale, according to DOE, was that "the minimal amount of crude oil likely to exist within the WIPP site" made waterflooding adjacent to WIPP unlikely (EEG-55, 1994, p. 21; EEG-62, 1996, p. xiv). CARD has long suspected that one of the reasons for reducing the boundaries of the WIPP site was the presence of obvious karst features in Zone IV (e.g. boreholes WIPP-33 and WIPP-14) as described by Barrows (1982, pp. 6-8, reprinted in EEG-32, 1985, Appendix A; see also Barrows to Chaturvedi, 8/6/82, Appendix B; Barrows to Chaturvedi, 4/7/83, Appendix C). Whatever the reasons, there are now, within the old Zone IV, 14 oil wells and 6 gas wells. Altogether, there are now, within two miles of the current WIPP site boundary, 101 oil wells, 18 gas wells, 7 oil <u>and</u> gas wells, 4 brine injection wells, and 9 dry holes (EEG-62, 1996, Figure 2.2-2).

All of this is in direct violation of EPA standards for the siting of repositories for nuclear waste disposal, and with good reason. The very purpose of geologic disposal is to emplace the nuclear waste in an area unlikely to be disturbed during the necessary period of waste isolation. No deep geologic disposal site is more likely to be disturbed than one in a known mineral district. Here is the text of the relevant EPA standard:

> Places where there has been mining for resources, or where there is a reasonable expectation of exploration for scarce or easily accessible resources, or where there is a significant concentration of any material that is not widely available from other sources, should be avoided in selecting disposal sites. Resources to be considered shall include minerals, petroleum or natural gas ... Such places shall not be used for disposal of the wastes covered by this part unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future. (40 CFR 191.14e)

DOE claims that because the WIPP site was selected before the EPA standards were promulgated, the natural resources provision does not apply, and thus the WIPP site has been "grandfathered" into existence. CARD agrees with Neill et al. (EEG-61, 1996, p. xvi) that there is no "grandfather" provision in 40 CFR 191, and that there has been no formal acceptance of WIPP as a repository.

It is worth noting that langbeinite potash, unlike sylvite, contains no chlorine, and is a desirable fertilizer for soils that cannot tolerate additional chlorine. Langbeinite is a rare mineral, found only in the Carlsbad area and in eastern Europe (DEIS, 1979, pp. 9-16, 9-18, 9-19; FEIS, 1980, pp. 9-21, 9-23).

The existence of potash within the WIPP site poses a number of dangers to the WIPP repository: (1) The DOE contends that "active institutional controls" will prevent potash mining within the WIPP site for 100 years after closure, even though the DOE has never committed to exercising such control and expects other government agencies to do so. After institutional controls are lost, potash mining could destroy much of the Salado Formation as a geologic barrier. (2) If water were to flood the potash mines, the water would travel laterally along marker beds in the Salado Formation, and could reach the WIPP shafts. (3) The potash mines themselves could serve as preferential pathways for migration of contaminated water from the WIPP repository. (4) Potash mining could cause fracturing, subsidence, and collapse of overlying strata, thereby increasing the hydraulic conductivity of the Rustler aquifers and damaging the casings of oil wells, as DOE acknowledges (SEIS, 1996, pp. 4-21, H-14).

Thus there is no such thing as an "undisturbed scenario." It is inevitable that the hydrology of the WIPP site and vicinity will be adversely affected by future potash mining. Accordingly, for purposes of performance assessment, groundwater flow in the Rustler Formation should not be modeled under steady-state assumptions. DOE states in the SEIS (p. H-14) that it has taken this into consideration by examining the impact of a 1000-fold increase in the hydraulic conductivity of the Culebra dolomite due to potash mining, but the reference given (DOE 1996f) is not listed in Appendix H. CARD expects to be granted ample time to analyze said reference after its identity is revealed to us.

One of the most plausible breach scenarios for WIPP involves exploratory drilling for oil and gas beneath the repository. After institutional controls are lost, which DOE expects to be 100 years after closure, someone could drill directly through the waste emplacement panels and penetrate a pressurized brine reservoir in the Castile Formation, creating an instant breach of the WIPP repository, and carrying contaminated brine to the Rustler aquifers or to the land surface. To DOE, pressurized brine reservoirs are only "hypothetical" (SEIS, 1996, Figures H-9, H-10, H-12, H-14), and an open borehole such as this would

only be a "potential" pathway between the brine reservoir and the WIPP repository (SEIS, 1996, p. H-48). According to DOE, this pathway could flood the repository and flush "water," but not radionuclides, to the overlying Rustler aquifers (SEIS, 1996, p. H-48). Even though the WIPP-12 brine reservoir is under artesian pressure and flowed from a depth of 3016 feet to the land surface at a rate of 45 gallons per minute (DOE, 1982, TME 3148, p. 3), DOE assumes that, under this drilling intrusion scenario, it would take 10,000 years for radionuclides to migrate as much as 200 feet above the WIPP repository in concentrations equal to or greater than one picocurie per liter (SEIS, 1996, Figure H-12). Accordingly, the dose to a member of the drilling crew is always within acceptable limits, never more than 520 millirem (SEIS, 1996, Table H-31). This dose is from ingestion of drill cuttings (SEIS, 1996, p. H-63) if a panel of contact-handled transuranic waste (CH-TRU) is penetrated. The dose from remotely-handled transuranic waste (RH-TRU) is only 220 millirem (SEIS, 1996, Table H-31). This defies common sense, because the maximum allowable surface dose for a canister of RH-TRU (1000 rem/hour), is 5000 times higher than for a canister of CH-TRU (200 millirem/hour). That is why RH-TRU is remotely handled.

Under the drilling intrusion scenario, DOE assumes that the borehole would be "plugged at abandonment using standard regulatory requirements and practices" (SEIS, 1996, p. H-49) "and thereafter maintains a relatively low permeability. ... For these assumed conditions, no releases to the Culebra were simulated." (SEIS, 1996, p. H-87) This enables DOE to consider radiation exposure only to the drilling crew, and nobody else. It defies common sense to assume that with 45 gallons per minute of brine contaminated with plutonium and associated with hydrogen sulfide gas flowing out of an exploratory oil well, the drilling crew is going to plug the hole. Moreover, DOE assumes that even if the hole is not cased during drilling, and contaminated brine were to reach the Rustler Formation, it would be transported only to a well used to supply water for cattle, which could then become a source of meat consumed by a cattle rancher (SEIS, 1996, p. H-14). DOE does not consider that contaminated brine could be carried all the way to Nash Draw, Laguna Grande de la Sal, and the Pecos River, thus exposing large numbers of people, because this could violate EPA standards for radiation exposure.

The latest breach scenario, and perhaps the most serious, is known as the Hartman Scenario. This involves brine injection, which the DOE refuses even to consider. This scenario is not hypothetical. It cannot be prevented by institutional control of the WIPP site. It is happening today. These are the facts:

Brine injection is utilized by oil companies for one of two reasons: (1) salt water disposal, which involves the injection of unwanted brine through a disposal well and into permeable rock strata bounded above and below by impermeable rock strata; or

(2) waterflooding, which involves the injection of pressurized brine into an oil-bearing zone in order to force additional oil to flow toward a producing oil well (EEG-62, 1996, p. 2).

In 1991, Doyle Hartman, an independent oil operator, attempted to drill an oil well on the Bates lease, 40 miles east-southeast of the WIPP site. Known as the Bates #2 well, it was located about two miles from a brine injection well operated by Texaco for waterflooding purposes. In 1953 the Bates #1 well, located 100 feet away, had been drilled successfully; the well had been plugged and abandoned in 1988. The Bates #2 well encountered pressurized brine at a depth of 2240 feet, and drilling had to be terminated at 2280 feet. Brine flowed from the Bates #2 well at a rate of 840 gallons per minute, or 1200 barrels per hour, for 5.5 days. Fluid pressures were so high that the well could not be shut in for fear of an underground blowout. A total of 298 truckloads were required to haul the salt water away, and a pipeline had to be constructed to help alleviate the problem.

When the Bates #2 well was finally brought under control by using rapid-setting cement to shut off the flow, a shut-in pressure of 1000 psig was observed at the land surface. This equates to a pressure gradient of 0.966 psi per foot of depth, compared to the normal gradient of 0.525 psi per foot of depth for a column of saturated salt water. The only source in the vicinity with documented pressure gradients equal to or greater than those observed at the Bates #2 blowout was Texaco's fluid injection well, two miles to the south (Van Kirk, 9/16/94; Bredehoeft to Lovejoy, 1/8/97). Hartman sued Texaco, won the case, and was awarded $5.6 million in damages (EEG-62, 1996, p. 8).

It turned out that pressurized brine injected by Texaco at 3000 feet below the surface (EEG-62, 1996, p. 131) had risen 700 feet vertically and migrated two miles horizontally through an anhydrite marker bed in the lower Salado, the same formation in which the WIPP repository is located. A failed well casing, due to long exposure to corrosive brine, was the most logical pathway into the Salado. The brine was being injected at pressures greater than lithostatic, high enough to induce massive hydraulic fracturing of the anhydrite marker bed over a large area that included the Bates #2 well (Bredehoeft to Lovejoy, 1/8/97). There are at least ten anhydrite marker beds in the lower Salado; they extend across the entire Delaware Basin, which is why they are called "marker beds." According to Dennis Powers of Sandia National Laboratories, the Hartman blowout probably occurred in Marker Bed 140 or 142 (EEG-62, 1996, p. 66), which are 67 feet and 104 feet, respectively, below the WIPP repository horizon.

Despite the 40-mile distance between the Bates #2 well and WIPP, the characteristics of the Salado marker beds remain the same. If pressurized brine is injected and is able to leak through the casing of an oil well into an anhydrite marker bed, it can be

expected to induce fracturing and to travel two miles or more (Chaturvedi, in EEG-62, 1996, pp. 104-105). There are already 130 oil or gas wells within two miles of the WIPP site; four of them have been converted to brine injection wells (EEG-62, 1996, Figure 2.2-2), at least one of which is operating at a pressure that exceeds the lithostatic pressure at the repository horizon (EEG-62, 1996, p. xvii). The consequences of waterflooding of the WIPP repository due to pressurized brine injection would be catastrophic (Van Kirk, 9/16/94, p. 12). If pressurized brine were injected into Marker Bed 139, which is four feet below the repository, the WIPP could be flooded with massive amounts of water, and dissolved radionuclides could be carried out of the repository, away from the WIPP site, and into the accessible environment (EEG-61, 1996, p. 6-3; EEG-62, 1996, p. 16).

It has been argued that waterflooding of the WIPP repository is unlikely because brine injection near WIPP takes place in the Bell Canyon Formation, at a much deeper horizon than at the Texaco well. Indeed, there are at least 15 brine injection wells within eight miles of the WIPP site (EEG-62, 1996, Figure 2.6-2), and all of them inject into the Bell Canyon Formation (EEG-62, 1996, p. 15). However, recent water level rises in the Culebra dolomite at WIPP test well H-9b, located 6.45 miles south of the WIPP site, are strongly correlated with brine injection into the Bell Canyon Formation, more than 4400 feet below the land surface, at a well (Devon Energy's Todd 26 Federal #3) located three miles away. There is more than 3700 feet of vertical separation between the Bell Canyon and the Culebra; between them lie the relatively impermeable salt beds of the Castile and the Salado; and yet injected brine was able to rise all the way to the Culebra. It is apparent that, in the vicinity of brine injection wells, the Castile and the Salado are not reliable geologic barriers (EEG-62, 1996, pp. 127-128, 132).

As Bredehoeft concludes: "The Hartman Scenario is not easily dismissed." (Bredehoeft to Lovejoy, 1/8/97). And yet the DOE does exactly that. DOE contends that, according to the criteria for compliance with EPA standards, "the most severe human intrusion scenario" that requires analysis is "inadvertent and intermittent drilling for resources" (40 CFR 194.33b1, cited in EEG-61, pp. 6-1, 6-2). DOE contends that "consequences greater than that of exploratory drilling" need not be considered (EEG-62, 1996, pp. xv, 16). Because the Hartman Scenario has <u>more</u> severe consequences than the drilling intrusion scenario, it need not be considered. CARD agrees with EEG; this "defies common sense." (EEG-61, p. SCR-6) The EPA criteria, at 40 CFR 194.32c, plainly require that DOE analyze the effects of "boreholes and leases that may be required for fluid injection activities." (EEG-62, 1996, p. 159) EPA, in its Supplementary Information, Subpart D, requires that DOE analyze the effects of "water-flood injection for secondary recovery of oil, solution mining and the disposal by injection of brine accumulated during recovery of

oil." Not to consider the Hartman Scenario is flagrantly illustrative of a callous disregard for human life.

Ultimately, waste containment at WIPP depends upon DOE's ability to seal the shafts and plug the boreholes perfectly, forever, because the overlying Rustler aquifers cannot be relied upon even to retard the migration of radionuclides in groundwater. DOE's Compliance Certification Application (CCA) describes in some detail the "presently envisaged shaft seal system" (DOE/CAO 1996-2184, pp. 3-15 to 3-21). DOE admits to three potential flow paths within the shaft seal system: (1) through the seal materials themselves; (2) along the interface with surrounding rock; and (3) through the "disturbed rock zone" (DRZ) adjacent to the shaft wall. Even if the engineered seal materials are of low permeability, and even if construction methods ensure a tight interface with the surrounding rock, the disturbed rock zone will be a groundwater flow path (DOE/CAO 1996-2184, p. 3-25). In DOE's words: "It is well known that a DRZ develops in the rock adjacent to the shaft immediately after excavation. After closure of the shaft this fractured zone is initially a major flow path regardless of the material placed within the shaft" because whatever seal components are used will be more permeable than intact Salado salt (DOE/CAO 1996-2184, pp. 3-23, 3-24). In the WIPP ventilation shaft, the disturbed rock zone includes five "washed out zones" which had to be cased with liner plates to prevent further caving of the shaft wall (TME 3179, Figure 1). With this in mind, it will be useful to examine the components of DOE's "presently envisaged shaft seal system."

(1) Compacted earthen fill will extend from the land surface to the the top of the Dewey Lake Redbeds. Obviously, this will be more permeable than surrounding Gatuna and Santa Rosa sandstone.

(2) A concrete plug will extend 40 feet downward from the top of the Dewey Lake Redbeds. At this interval, DOE admits that the shaft will have to be "grouted before removal of the shaft lining to assure structural stability of the shaft wall."

(3) Compacted earthen fill will extend from the concrete plug through the Dewey Lake Redbeds to the Rustler Formation. This will be more permeable than surrounding sandstone and siltstone.

(4) Bentonite clay will extend through most of the Rustler Formation, including the Magenta and Culebra dolomite, both of which produce water in the WIPP shafts. The clay would be relatively impermeable, allowing Rustler groundwater to travel along the interface and through the disturbed rock zone.

(5) A concrete plug will be emplaced through 20 feet of the lower unnamed member of the Rustler Formation. Open fractures were observed at this horizon; groundwater will be able to travel along the interface and through the disturbed rock zone.

(6) An asphalt column will bridge the Rustler-Salado contact. Unsaturated Rustler groundwater will travel along the interface, dissolve the Salado salt, and enlarge the disturbed rock zone.

(7) A concrete plug will be emplaced through 23 feet of the Upper Salado. This is intended to fill "irregularities in the shaft wall," but will be ineffective because the disturbed rock zone will be continually enlarged by dissolution.

(8) Bentonite clay will extend through most of the Upper Salado. This will not prevent dissolution in the disturbed rock zone.

(9) Another 23-foot concrete plug will be emplaced near the top of the McNutt Potash Unit. Again, this will be unable to fill irregularities in a shaft wall undergoing active dissolution.

(10) A 560-foot column of crushed and compacted salt will extend from the concrete plug almost to the repository horizon. The crushed salt will be more permeable than the rock salt. DOE admits that salt column will offer "limited resistance to brine migration" for about 100 years after emplacement.

(11) Another 23-foot concrete plug, at the bottom of the salt column, will be unable to fill irregularities in the shaft wall.

(12) About 100 feet of bentonite clay will be emplaced at the bottom of the shafts, "to promote early healing of fractures in the surrounding salt." Again, the interface and the disturbed rock zone will be more permeable than the bentonite clay.

(13) A salt-saturated concrete monolith will be installed to fill the underground excavations at the repository horizon.

It is apparent that the "presently envisaged shaft seal system" will not be able to prevent the downward migration of unsaturated Rustler groundwater. It surely will not be able to withstand pressurized brine, whether from the Castile brine reservoir, from salt water disposal, or from waterflooding operations.

In addition to the four WIPP shafts, there are six deep boreholes within the WIPP site that penetrate deeper than the repository horizon. DOE seems aware of only four of them (WIPP-13, WIPP-12, ERDA-9 and DOE-1). There are also two deep drill holes (Badger Federal and Cotton Baby, identified in EEG-61, 1996, p. 3-7) which were abandoned by private operators (EEG-55, 1994, Figures 11, 12, 13; also shown in FEIS, 1980, Figure 8-6); these do not appear on the map of unplugged boreholes in DOE's Compliance Certification Application (DOE/CAO 1996-2184, Figure 3-9).

"The DOE had planned to develop special borehole plugging procedures for boreholes at the WIPP site. It now appears that conventional plugging procedures for commercial wells will be

followed." (EEG-61, 1996, p. 3-6) Thus it is with good reason that EPA requires DOE to assume, for purposes of performance assessment, "that the permeability of sealed boreholes will be affected by natural processes, and ... that the fraction of boreholes that will be sealed by man equals the fraction of boreholes which are currently sealed in the Delaware Basin." (40 CFR 194, Subpart C) DOE, in its Compliance Certification Application, speaks of shaft seals and borehole plugs in the present tense (DOE/CAO 1996-2184, pp. 3-19 to 3-21); DOE has no right to do so, as the technology for sealing shafts and plugging boreholes in salt formations has not been demonstrated. In fact, DOE attempted in 1977 to plug the ERDA-10 borehole at the Gnome Site in Nash Draw. Four separate plugs were emplaced for a total length of 4430 feet (SAND 81-2034), but no report appears to be available describing the success or failure of the attempt.

Ever since WIPP tunnels were excavated, saturated brine from Salado marker beds has been seeping into the WIPP repository. This brine would be capable of flooding the WIPP tunnels, corroding the steel drums, and dissolving the waste, creating a radioactive slurry at the repository horizon. Because the brine is saturated it would not be capable of dissolving any more salt; and once the WIPP tunnels are filled, the contaminated brine would have no other place to go but up the WIPP shafts, in what is known as the "undisturbed scenario." It is CARD's position that the sealing of shafts and the plugging of boreholes are too important to be left to chance. The credibility of the WIPP site depends upon it. Until the technology is demonstrated, in the field, it is premature even to consider allowing WIPP to open.

ALTERNATIVES TO RADIOACTIVE DUMPING

There are alternatives to radioactive dumping. DOE dismisses them too easily. In the Final Environmental Impact Statement (FEIS, 1980), DOE devoted more than a thousand pages to geologic disposal, and only three pages to alternative technologies (pp. 3-2 to 3-5). In the Supplemental Environmental Impact Statement (SEIS, 1996), DOE devotes over seven hundred pages to geologic disposal, and only two pages to alternative technologies (pp. 3-43 to 3-45), often stating that these alternatives were considered and rejected in the FEIS. From beginning to end, DOE has skewed the NEPA process so as to make the decision to proceed with WIPP appear reasonable and inevitable. This is in direct violation of NEPA case law, which states that the Environmental Impact Statement should treat the decision "as an impending choice to be pondered, (not) as a foregone conclusion to be rationalized." [372 F. Supp. 223, 253 (1974)] (For a discourse on NEPA case law as it applies to WIPP, see "Radioactive Dumping: The State of the Art," reprinted in WIPP-DOE-173). These are some of the alternatives to radioactive dumping:

Transmutation of isotopes with long half-lives into isotopes with short half-lives could greatly reduce the necessary period of waste isolation. DOE rejected transmutation because: (1) the process would be carried out in a nuclear reactor; (2) the process has not yet been proven for large-scale facilities; (3) waste products would be created in the process, so that geologic disposal might still be necessary; and (4) transmutation could not be performed upon contact-handled transuranic waste (CH-TRU), which consists largely of contaminated laboratory materials. But transmutation might be feasible for remotely-handled transuranic waste (RH-TRU) and high level waste (HLW), in which radioisotopes are more highly concentrated. Transmutation has been demonstrated on an experimental basis at Los Alamos National Laboratories (LA-UR-94-3022; LA-UR-94-4351; LA-UR-95-1792).

Vitrification would combine RH-TRU and HLW with molten glass. The advantage to vitrification is that it would make the waste less mobile, and therefore easier to contain. The waste would be less able to be entrained in the air, and less able to be transported by groundwater. DOE rejected vitrification because of the large volume of CH-TRU, again failing to address the feasibility of the process for RH-TRU and HLW. DOE argued that a vitrification program would delay TRU waste disposal, skewing the decision-making process in favor of geologic disposal.

Engineered barriers in the form of improved waste containers could lengthen the period of time before waste in a geologic repository would come in contact with the host rock. In the FEIS (1980, pp. 9-159, 9-160), DOE hoped to develop a canister that could remain intact for 300 to 500 years, a span of time embracing ten half-lives of cesium-137 and strontium-90, which are the major heat-producers in HLW. Again, DOE does not consider improved waste containers for disposal of TRU at WIPP.

Taken together, these alternatives could make isolation of RH-TRU and HLW possible. Short-lived isotopes, in vitrified form, in containers designed to resist corrosion, emplaced in a geologic repository, might remain isolated from the environment for ten half-lives or more, during which time the radioactivity will have decreased by a factor of 1000. Instead, DOE plans to bury long-lived isotopes, untreated in any way, in steel drums, in direct contact with wet salt, the most corrosive host rock imaginable.

It is CARD's position that no waste should be brought to WIPP. The waste should be stored above ground, in a monitorable and retrievable manner, until a solution is found. DOE admits (DEIS, 1979, p. 9-165) that the environmental effects of leaving the waste where it is, in the short term, would be less than the effects of retrieving it, identifying it, packaging it, trucking it, unpackaging it, lowering it down the WIPP shafts, and burying it at WIPP. The $17 billion that DOE plans to spend on WIPP could fund a genuine scientific effort to solve the problem.

CARD

CITIZENS FOR ALTERNATIVE TO RADIOACTIVE DUMPING

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3-5-97

NUCLEAR TRANSMUTATION AS A MEANS OF REDUCING THE MENACE OF PLUTONIUM AND RADIOACTIVE WASTES.

You can't get rid of radioactive substances by burying them, at least not safely, at a flawed facility like WIPP. The half-lives of the isotopes are immutable; there is nothing that you can do to eliminate radioactive substances.

Or is there? Yes, there is an alternative to burying radioactive substances: nuclear transmutation of the offending radioactive isotopes, the turning of them into stable isotopes and isotopes that have shorter half-lives than the starting materials,thus eliminating the need for virtually perpetual reposition of the radioactive substances, or at least to a great degree reducing the far future hazards of the waste.

A great beauty of the transmutation idea is that as envisioned, it would involve a system that produces far more energy than it uses to transmute the waste, so that a nuclear transmutation facility could produce electricity to supply to the grid as it is transmuting waste.

HOW WOULD IT BE DONE?

One vision of a transmutation system comes from Los Alamos National Laboratories (LANL), and is described in various publications of LANL that are available to the public (two publications are cited below). In very simple terms, it would consist of a powerful accelerator that would direct an intense beam of protons to a "target ." The target would be a material which when bombarded with protons of the proper engergies would produce a shower of neutrons (many neutrons per proton), and of course the plutonium or other wastes that are being transmuted; it is the intense flux of neutrons that is responsible for the transmutation reactions. The system would be set up so that there would never be a critical mass of plutonium or other fissile isotopes in the system at any one time, so an explosion caused by a runaway chain reaction could not occur.

The transmutation reactions would generate heat, which would be extracted from the system to drive a steam turbine, to run a generator, to produce electricity.

Some of the electricit ould have to be fed back to the proton celerator, but most of it could be fed into the electrical power distribution grid.

If the plutonium stockpiles and other wastes are ever all used up, then the system could still be run by using naturally occurring thorium or uranium, if there were a need and desire to do this. This technology is indeed elegant and beautiful, and would be very useful if developed and put to use. It would be certainly be much better than the perilously dangerous unsoundness of WIPP.

IS IT FEASIBLE ?

Very definitely, this vision is quite feasible. The technology involved is not extraordinarily difficult, and much of the technology is already developed or on the way to being developed. The required proton accelerator would basically be a scaled-up version of an existing Los Alamos accelerator.

If there is a will to do it, and if the funds are made available (economically it would be a much better deal in the long run than WIPP, though initial development and construction costs would be high), then this vision most definitely can be made to come to pass. Relevant research has also been done in Russia and in the Czech Republic, and in other countries.

A Means Of Preventing Future Plutonium Mines.

And as far as the plutonium is concerned, it is far, far better to transmute it into something other than plutonium, so that it can never be used to produce a fission device. Simply burying the plutonium would open up the possibility that the repositories containing plutonium could anytime within the next many, many thousands of years be made into plutonium mines. Plutonium mines-a dreadful prospect indeed.

Conclusion.

Accelerator Transmutation of Waste (ATW) is a brilliant and technologically elegant possible future means of dealing with the menace of accumulated plutonium and various accumulated radioactive wastes. This technology offers the possibility of virtually eliminating dangerous plutonium, and dramatically shortening the period of most dangerous activity of the various radioactive wastes. It is far better in the long run both economically and environmentally than WIPP, which is unsound and dangerous as a result of many flaws.

FOR FURTHER READING:

Arthur, E.D. Accelerator-based Systems for Plutonium Destruction and Nuclear Waste Transmutation, Los Alamos National Laboratories, Los Alamos, N.M.

AIP Conference Proceedings-International Conference on Accelerator-Driven Transmutation Technologies and Applications, Las Vegas, Nevada, July 25-29, 1994. Los Alamos National Laboratories, Los Alamos, N.M.

(contains many technical papers, totally over 900 pages)

WIPP Waste Storage Concerns at Los Alamos National Laboratory (LANL)

By Deborah Reade

WIPP Waste is transuranic (TRU) waste that has been generated after 1970 and has been retrievably stored. This waste is expected to be retrieved from storage at LANL and disposed of at WIPP if it meets or can be treated and packaged to meet the Waste Acceptance Criteria (WAC) for that repository. LANL now stores and is expected to generate the 4th largest volume of WIPP waste of the entire Department of Energy (DOE) system–after Hanford, Idaho National Environmental Engineering Laboratory (INEEL) and Savannah River Site.

In the 25 years from 1971-1995, LANL has retrievably stored 55,000 drums of contact-handled transuranic (CH-TRU) waste and about 500 drums of remote-handled transuranic (RH-TRU) waste onsite. *(Drum* means a 55-gallon drum of waste or its equivalent volume.) In the next 27 years from 1995-2022, LANL is expected almost to double its volume of TRU waste to 90,000 drums of CH-TRU waste and 950 drums of RH-TRU waste–generating almost 1500 drums of TRU waste per year from its Plutonium Processing Facility.[1] TRU waste and TRU mixed waste that is intended to go to WIPP is stored in several different ways at *Area G of Technical Area 54*–the primary active radioactive waste storage site at the Laboratory.

All waste generated after 1991 (and some generated after 1985) is stored in fabric domes and can be easily monitored and inspected. In 1991 the lab also began to separate TRU waste from TRU mixed waste in storage. From 1979-1991, waste was placed in *bermed storage*–closely stacked drums on asphalt pads above ground and covered with dirt. In 1993 after holes were found in some of the bermed-storage waste containers, the state of New Mexico fined LANL $600,000 and required the lab to retrieve the waste from bermed storage and place it in fabric domes where it could be regularly inspected. That process is still going on in 1997. Currently there are about 7 TRU waste storage domes at LANL with several more planned for the bermed storage waste.

From 1971-1979 waste was buried at Area G in pits, trenches and shafts. The difference between this waste and TRU waste buried before 1971 is mainly that the later "retrievably" stored waste is more likely to be in some kind of container. Some is buried in small drums inside concrete casks; some is in drums placed in trenches on concrete pads and covered with dirt; and some waste was mixed with concrete, poured into corrugated metal pipe (CMP) and buried under dirt in trenches or pits. RH waste, which requires more shielding, was placed in deeper shafts which may or may not have been lined with CMP or concrete. Pre-1971 TRU waste is permanently disposed of at LANL and is *not* planned to be sent to WIPP. Although volumes can only be estimated for this waste, there may be at least 12,500 drums of old TRU waste non-retrievably buried at Area G and other sites at LANL.

LANL is listed as a storage and consolidation site in the draft SEIS-II for the proposed action and for most of the alternatives. This means that it is expected to accept WIPP waste from the Pantex Plant in Texas and from Sandia National Laboratories in Albuquerque and to store that waste as well as TRU waste it generates on site until that waste could be shipped to WIPP. In March of 1997, in fact, three drums of this waste were sent from the Pantex Plant to LANL for characterization and storage. DOE believes that TRU waste can be safely stored at the storage and consolidation sites for

many years. In the 1980 WIPP FEIS DOE stated that *"...no environmental reasons have been found why TRU waste could not be left...stored as it is for several decades or even a century;"*.[2] In the 1996 draft SEIS-II, storage is planned to last up to 120 or 140 years under some of the alternatives.

Yet many people living near LANL are concerned that the WIPP waste will contaminate their water, air or soil unless it is moved quickly to WIPP. There are ominous indications that radioactive contamination is moving offsite. Some has already reached the Rio Grande and the main aquifer under the Laboratory may be compromised. Tritium, plutonium and other radionuclides have been found in groundwater in several canyons on or near laboratory property. Plutonium ten times fallout levels has been found on San Ildefonso Land.[3] Tritium vapor is coming right out of the rock on the sides of the mesa where Area G is situated.[4] This is of particular concern because since tritium vapor travels more quickly, it may be a warning that heavier, less mobile radioactive contaminants are following behind. In 1990 LANL delivered the greatest radioactive dose to the surrounding population from air emissions of any DOE facility.[5] They have continued to release contaminants at a rate 3 times that of any other DOE facility, mostly from the Neutron Science Center's *Los Alamos Meson Physics Facility (LAMPF)*. Obviously, there are contamination problems associated with LANL and these problems may well become more serious and reach farther off site in the future.

But is the waste that is intended to be shipped to WIPP the source that is and will be contaminating our air, soil and particularly, our groundwater offsite?

In fact, the WIPP waste is actually one of the least likely candidates as the source of this contamination. That waste is retrievably stored in at least some type of container. Except for the pre-1976 waste, it is all stored above ground and soon will all be placed in domed storage where it is monitored regularly. The 1971-1976 waste is of some concern since the carbon-steel drums in which much of it is packaged are coming to the end of their life expectancy (about 20 years). Although LANL has inspection boreholes around and beneath much of Area G, the containers themselves cannot be inspected without retrieving them as the domed storage drums can. Ironically, however, it is the WIPP project itself which can be said to be keeping this waste from being placed in safer storage. LANL's waste management budget has been greatly cut in recent years and LANL has chosen to spend the remaining money on preparing to ship the above-ground waste to WIPP instead of on more safely storing the buried waste. LANL doesn't expect to start retrieving the 1971-1976 TRU waste in the pits and trenches of Area G for at least 10 years–longer if funding is further cut.

It is the *legacy waste* and other laboratory processes both past and current which are the probable sources for the contamination which is on its way down the mesas. Legacy waste is waste that has been disposed of in the past. We know much less about this waste than we do about the WIPP waste, even though the transuranic waste has not been fully characterized. In the early days of the Laboratory, radioactive and hazardous wastes were often buried without special containment in the ground or poured untreated into the canyons at outfalls. (Liquid radioactive waste is now treated at the *Radioactive Liquid Waste Treatment Facility*. However, a small amount of radioactivity remains in the water that results from this treatment. This wastewater is still poured into Mortandad Canyon where elevated levels of various radioactive contaminants–mostly tritium, plutonium and americium–have been found as well as nitrates at ten times the level of state standards (from plutonium processing). A retrofit of the treatment facility is being built which *may* further reduce contaminants released into the canyon.) Nineteen canyons may be contaminated by past laboratory activities.[6]

DOE has identified around 2000 contaminated sites. Some of these sites will require no further action but at least 1000 will need to be further investigated and/or cleaned up and are potential release sites. Forty to fifty of these sites are so large or have such a complex mix of contaminants–both radioactive and hazardous that they will need to go through the full corrective action process.[7] Fourteen old dump sites or *Material Disposal Areas* (MDAs) will probably be stabilized and left where they are. This means that they will probably be capped or covered by a combination of natural materials like clay and synthetic materials to protect them from water runoff and filtration as well as from digging and burrowing animals.[8] Some MDA sites may require further stabilization, for instance, injecting grout into or under the waste. Runoff, especially from storms, but also runoff from melting snow in the spring is washing radioactive contaminants from MDA sites as well as from old and current firing ranges and other contaminated areas into canyons that end up at the Rio Grande. Old firing ranges had distributed *110 tons* of depleted uranium on the Pajarito Plateau by 1979, in sizes ranging from fine dust (10% or 11 tons of depleted uranium are believed to have been aerosolized during the explosions) to pieces of shrapnel embedded in canyon walls. These explosions also dispersed large quantities of mercury, beryllium and lead. Although these materials wash off the mesas during spring runoff and storms, LANL insists on continuing uncontained explosions of these materials with current testing programs and with the planned DARHT project.

Tritium, cesium-137, strontium-90 and other radioactive constituents have been found in alluvial groundwater downgradient from 2 sites in one of the main canyons within the Laboratory.[9] Tritium has been found in the main aquifer which was believed to be protected from possible contamination by the Bandelier Tuft above it. Tritium has also been found in wells near the Rio Grande. Tests from those wells have led the State's DOE Oversight Bureau technical staff to believe that the tritium does *not* come from fallout in groundwater recharge as the Laboratory has claimed.[10]

Even if its stored TRU waste were gone LANL would still be a major waste management site. DOE defines a major site in their Draft Waste Management PEIS as a site *"...that may receive wastes generated offsite, manage high-level waste, and/or host disposal facilities."*[11] LANL generates no high-level waste but it has some fuel rods buried at Area G. It is slated to receive TRU wastes from Sandia National Laboratories, has started receiving WIPP waste from the Pantex Plant and is a major disposal site for other waste as well.

LANL has the third largest inventory and expected generation of low-level waste (LLW) of the entire DOE complex–750,000 drums of LLW.[12] LANL has or will dispose of this waste–permanently bury it–onsite. While LANL is expected to generate only 1500 drums per year of TRU waste, it is burying about 24,000 drums of LLW at Area G every year.[13] Low-level waste is buried in pits, trenches and shafts–some lined, some not–at Area G. Again, this permanently disposed of waste is more likely to be the source of current or future contamination than waste that is monitored and segregated for shipment to WIPP.

Low-level waste is, of course, not necessarily low level in terms of radioactive content and is divided into contact- and remote-handled waste just like transuranic waste. Some LLW is very "hot" and requires shielding. LLW is also divided into alpha and non-alpha. Alpha LLW includes the same radionuclides like plutonium and americium that are in the WIPP waste, but in smaller concentrations. The LLW plutonium is still radioactive for 240,000 years. And, because of the large volume of LLW that is buried onsite, a significant amount of these alpha-emitting radionuclides is present at Area G and some other disposal sites at LANL.

Of course, although other waste categories appear to be responsible for contamination that has been found offsite, potential storage problems do exist for the WIPP waste as well. These problems seem to center on natural disasters or human error. The best monitored TRU waste is that in the fabric domes. These domes could be vulnerable to extreme tornado-type winds (fortunately, not common in northern New Mexico), earthquakes or fire. In fact, fire might be the most likely potential problem in the short term. Like the 2 fabric domes used for low-level mixed waste that is stored before being shipped offsite for treatment and disposal, the fabric domes for the TRU waste are treated with fire-retardant chemicals. However, the domes would still be vulnerable if a major forest fire should start burning the Laboratory itself. Although vegetation has been removed from around the waste storage areas, high winds can cause a fire to jump large distances. Of course, if the Laboratory were burning, other structures might be contributing large doses along with the WIPP waste which would then be just one part of a much larger disaster. There have been two major forest fires at or near the Laboratory. The last fire occurred the summer of 1996, burned to within two miles of the Laboratory boundaries and blanketed Santa Fe and nearby communities with heavy smoke for several days.

Also, there could be a storage facility fire which starts within a waste dome itself. The WIPP waste contains a lot of flammable gases which have built up in the drums. The drums are vented, but gases–especially methane–could build up in sealed plastic bags within the drums. Human error might allow incompatible materials to be stored in the same drum causing an explosion or fire. This has already happened at DOE facilities.[14] In fact, in 1989 there was a spontaneous depleted uranium fire in a drum of waste at LANL which had been opened[15]. Chemical incompatibility is also one of the probable causes of several fires which may have been the source of contamination at Area G.[16] Only two TRU waste fabric domes have fire suppression systems. Fire from within a dome is not considered to be extremely likely so only the domes that are most at risk have these systems.

Waste storage can also cause exposures to workers as they handle and inspect the waste. Some drum-drop and puncture accident scenarios have life-threatening or permanently debilitating effects on the waste-handler from the volatile organic compounds in the waste, not from the radioactivity.[17]

Some sites, like Rocky Flats, are considering storing their TRU waste in concrete vaults which would go a long way toward solving most of the above problems. However, at LANL we don't have the money to place the retrievably buried waste even in fabric domes, let alone to build a concrete vault for all the WIPP waste. We appear to have a choice either to put our money into more secure storage, disposal and stabilization or to concentrate on getting WIPP open now. CARD believes that the effects of leaving the waste in more secure storage at LANL are less than the effects of retrieving it, characterizing it, packaging it, transporting it, unloading it and burying it at WIPP. Concentrating on providing better containment not only for the WIPP waste but also for all the waste that is stored or disposed of at LANL would give us increased security in both the short and the long term. We would then be able to pursue *actively* a variety of alternative solutions. Everything from an as-yet unconceived of technology for separating TRU waste radionuclides from soil or trash to waste forms that would remain stable for 240,000 years and could be *safely* buried.

Moving the TRU waste from LANL to WIPP will only remove the tip of the iceberg and will add to the dangers from radioactive materials transportation to the communities near LANL. The huge amount of other waste which is buried in or scattered over the plateau will still be there. Contamination from 50 years of poor containment is headed toward the surrounding population.

This is our reality and we have to address it. We can spend our money on WIPP or we can spend it to make containment more secure at LANL while pursuing appropriate technologies–the choice that CARD believes is the right one.

Footnotes

[1]*Draft Waste Management Programmatic Environmental Impact Statement–Summary*, U. S. Department of Energy, August 1996, p. 46.

[2]*Final Environmental, Impact Statement Waste Isolation Pilot Plant, Volume 1*, U. S. Department of Energy, October 1980, p. 4-2.

[3]*How Safe is New Mexico's Atomic City?*, Niklaus & Feldman, Southwest Research & Information Center, 1980, p. 23.

[4]*Personal communication* 3-12-97 with Stephen Yanicak, New Mexico Environment Department, DOE Oversight Bureau.

[5]*A Citizen's Guide to Los Alamos National Laboratory,* Concerned Citizens for Nuclear Safety, November 1993, p. 16.

[6]*The 1996 Baseline Environmental Management Report, Volume III,* U. S. Department of Energy, June 1996, p. NM-33.

[7]*Personal communications* 3-12-97 and 3-13-97 with John Mack, Team Leader Waste Management, DOE Los Alamos Area Office.

[8]*Personal communication* 3-12-97 with Ted Taylor, Program Manager, Environmental Restoration Program, Office of Environment and Projects, DOE Los Alamos Area Office.

[9]*The 1996 Baseline Environmental Management Report, Volume III*, p. NM-34.

[10]*Environmental Report, Volume 1, Issue 1,* New Mexico Environment Department, DOE Oversight Program, Summer 1994, p. 4.

[11]*Draft Waste Management Programmatic Environmental Impact Statement–Summary*, p. 8.

[12]*Draft Waste Management Programmatic Environmental Impact Statement–Summary*, pp. 36-37.

[13]*The 1996 Baseline Environmental Management Report, Volume III*, p. NM-43.

[14]*An Assessment of the Flammability and Explosion Potential of Transuranic Waste, EEG-48,* Matthew Silva, June 1991, p. 18.

[15]*Ibid,* p. 35.

[16]*Non-Point Source Summary for TA-54 SWMU-19-SH68,* U. S. Department of Energy, December 1993, p. 3.

[17]*Waste Isolation Pilot Plant Disposal Phase Draft Supplemental Environmental Impact Statement,* U. S. Department of Energy, November 1996, p. G-45.

3/17/97

Human Error and the Department of Energy

by Deborah Reade

Human error must be added as a factor to the Department of Energy's (DOE) calculations to show compliance with the Environmental Protection Agency's (EPA) criteria for permanent disposal of transuranic (TRU) waste. DOE says it has included human error because it is already included in selecting the parameters that are plugged into DOE's formulas. CARD believes, however, that the likelihood of human error significantly affecting the probability of containment is high for reasons described below and that it should have its own separate place in DOE's calculations

William R. Freudenburg in his paper *Human and Social Factors in the Transportation of Nuclear Wastes,* written for the state of Nevada in 1991, describes various human and organizational factors that lead to increased risks–especially in complex technological systems like the WIPP project. These factors can be organized primarily into two groups: "the human and social *attenuation of risk estimates* and the *organizational amplification of risks.*"[1]

Risk estimates can be too low because of:

"*1. Overconfidence in the ability to foresee all possible failure modes...*

2. Insensitivity to the problems of small 'sample sizes. Risk assessors are often placed in a situation of needing to produce estimates on the basis of incomplete or inadequate data. Under the circumstances, analysts are often forced to 'make do' with whatever data happen to be available...As scientists are all too well aware, however, the results of the first few trials, first few interviews, initial case studies, and so forth, often will wind up differing significantly from the results of a more thorough research program. This is the principle behind the well-known emphasis on replicability in scientific research, and it is often a cause of problems for risk assessments that are forced to rely on whatever data may be available."[2] This quotation would seem to have been written exactly to describe the waste characterization that has been done for the WIPP project where only tiny percentages of the waste are sampled or visually inspected or incomplete process knowledge is relied on. Then these incomplete figures are averaged and used to describe tens of thousands of drums of waste.

*3. "Failures to foresee system interactions and interdependencies...*Virtually by definition, moreover, the 'unforeseen' errors are unlikely to be taken into consideration in the calculation of risk probabilities...Some of the most technological risks, unfortunately, are related instead to systemic or conjoint problems (e. g. the simultaneous occurrence of two or more problems that might not have been individually significant) and to factors that only exert an influence after a system has been operational for a significant period of time."[3]

4. "'Calibration errors' and Cognitive Dissonance. While members of the risk assessment community often refer to the difficulties experienced by members of the general public in calculating probabilities, it is less well understood that calibration errors–mistakes in estimating probabilities–also present serious problems for persons with scientific training. The most serious problems occur in the absence of reasonably definitive data–a situation that unfortunately characterizes much of a risk assessor's work."[4]

Organizations can increase risks in a variety of ways. For instance, "...the lack of organizational commitment to risk management may be one of the *predominant* sources of 'real risk' from the operation of

a technology."[5] DOE claims to be committed to risk management but one might question if this is true in actual practice. There are examples throughout the DOE system of a need for improved risk management. Everything from the 1993 "rock-on-a-rope" incident at Hanford when "...virtually all sampling activity was suspended for more than 6 months following a safety violation in which a maintenance worker contaminated himself and others while using unapproved procedures to unclog a blocked drain. This incident, referred to as the "rock-on-a-rope" occurrence because of the extremely primitive methods used, was the culmination of a series of incidents..."[6]; to Los Alamos National Laboratory's (LANL) series of 4 fatal or near-fatal accidents in a period of 19 months. These accidents included the 1994 death of a security officer who was shot during an anti-terrorist training exercise by a fellow officer whose gun held live ammunition instead of blanks. One of the accidents was at least partly caused because the project involved was "...'schedule driven'–meaning that a sense of urgency related to artificially-set deadlines overrode safety precautions."[7] CARD has long maintained that DOE's need to meet its schedule to open WIPP has caused various tests necessary to reduce uncertainty in important areas of site hydrology, waste characterization and repository characteristics, to be done incompletely or not done at all.

Lab officials defended LANL's poor safety record by making a distinction between industrial and radiological accidents, stating that "...the safety procedures related to radioactive work at the lab are sound 'because that's what we're experts at.'"[8] Unfortunately, at the same time they were making this statement, a person was being contaminated about once every three weeks at the CMR and Plutonium Processing Facilities.

As an example of massive human error in a project more similar to the WIPP we can look at the construction project for the multi-million dollar *Nuclear Materials Storage Facility* at LANL. "After construction completion, it was determined that design and construction deficiencies existed that precluded the start of operations. As a result, the facility has not operated nor has it stored special nuclear material."[9] Among numerous other deficiencies, the material access area entry (loading and unloading area) did not fit the vehicles that the materials were transported in. The only way to use the facility was to do a "...partial demolition within the facility..."[10] This shows that major mistakes can be made on paper before something has been actually tested or used. This especially applies to the sealing systems at WIPP. Because we have no field tests of these systems, we won't know if we actually have the technical ability to seal shafts in salt until all the waste is in the ground and possibly destruction of the waste containers has occurred.

Other risk analysts have also addressed the human error factor. Tuler et. al. in their report *The Effects of Human Reliability in the Transportation of Spent Nuclear Fuel,* also written for the state of Nevada, state that "...human actions have been shown to be major causes of system failures in many complex technological systems..."[11] and that "...human errors in quality control have been a continuing problem in the nuclear industry..."[12] In describing the type of organizational thinking which can lead to choosing the more risky alternatives, they might have had the DOE in mind; "...*groupthink* is of particular concern because it may also contribute to more risky decisions (e.g., 'risky shift') and may lead to especially severe consequences in hazardous situations...The major factors contributing to such behavior are the uniformity of members, the size and isolation of a group, norms, cohesiveness, and personalities [Reason 1987b]. In groups experiencing groupthink, the powerful forces of perceived togetherness act in concert to render the possibility of failure unthinkable-and if not unthinkable, then certainly unspeakable" [Reason 1987b: 124]."[13]

Management throughout the DOE complex is also a problem. Program and laboratory managers "...describe DOE's management as 'fractured' and not particularly adept at combining the expertise of various program areas to tackle cross-disciplinary problems."[14] And the U. S. Government Accounting Office (GAO) has said that "DOE's elaborate and highly decentralized field structure has been slow to respond to changing conditions and priorities, fraught with communication problems, and poorly positioned to tackle difficult issues requiring a high degree of cross-cutting coordination."[15] WIPP would seem to be a difficult issue requiring a high degree of cross-cutting coordination.

When management is in disarray, project risks increase. Poor management and planning has left us where we are now–trying to complete a complex clean-up project without basic knowledge about the waste, the site and the repository. According to one laboratory manager in the DOE system "...developing a basic understanding of underlying problems before developing waste cleanup technologies is important. If the basic science is not understood, environmental remediation problems may elude solution..."[16]

And finally, there is the problem of traditional human error or worker competence. According to John Crawford Jr., a former member of the Defense Nuclear Facilities Safety Board and a nuclear engineer, "We're not saying the DOE doesn't have enough people...We're saying it doesn't have enough people who are technically qualified."[17]

Several of the above descriptions of deficiencies in risk analysis have already happened at WIPP with the waste hoist accident that took place on July 25, 1987. Two years before this accident occurred DOE concluded that a waste hoist accident had an annual probability of only 1 in 60 million. Even after the New Mexico Environmental Evaluation Group (EEG) informed DOE that several factors including "human factors and operational errors...were not conservative or [were] overlooked..."[18] in their probability calculations, DOE continued to maintain that a catastrophic waste hoist accident was extremely improbable *(1 human error–attenuation of risk estimates.)*

To replace a faulty hydraulic valve, the manufacturer sent a differently designed valve without documentation *(2 human errors–the wrong valve and lack of communication–both occurring outside the WIPP project system.)* Workers made the valve fit but it failed and the waste hoist jerked upward for 30 feet *(traditional human error–incorrect installation.)* Then they tried to make it fit again and the hoist jumped 300 feet *(2 human errors–incorrect installation and lack of learning from mistakes.)* According to DOE's Unusual Occurrence Report on the incident, among other problems, there was an "...absence of a quality assurance input for this process. The responsible operations personnel failed to properly manage the entire procedure..."[19]

The possibility of human error occurring exists throughout every aspect of the WIPP project form the possibility of outside contractors supplying materials that are not to specifications, to improper procedures by workers loading waste containers or installing seals. Human error can also occur in the risk assessment itself by systematically underestimating risks and can be compounded by the practices and attitudes of the DOE as an organization with a long history of mistakes and site contaminations. Human error throughout the system must be taken account of with a separate factor for human error in DOE's calculations to show compliance. And DOE should be required to eliminate or reduce the large uncertainties that exist about waste characterization, waste interactions in and with the repository, site hydrology and repository performance (especially shaft and borehole seals.) There are too many unknowns in DOE's models and too many things like human error that are left out of their calculations completely.

Footnotes

[1]*Human and Social Factors in the Transportation of Nuclear Waste,* William R. Freudenburg, May 1991, p. 3.

[2]*Ibid,* pp. 5-7.

[3]*Ibid,* pp. 7-8.

[4]*Ibid,* p. 11.

[5]*Ibid,* p. 25.

[6]*Management and Technical Problems Continue to Delay Characterization of Hanford's Tank Waste,* U. S. General Accounting Office, January 1996, p. 12.

[7]*The New Mexican,* February 22, 1996, p. A-3.

[8]*Ibid,* p. A-3

[9]*Site-Wide Environmental Impact Statement Information Sheet No. 5: Nuclear Materials Storage Facility Renovation,* Los Alamos National Laboratory, September 1994, p. 1.

[10]*Ibid,* p. 2.

[11]*The Effects of Human Reliability in the Transportation of Spent Nuclear Fuel,* Seth Tuler, et. al., June 1988, p. 4.

[12]*Ibid,* p. 13

[13]*Ibid,* p. 43.

[14]*Department of Energy, National Laboratories Need Clearer Missions and Better Management,* U. S. General Accounting Office, January 1995, p. 18.

[15]*Department of Energy, Framework Is Needed to Reevaluate Its Role and Missions,* U. S. General Accounting Office, statement of Victor S. Rezendes, June 21, 1995, p. 2

[16] *Department of Energy, National Laboratories Need Clearer Missions and Better Management,* p. 31.

[17]*The Washington Monthly,* The DOE's Dirty Laundry, Simon Walsh, p. 10.

[18]*Probabilities of a Catastrophic Waste Hoist Accident at the Waste Isolation Pilot Plant, EEG-44,* Moses A. Greenfield, Ph. D., January 1990, p. 9.

[19]*Ibid,* p. 19.

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