UNSAFE RADWASTE DISPOSAL AT WIPP

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Note:

In several places in his paper, Dr. Snow states that a near-surface or above-ground, centralized, monitored retrievable storage facility, possibly at WIPP, is now the only option to disposal at WIPP. However, it is CARD's position that the WIPP waste should remain in monitored retrievable storage ***at the generator sites*** *while research is pursued to find a truly safe method for final disposition of this waste. The Department of Energy has stated that the WIPP waste could stay safely at the generator sites for at least another 50 years. CARD believes that the risks from transporting 35,000 shipments of waste around the country to WIPP or another centralized facility are great and outweigh the risks from properly storing the waste where it is generated or currently stored.*

The (Short Version) of this paper is also available in the Non-Technical Section.

Summary

At WIPP, radioactive waste is being disposed of permanently in drums and boxes placed in rooms excavated in the Salado salt beds. Like all other excavations below the water table, the repository will saturate, and dissolved radioactivity can ultimately escape via boreholes, shaft.s or fractures to the overlying Rustler evaporites. The most evident aquifer in the Rustler, the Culebra dolomite, is claimed by DOE to provide such slow transport that the Rustler can be considered an adequate barrier to waste migration. But performance assessment modeling, based on insufficient exploration data, unsupportable deductions and faulty assumptions led to that claim. This paper asserts that the Rustler formation overlying and down-gradient of the WIPP repository will not provide the claimed geologic containment because karst conduits are present that will facilitate rapid, ephemeral flow. If disposal is not halted and timely rectified, escaping radioactivity may reach Nash Draw within a thousand years, contaminating the Pecos River and Rio Grande. Until a suitable disposal site or method is engineered, a monitored retrievable

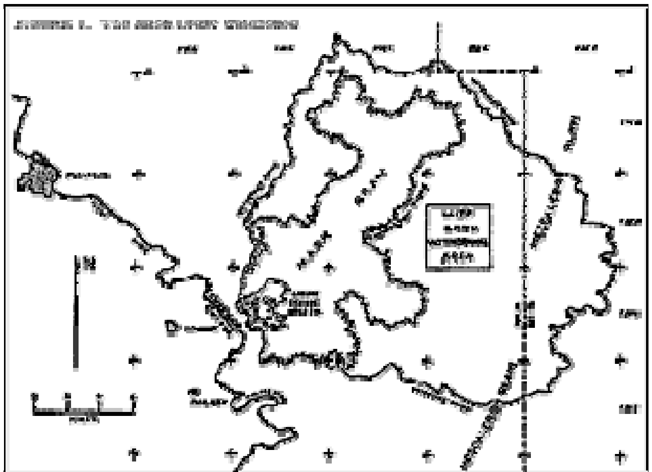
storage facility may offer the only alternative.

Introduction

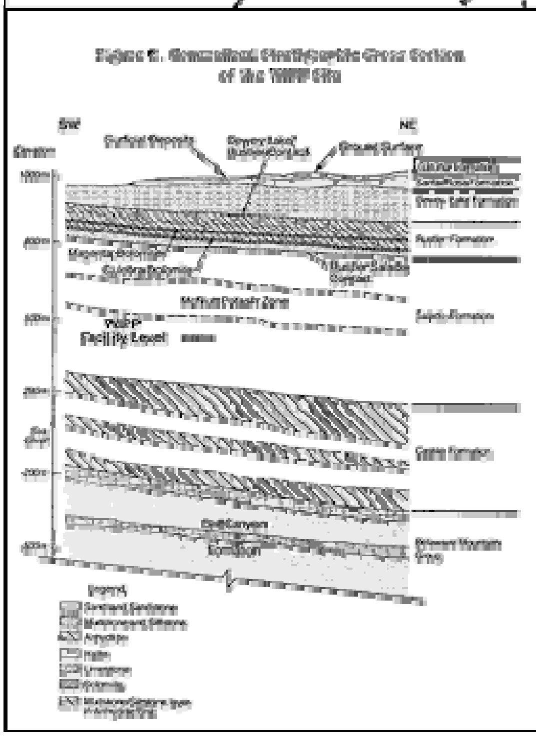
In 1998, the Department of Energy (DOE) became certified to dispose of transuranic (TRU) waste transported from military generation sites around the country, placing it irretrievably in rooms excavated in deep salt beds beneath the Waste Isolation Pilot Plant (WIPP), Carlsbad, New Mexico, and is presently expanding the facility. The urgency to eliminate surface stockpiles and to decontaminate bomb- making plants and test facilities at Rocky Flats, Argonne, Arco, Mound, Oak Ridge, Hanford, Savannah River, Nevada Test Site and the Lawrence Livermore and Los Alamos Laboratories gave stimulus to the conclusion that WIPP would provide safe, permanent isolation, that excessive plutonium and other radionuclides will not be conveyed in solution by groundwater moving from the repository through covering rocks to the accessible environment (surface or 5 km distant) in less than the 10,000 years mandated by 40CFR191.

Deep geologic disposal has seemed to be the answer. Natural radioactivity in the biosphere results in mild carcinogenesis that humans accept, while uranium ore bodies that could not be tolerated are shielded by intervening thicknesses of rock. Low solubility of ore minerals, and dilution and slow transport as solutes in groundwater have protected us. But in the last half-century, mining and processing of uranium ore, fission, bomb manufacture, and waste reprocessing have concentrated uranium and transuranic elements at numerous accessible places. It is logical to reverse the destination of the radionuclides, such as plutonium and americium resulting from bomb making, by burying these wastes deep in the earth. But such geologic disposal methods have proven so difficult to validate that every nuclear nation remains burdened with dangerous stockpiles of spent fuel, unneeded bomb triggers and contaminated materials. WIPP is the first and only permitted disposal facility in the world for TRU wastes. But because adequate containment conditions were not proven at the WIPP site, the facility does not make the case for safe geologic disposal. A single monitored retrievable surface or near-surface facility may be the most prudent U.S. repository until a better technology develops.

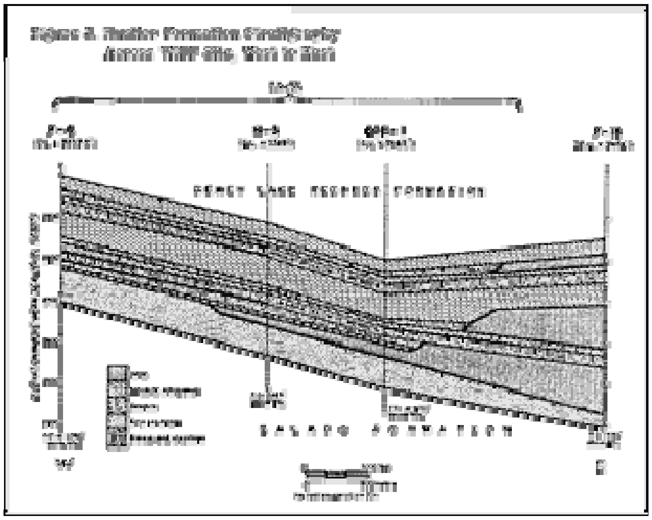
Various geologic media have been studied as potential hosts for the permanent disposal of U.S. radwastes. Crystalline rocks, including granite, basalt and metamorphics, though possessing low permeabilities that assure slow transport rates, were disqualified because all sites are water-saturated and connected to potable water sources. Though pervasive but tight fractures are the typical conduits for leakage, it has never been possible to prove the absence of preferred pathways, such as fault zones, that would shorten travel-times to streams or aquifers. Since 1957, rock salt has been considered a favorable medium because of the perception of a nearly impermeable, self-sealing nature. However, abandoned salt mines near Lyons, Kansas were disqualified in 1972 because the overburden rocks are perforated by many old drill holes.



Salt domes of the Gulf Coast region were considered but disqualified due to the probability that fluids in a sealed cavern subject to creep closure would be ejected, ultimately reaching overlying aquifers. WIPP is similar in these regards. Bedded salt near



Hereford, Texas failed as a candidate by decree of an economy-minded Congress, together with the candidate site in basalt at Hanford, Washington. That left. for active investigation only a site in welded tuff at Yucca Mountain, Nevada for civilian power-plant radwastes, and bedded salt at WIPP for military radwastes. Though high permeability and deep drainage of the fractured tuff at Yucca Mountain provides an unsaturated environment, remaining uncertainties of future climate conditions, faulting, volcanism and seismically-driven hydrothermal upwelling (Hill, et. al. , 1995; Hill and Dublyansky, 1999) cast doubts on the adequacy of waste isolation there. The WIPP site, selected in 1975 (U.S. DOE, 1997, p. 2-11), survived the purging of salt sites while the Atomic Energy Commission clothed the early investigations in military secrecy. At the onset of controversy concerning karst features over the WIPP site, the consulting role of the U.S. Geological Survey was discontinued, making Sandia National Laboratories the sole consultant to DOE. Technical oversight improved when the 1987 No-Migration Petition to the new EPA disclosed project weaknesses. Since then, DOE has maintained a mission-oriented relationship with its consultant, Sandia National Laboratories. Consequently, serious faults in the investigations have been perpetuated from the early 1980's through the 1996-1998 certification



uncemented muddy sandstones and siltstones. Overlying the Dewey Lake is the Santa Rosa formation, 0 to 217 ft. of coarse sands and conglomerates interbedded with shales, mainly beneath the eastern half of the LWA. Windblown sand masks most of the semi-arid surface of the Mescalero Plain, which slopes gently west to Livingston Ridge, the edge of Nash Draw (Figures 1 and 5). It is Doe's position that any contaminated brines that escape the repository will be conveyed upwards via exploration boreholes through the Salado but not to the surface. Rather, contaminants are predicted to move laterally via the thin Culebra dolomite aquifer in the Rustler (Figure 3). On the site, an ill-defined water table is in the Dewey Lake redbeds, sloping westerly. But in the Culebra, the piezometric surface slopes westerly, southwesterly or southerly, depending upon place and time of observation. Because bedding dips northeasterly, nearly in the opposite direction, the water table offsite to the west of the LWA is in the Rustler, leading to outcrop areas in Nash Draw, 1.1 to 4 miles beyond (Figure 1), or to Malaga Bend on the Pecos River, 13 to 15 miles southwest of the LWA. Nash Draw is a subsidence trough formed by dissolution of the underlying Salado salt, which caused fracturing, brecciation and subsidence of the overlying Rustler (Kelly, 2000). Uncertain regional boundary conditions and a great range of transmissibilities across the site leave doubts about the paths and destinations of contaminants that may escape the repository, thus uncertainties of the time to reach outlets or the nearer accessible environment, nominally the subsurface limits of the LWA.

Performance Assessment

Repository performance is judged according the radioactivity accumulated over 10,000 years outside the accessible environment boundary. Limits in Curies based on health effects at a surface body of water are prescribed by the EPA in 40 CFR 191.13 for all radionuclides in the expected inventory of materials disposed. Performance Assessment (PA) is a modeling exercise of prodigious complexity (Helton, et. al., 2000), designed to take into consideration all physical properties of the wastes, the repository and its geologic environs, including effects of climate and man- made perturbations. It is a collection of models, each of which embodies a time-dependent mathematical representation, a method of numerical evaluation and a computer code. There is a model to represent the two-phase inflow and outflow of brine and gas between a sealed repository and anhydrite beds in the salt a few feet above and below the repository horizon. There is a model to calculate the hydrogen that will evolve from the reaction of brine with disintegrating steel drums and cellulose in the waste. There is a model to calculate the changing radionuclide inventory as it decays, dissolves in the brine and is absorbed by engineered backfill materials. There is a model to describe the groundwater flow in the Culebra dolomite aquifer (assumed to be the sole conduit) above the repository, and a model to calculate transport of each radionuclide species through time and distance along Culebra pathways. PA incorporates several different scenarios, such as no human disturbance during the 10,000 years, or mining of potash in the overlying McNutt Member of the Salado, or oil-well interceptions of the repository and/or pressurized brine reservoirs in the underlying Castile Formation, plus implications of borehole drilling, plugging and blowout prevention. Because a single PA requires many man- years of effort and millions of dollars worth of Cray CPU time, few have been done. Scores of physical properties are factors in the computations, many of which are ill-defined, so are best described as distributions. The methods of Monte-Carlo sampling are used, several hundred iterations providing a range of answers, each a distribution function of the cumulative releases over the 10,000 years. The proportion of iterations that satisfy the EPA criteria measures the probability of acceptable results. Any scientist has to admire the elegance of the computation procedure even if his expertise covers only a part, while the manager or politician reveres that which is understandably baffling. But scrutiny reveals that underlying the mathematical elegance and the comprehensive array of data manipulated are numerous assumptions, many of which have over-riding significance to the results. Some of the hydrogeological assumptions violate the perceptions of qualified critics, such as Anderson, 1978, Ferrall and Gibbons, 1980, Barrows, 1982, Snyder, 1985, Phillips, R. H., 1987, Snow, 1998 and Hill, 1999, and arguably differ from actual conditions. Management has exerted its will to succeed in the licensing process, influencing the scientific staff to adopt models and select studies favorable to Doe's objectives, biasing the results of PA. A critic must use Doe's own data and draw inferences from his own observations to show where investigations have gone astray. There are areas of geology, rock mechanics and hydrology that deserve re-assessment in that light.

Contaminated Brine Discharge from the Repository

The starting point for all PA model realizations is the calculation of brine inflows aft.er the repository is filled and sealed. As noted by Brinster (1989, p. II-19), the Salado is not homogeneous salt, but rather, " . . . consists of salt rhythmically interbedded with anhydrite, polyhalite, some glauberite, and some thin mudstones." The salt was formerly believed to be so impermeable that the rooms would remain dry, but the appearance of small brine seeps soon aft.er opening the first research rooms showed that DOE must contend with a wet waste environment.

Excepting direct recovery of solid waste carried to the surface along with cuttings from inadvertent oil wells, all other scenarios entail radionuclide transport via flowing groundwater. The project might have been aborted if DOE had been more respectful of the historic problems of water in salt and potash mining. At WIPP, brine that accumulates will eventually saturate downdip openings, corrode containers and packaging and dissolve radionuclides. Generated gas will collect updip. The computed brine inflows depend on the measured permeabilities of fractured anhydrite beds above and below the repository horizon, but only the 3.0-ft. thick Marker Bed #139, 9.5-ft. below the repository floor, Marker Beds A and B, totaling 0.7 ft. thick and lying 4.3 ft. above the roof and the 0.6-ft. Marker Bed #138, 39.2 ft. above the roof have been modeled as inflow contributors. That limitation was due to the assumed extent of the DRZ, the disturbed rock zone (fractured salt) expected to form around the rooms as they close. The consequences of gas generation, cavity pressurization and two-phase outflows of brine and gas through those four anhydrite beds indicated (by PA) that the undisturbed scenario poses no hazard of a significant breach or accumulation beyond the accessible environment.

The fallacy of that conclusion stems from a misconception of the behavior of the Salado overburden. The 13-ft. high by 33-ft. wide rooms will be short-lived. Large open fractures appear in the ceilings of all rooms within months of mining. Several roof-falls and floor heaves have already occurred, so an extensive array of roof bolts has been installed to delay the failure of the remaining experimental rooms long enough to fill them with drums. These, and all future rooms will suffer collapse of major roof slabs bounded above by weak clay-bed partings. Such falls will crush the drums, and liberated waste will penetrate the fractures. DOE has assumed roof fractures extending upwards only to Marker Bed #138, but as creep subsidence incorporates whole panels and then the repository width, horizontal slip and openings will occur on successive higher clay seams, most bounding stiff anhydrites. Horizontal slickensides observed in Rustler clays at the Exhaust Shaft. (Holt and Powers, 1986) manifest the shear failure to be expected in Salado clay seams, a consequence of local subsidence. Inclined fractures laterally limiting roof slabs will interconnect the rooms and panels via the slip surfaces and fractured anhydrite beds situated farther above the repository, each of which will contribute to increasing inflows of brine. Experience at potash mines in similar salt sequences (notably at K-2 Mine in Saskatchewan) indicate that such roof behavior is typical. At the Canadian mines, the fractures sometimes breach the top of salt into an aquifer, causing inflows that flood the mine (Tofani, R., 1983, Van Sambeek, 1993). Aft.er shaft. leakage, such roof breaching is the next most common cause of flooding of salt and potash mines, all of which ultimately flood because they lie below the water table and have inhomogeneous, deforming roof-rocks. Such subsidence experience invalidates the assumed limited height of the disturbed rock zone around WIPP rooms and the continuous plastic creep and room closure envisioned by the designers. Fundamental to subsidence prediction at WIPP is that ultimately, inclined fractures, as shown by MacIntosh (1990) will bound a de-stressed region extending over entire panels of rooms. Because each anhydrite bed (numbering about 40 above the repository) has a thin, weak clay parting at each of its faces, the bedded, subsiding roof will be split into many independent beams, like a glu-lam beam that has come unglued. The deflections and accompanying inclined fractures will drain not just Marker Beds #138 and #139, plus A and B, but many more anhydrite beds above them, increasing the inflow rates accordingly. Some fractures extending up from the repository will not anneal, but because of movement and flow, will remain open for gas and brine leakage during the years of pressurization by closure and gas generation.

Far-field pore pressures approaching lithostatic in salt not only drive the brine inflows along the anhydrites and clays, but also ensure that little subsequent outflow follows the bedding during pressurization. In PA, the Salado above anhydrite marker #138 up to the Rustler is assumed to be salt with very low permeability distributed uniformly around a median of 6.1×10^{-20} ft..^{2}. Utilizing Darcy's Law (Helton, 1991, p. 83 and Table 4), flow upward across the 1300 ft. of salt (about 85%) and fractured anhydrite beds (about 15%) up to the Culebra dolomite aquifer was computed as though the interval is a continuous porous medium. What is significantly wrong with the model is that it assumes no fracture conduits reaching high above the panels. Rather, as pressures in the sealed repository rise, gasses will cause the subsidence fractures to propagate unstably to higher levels where smaller rock stresses prevail, facilitating subsequent brine leakage to the Culebra and other aquifers much sooner and at higher rates than the PA model predicts. Because of the non-conservative assumption that the Salado is structureless, and consequently because the rock mechanics model is unrealistic of long-term subsidence, the conclusion from PA calculations that the undisturbed scenario is innocuous has to be wrong. Histories and subsidence behavior of the analogous Salado interval above the McNutt horizon at nearby potash mines of Eddy County, NM could have been studied, reported and modeled, to derive more realistic WIPP- site subsidence predictions. Sandia rock mechanics wanted to do that at the Horizon (Amax) Mine (Crosser, 1998), but funding was denied them. It is common geotechnical experience that in a significant proportion of dams, tunnels, aqueducts or deep mines, if there are potential but unknown geologic defects or mechanical inhomogeneities, failure will occur by reason of unexpected hydrologic effects. Therefore, in sensitive and doubtful situations, especially conservative assumptions are appropriate. Instead, WIPP modeling employed idealistic assumptions of continuous media, when discontinuous (fracture) properties would have been appropriate. The conservative expectation is that subsidence fractures at WIPP will propagate first by gravity, then

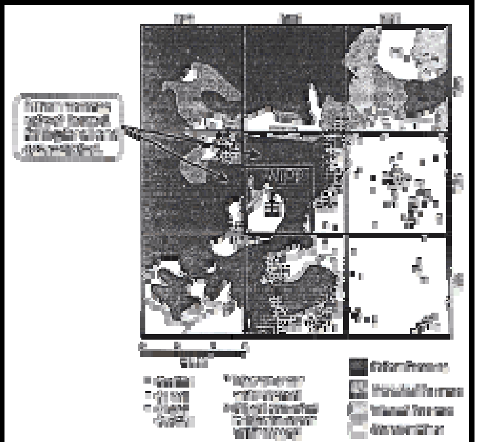


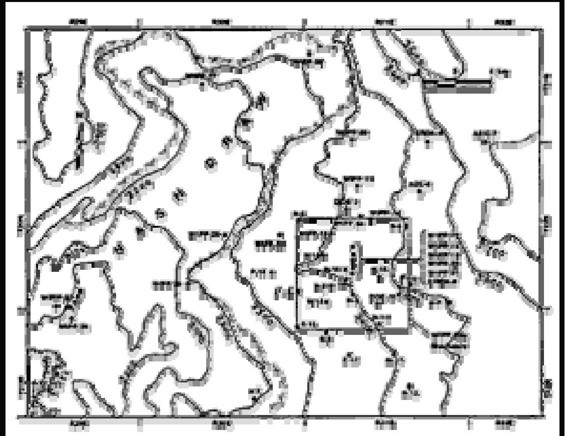
Figure 4. Lease grade potash ore and oil and gas wells

unstably upwards to the Rustler due to the gas pressure generated in the repository, followed by contaminated brines aft.er the gas has dissipated and rooms become saturated. Sealed shaft.s and boreholes nearby will probably retain their integrity unchallenged, because fractures will provide easier egress for fluids.

There is currently a concentrated leakage occurring into the Construction and Salt Handling Shaft. from the top of Dewey Lake redbeds at 20 to 70 ft. in depth, thence into the repository, believed to arise from runoff at the parking lot. In European potash mining experience, such incipient karstic shaft. leakage has been found to be irreparable. The first drop of water signals the eventual flooding of the mine.

Because human intrusion is a potential cause of repository breaching during any 10,000-year regulatory period, one of the tenets of radwaste disposal is that a candidate environment should be free of valuable natural resources that could stimulate future explorations. Since the LWA is underlain by exploitable potash beds in the McNutt interval (Figures 2 and 4) and is surrounded by oil and gas wells, the scenarios of one or more inadvertent interceptions of the waste rooms by future drill holes are very credible. PA calculations suggest that the raising of contaminated cuttings to the surface poses the greatest (though minimal) threat to posterity. Direct flows of contaminated brine along boreholes open to the surface has been minimized in PA by assumptions of borehole plugging by future operators. Utilizing EPA modeling guidance that borehole permeability should be " . . . typical of a borehole filled by the soil or gravel that would normally settle into an open hole over time," about 3.23×10^{-11} $ft.^2$, the maximum calculated rate of flow to the Culebra was estimated to be about 2800 $ft.^3$/yr. (Helton, 1991, p. 24), a magnitude unrealistic of the rates that could be driven along an open borehole that intercepts a saturated repository at near-lithostatic pressures, or along fractures initiated by subsidence or oil-field water-flooding (Bredehoeft., 1997). Small values are appropriate to sealed boreholes (plugged with concrete or mud) that become leached and porous as cement deteriorates over years, but axial seepage may maintain a conduit outside the seals. Thus, flow rates to the surface and the Culebra have been unconservatively discounted for human-intrusion scenarios, as well as for hydrofracture and subsidence-induced fracture conditions.

Regional Flow in the Rustler Formation



Transport modeling entails many parameters, known or approximated. In order to model the paths and rates of transport of radionuclides in groundwater, there must be defined all necessary groundwater fluxes, boundary conditions, material properties and chemical processes. In this instance, a boundary following divides encompasses about 2300 square miles to form the lateral limits, while the top and bottom of the Culebra dolomite, 23 ft. thick, form the vertical limits. Fixed hydraulic heads are assigned at the lateral boundaries, commensurate with measured or deduced heads, and the model limits are defined as either no-flow (impermeable) or discharging (permeable) boundaries. If arranged conservatively, those boundaries are so distant from the LWA that errors in selecting heads and flow properties there should have little effect at the LWA perimeter, the compliance boundary. Heads within the model, determining gradients everywhere, have been adjusted according to measured heads at wells penetrating the Culebra dolomite. If the PA model was grossly correct, that only regional flow based on current heads in the Culebra mattered, the effort might justify minimal transport via the groundwater pathways. DOE relies upon low matrix-dominated permeability of the Culebra (modeled as a single fracture) in its claim that the Rustler is thus a barrier to significant flows to the accessible environment.

The facts reveal the Rustler to be a much more complex aquifer, in terms of properties and boundaries. As Figure 5 shows, the topography slopes gently from a divide 7 miles NE of WIPP westerly towards Nash Draw, which wraps around the NW, W and SW sides of the LWA. Nash Draw is 20 miles long, bounded on the east by a ragged scarp called Livingston Ridge. Dissolution of the Salado salt at the base of the Rustler has produced a brine aquifer beneath Nash Draw in the thick zone of insoluble rubble formed by subsidence and brecciation of the overlying units (Kelly, 2000). But the Rustler mainly discharges at higher levels and to the surface in the vicinity of the salt pan, Laguna Grande, where it evaporates, at least in today's climatic setting (Phillips, 1987). The lake bottom is a deposit of at least 55 ft. of fine gypsum, attesting to a long-term anhydrite source, distinct from the sodium chloride of Salado origin discharging to the Pecos River via the brine aquifer (Phillips, 1987). Phillips documented the ephemeral nature of discharge from a lake north of Laguna Grande called Laguna Pequena (W/NW Sec. 3, T23S, R29E), recording a flow of over 100,000 gallons per minute into Laguna Grande on September 5, 1984 aft.er a record rainfall event stimulated spring flow. There was no surface inflow to Laguna Pequena, and the outflow diminished rapidly aft.er the measurement (Phillips, 2001). Phillips (1987, pp. 244-248) makes a convincing geochemical argument for a Rustler source of most water discharging to Laguna Pequena and Laguna Grande, which must be the long-term destination for any WIPP-site groundwaters.

The current southerly gradient beneath the LWA, and a fairway of high Culebra transmissibility southwards through DOE-1, directs modeled Culebra flow paths from the repository southward into regions of low transmissibilty and to a distant discharge area on the Pecos River (Malaga Bend). But had they incorporated the low heads at WIPP-29 (2968 ft.) and Laguna Grande (2950 ft.), modeled paths would have turned west to Nash Draw (Phillips and Snow, 1998, p. A-8). Gradients in the Rustler are centripetal to

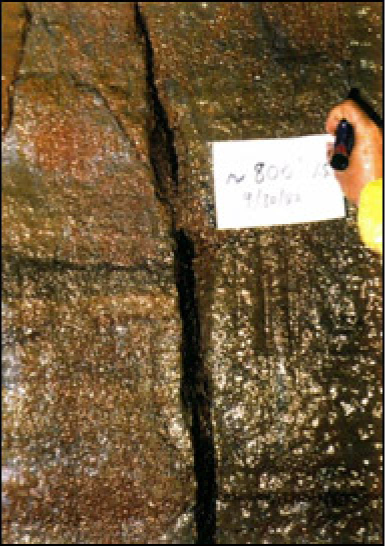


Figure 8: Solution-enhanced fracture

Laguna Grande (Kelly, 2000), consistent with the regional evidence that the Rustler drains westerly to Nash Draw. Computed travel times through the Culebra would have been much shorter if model heads had been realistically represented.

Another significant and erroneous assumption used in PA is that the Culebra dolomite is the only aquifer of concern for radionuclide transport from the repository to the limits of the LWA. Drill holes through the Rustler encountered mainly anhydrite, a dense, hard, impermeable rock in its intact form, thus the Magenta and Culebra dolomites were considered the only persistent aquifers that could be tested and characterized (See Figure 3). During shaft-sinking, Chaturvedi and Channel, (1985, Plate 1) found that there is a steep fracture with a dissolution-enlarged opening across the brittle Unnamed Lower Member anhydrite (below the Culebra), so the dolomites cannot be confined. Figure 8, illustrating that fracture, suggests not only open-conduit flow across the Culebra, but also that karst channeling must have occurred at the top of the Salado salt directly above the repository. At various levels in the 250-550 ft. thick saturated Rustler and Dewey Lake interval there may be infrequent, large-capacity fracture-dissolution conduits not usually intercepted or characterized by the vertical drillholes completed for testing the Culebra. Thus, the simplistic, two-dimensional PA model of continuous confined flow in the Culebra dolomite (23 ft. thick) fails to characterize the entire Rustler, which can capture repository discharges via boreholes or fractures, and channel more rapid open-conduit karstic flow. A tiny fraction of the formation's volume, as cave passages, may occasionally convey the preponderant fraction of the discharge, at great rates unrepresented by Doe's modeling of an intact, thin, matrix-dominated Culebra dolomite (Hill, 1999).

The Culebra dolomite has been modeled as a continuous porous medium cut by a single horizontal fracture, an erroneous conception argued to be conservative. First of all, the horizontal fractures are bedding plane breaks on shaley partings without significant hydrologic importance because they are tightly closed until unloaded or sampled by coring. As may be seen at Culebra Bluffs, there are numerous vertical and inclined fractures (Swift., 1992). Many are enlarged by dissolution near the surface, and these are probably good conductors, but DOE has never tested their individual properties in the buried Culebra. They form two orthogonal sets trending NE and NW (a tectonic pattern pervasive throughout the Delaware Basin). Cores reveal their antiquity by mineral infillings of gypsum that render the fractures locally impermeable, indeed, partitioning the matrix into isolated permeable blocks, the probable character of the Culebra east of the LWA (as at P-18). Inclined fractures are also present at Culebra Bluffs and probably wherever differential subsidence has occurred over regions of salt removal. In the subsurface, inclined fractures are also gypsum filled, but to a variable degree due to dissolution. Westward across the site, the proportion of fractures lacking gypsum infillings seen in drill cores increases (Ferrall and Gibbons, 1980), and gypsum infillings are absent at Culebra Bluffs. Neill, et. al, (1998, p.11) suggest that fracture openings formed due to dissolution of Rustler salt and consequent deformations. It may be that within the LWA, Culebra flow is not controlled by either matrix permeability nor by fracture permeability, but by elongate dissolution channels formed, perhaps at the intersections of fractures and the Culebra contacts. If DOE had fully characterized

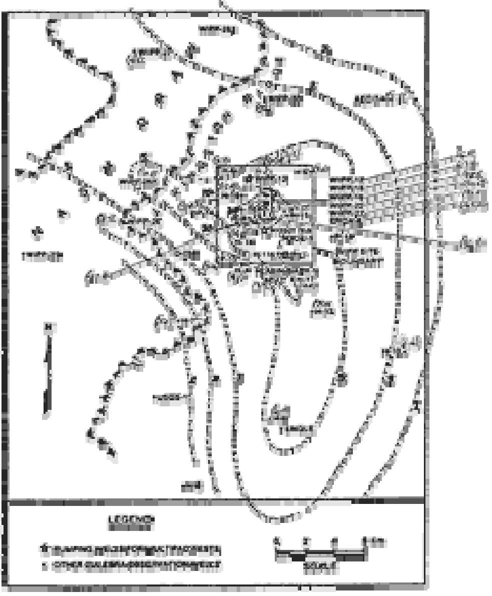


Figure 6: Recovery of Water levels in Culebra Dolomite Wells, March, 1983 - August, 1984

Culebra fracture flow properties by slant-hole coring, dissolution conduits would also have been found and described, and by necessity, modeled.

Tests have revealed such a great range of transmissibilities (T = hydraulic conductivity times aquifer thickness) near wells completed in the Culebra that the degree of channeling must be the main variable across the site. East of the LWA, measures are on the order of 10^{-3} ft.^{2}/day. It is on the order of 0.1 ft.^{2} /day on site, on the order of 10^2 ft.^{2}/day west of the LWA, and 10^3 ft.^{2}/day in Nash Draw. Thus T increases westward by five to six orders of magnitude (Phillips and Snow, 1998, p A-3). Many individual tests give different transmissibilities, depending upon the observation well used to interpret drawdowns. Of 42 wells tested, high measures were reported at wells WIPP-13, H-6, P-14, H-11, DOE-1 and DOE-2 (Figure 5). Local and directional variability is typical of karst regions with widely distributed solution channels, reflecting chance proximity of each test well to the conduits. The observed irregular increase of T from east to west reflects a systematic increase in the dissolution of fracture fillings, coalescence of smaller channels into larger conduits and the development of cross-connecting fractures and channels to other Rustler strata (Hill, 1999, Neill, et. al., 1998). Since pumping tests in the Culebra produce greatly different responses at adjacent observation wells, reflecting Rustler anisotropy and heterogeneity, the conservative approach to modeling would be to utilize at a site the greatest interpreted transmissibility, or at least the geometric mean of directional values. Instead, DOE has arbitrarily assumed transmissibility values at well sites within 1.5 miles of the center of the repository that are one to two orders of magnitude smaller than the highest values revealed by the hydrologic tests (Phillips and Snow, 1998, p. A-3). The consequence is that computed travel times across that first 1.5 miles from the source are exaggerated by similar magnitudes.

Consistent with Doe's assumptions that Culebra flow is confined and that transmissibility is due solely to matrix or hypothetical horizontal fracture properties, PA modeling was conducted with a continuous T-field interpolated from 39 selected observations. The mathematical method assumes that T is a continuously varying point-function, an invalid procedure in the presence of occasional large, discrete solution conduits of unmeasured, thus uncertain conductivity, randomly placed with preferred orientations due to fracture controls and former hydraulic gradients. At WIPP-33, a site 0.54 miles west of the LWA, a hole drilled in the center of a sinkhole intercepted a cavern in the Dewey Lake and four caverns in the Rustler as deep as the Magenta dolomite. DOE neglected to test that well hydrologically nor subsequently to monitor it. Though only that test hole and one shaft. exposure (Figure 8) indicate the actual geometry of parts of the karst conduit system, that deficiency stems from an apparent unwillingness to explore for such features. Prudence should have demanded a conservative interpretation of the potential consequences of karst, at least until the necessary investigations were done.

Flows were computed according to the present-day fresh-water head (depending upon pressure, density and level) distribution in the Culebra, whose gradient is generally southerly over the LWA, tending to direct discharge towards Malaga Bend. The gradient in the overlying Magenta dolomite is westerly, as may also have been the gradient in the Culebra before pumping and drainage to the shaft.s altered it in the 1970's and 1980's. Culebra heads have been systematically rising for years, particularly since the sinking of the Air Intake Shaft. and the stanching of copious inflows to the repository that occurred. As the synoptic data in Figure 6 indicates (Snow, 1998), the heads at all well-recorded observation wells completed in the Culebra continued to rise during more than five subsequent years. It is possible that a primitive westerly gradient may ultimately be restored long aft.er repository closure, directing the gradient for all Rustler flows towards Nash Draw. The gradual rise indicates that on that scale and in that five year time span, the Culebra itself behaves as a continuous aquifer of modest transmissibility, at least at the points of observation where wells are completed. If large conduits are present at other levels or places, there could be transient head fluctuations that occur mainly in such a system of solution caverns, not recorded on hydrographs of the wells because none penetrate the karst conduits, nor were they instrumented for brief excursions.

Mercer (1983), Chaturvedi and Channel (1985, p. 40) and Brinster (1989, p. IV-75) discussed the fact that the Magenta has freshwater heads as great as 155 ft. higher than that of the Culebra within most of the LWA (except at WIPP-13), but that the two dolomites have coincident heads from the west boundary of the LWA to Nash Draw. Such a head difference at locations within the LWA may be wholly post-disturbance, reflecting short-term Culebra confinement and perhaps the sealing of old karst features between the two strata.