POTENTIAL FLOW PATHS FROM THE WIPP SITE TO THE ACCESSIBLE ENVIRONMENT

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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 the 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 the 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 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 the 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 the 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 the units overlying the Culebra has been neglected, there is no detailed knowledge of the shallow water table or 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 potentiometric 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 said to be “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 x 10^{7} ft^{2} in natural extent), and net evaporation rates are so high (4.38 ft/yr), that the Rustler flow discharging to Laguna Grande and evaporated by the lake must be an order of magnitude greater (4.40 x 10^{8} ft^{3}/yr) than the incremental flow discharging to the Malaga Bend reach of the Pecos River (6.56 x 10^{7} ft^{3}/yr) (Phillips, 1987, pp. 219-222, 232-235, revised). Further, the Malaga Bend brine springs have geochemistry more consistent with the “brine aquifer” at the top of the Salado, while Laguna Pequeña, which flows into Laguna Grande, has geochemistry more consistent with the gypsum and dolomite aquifers of the Rustler (Phillips, 1987, pp. 242-248). Laguna Pequeña 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 to Laguna Grande 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	distance (mi)	conductivity (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	1230000	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 flowpath 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 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. (183), 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 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, 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.

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

well	TDS	NaCl	$CaSO_4$
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.

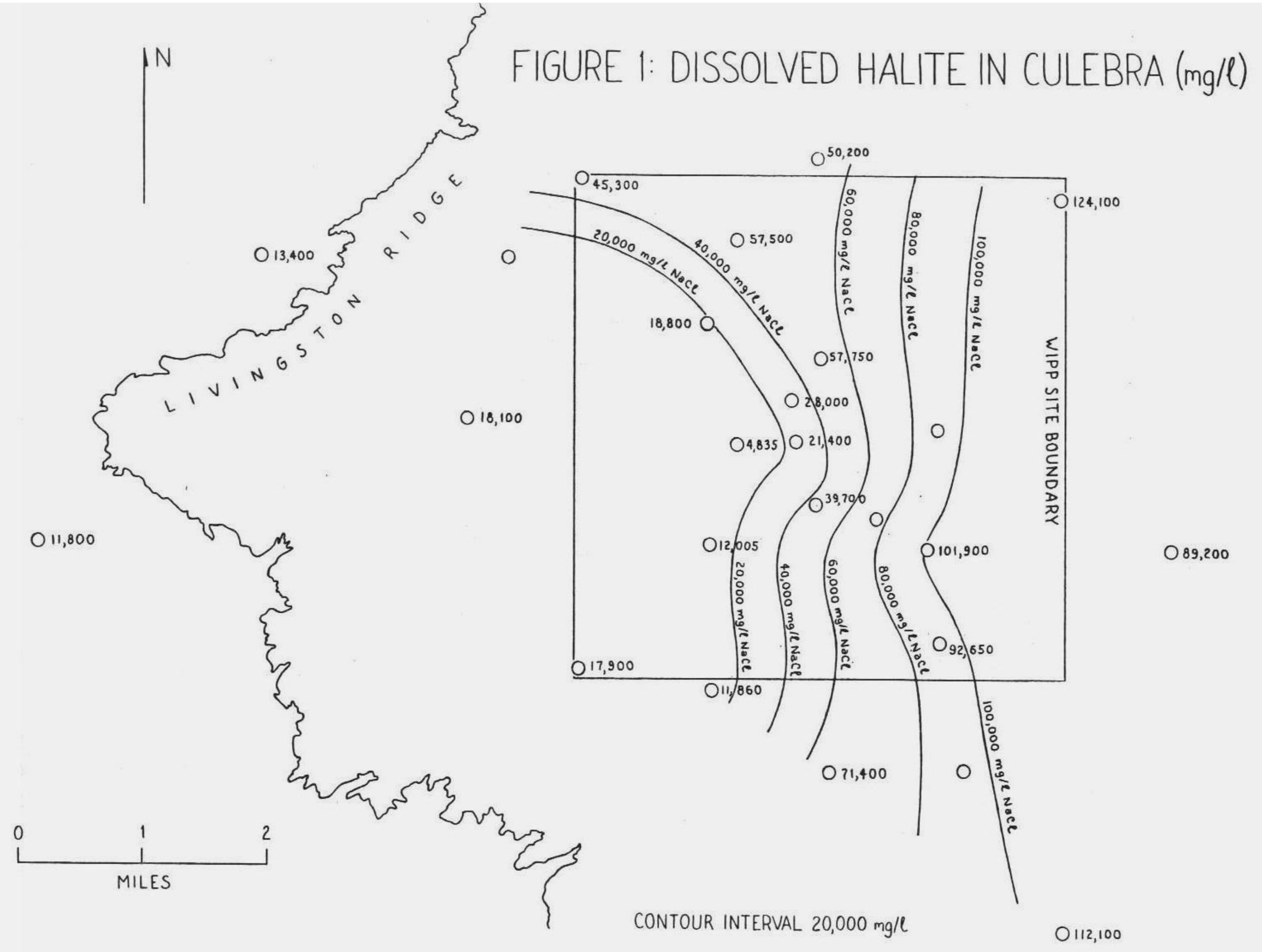

FIGURE 1: DISSOLVED HALITE IN CULEBRA (mg/l)

FIGURE 2: TOP OF SALT IN RUSTLER

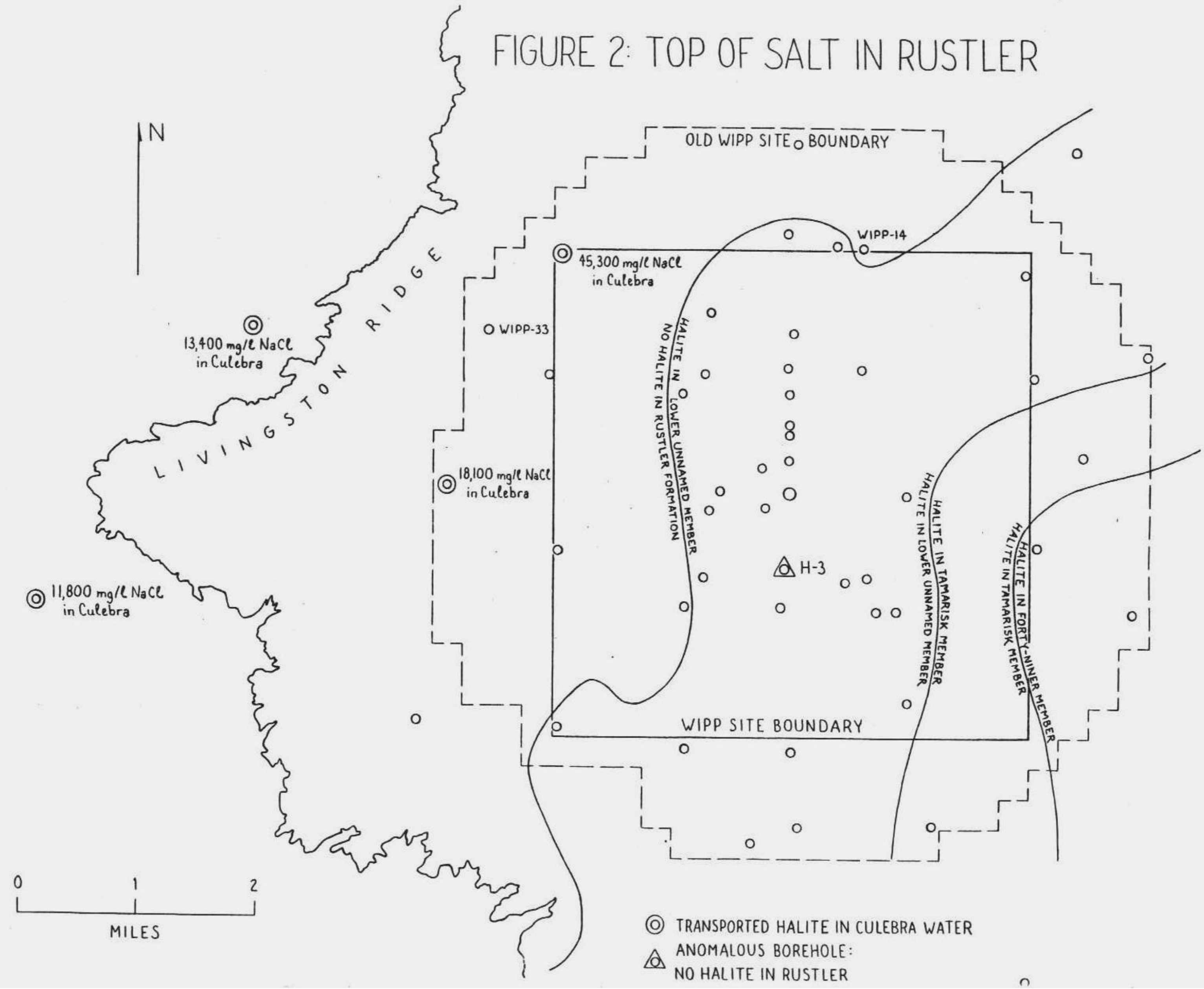

TABLE 2: COMPARISON OF FRESH WATER HYDRAULIC HEADS, MEASURED IN FEET ABOVE SEA LEVEL

well	Salado	Culebra	Magenta	Forty-Niner
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		3011		
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 set is difficult to assemble from the various sources of data presented in the Application.

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, 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 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	conductivity (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 the 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 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 feet thick (24.3 feet of dolomite, 21.7 feet 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 feet), 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 feet) and Magenta (3116 feet) 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, 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 feet) to H-6 (3057 feet) to WIPP-25 (3054 feet). 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	conductivity (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 Medaños (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 by 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-permeablity 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 top of the Salado is able to rise through the lower unnamed member and 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 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.

ADDENDUM

From Rebuttal to DOE Response to CARD Comments, pp. 2-4

Our original report was based on the multiwell pump tests centered in the Culebra at test wells H-3 and DOE-2. In the multiwell pump test centered in the Culebra at test well WIPP-13, response times were even more rapid. DOE-2, which is 0.92 miles from WIPP-13, "responded within one hour to the beginning of pumping," and H-6, which is 1.35 miles from WIPP-13, "responded within 8 hours." (CCA, Appendix SUM, p. 110). The delay in maximum drawdown at H-6, relative to the time at which the pump at WIPP-13 was turned off, was only 5 hours (CCA, Appendix SUM, Table 4.7). The apparent transmissivity between WIPP-13 and DOE-2 is 57 ft^2/day; between WIPP-13 and H-6 it is 69 ft^2/day (CCA, Appendix SUM, p. 114).

The WIPP-13 pump test also showed efficient hydraulic connections to test wells P-14 and WIPP-25. Figure 2 of "Cavernous Zones at the WIPP Site" has been revised accordingly, depicting P-14 and WIPP-25 as bull's eyes. At P-14, which is 2.63 miles from WIPP-13, the first drawdown was in 71 hours, and the delay in maximum drawdown was 56 hours (CCA, Appendix SUM, Table 4.7). The apparent transmissivity between WIPP-13 and P-14 is 260 ft^2/day (CCA, Appendix SUM, p. 114). The transmissivity at P-14 had been previously measured (in single-well tests) at 324 ft^2/day (LaVenue et al., 1988, SAND 88-7002, Table C.1). At WIPP-25, which is located in Nash Draw, 3.87 miles from WIPP-13, the first drawdown was in 76 hours, and the delay in maximum drawdown was only 26 hours (CCA, Appendix SUM, Table 4.7). The apparent transmissivity between WIPP-13 and WIPP-25 is extremely high, 650 ft^2/day (CCA, Appendix SUM, p. 114).

WIPP-13 is located within the WIPP site, 0.51 miles inside the northern boundary, and 1.33 miles inside the western boundary. WIPP-25 is located about one-half mile west of Livingston Ridge, in Nash Draw, which DOE admits is a "karstic feature." (EPA Docket, A-93-02, Item # II-H-46, p. 27) The Culebra and Magenta hydraulic heads are known to be equal at WIPP-25, where Magenta transmissivity had been measured (in single-well tests) at 375 ft^2/day, and Culebra transmissivity at 650 ft^2/day. As this is equal to the transmissivity for the entire distance between WIPP-13 and WIPP-25, the flow path between the two wells must be karstic.

Located almost exactly midway between WIPP-13 and WIPP-25 is borehole WIPP-33 (1.87 miles west of WIPP-13, and 2.02 miles east of WIPP-25). At WIPP-33 five water-filled caverns were found – two in Magenta dolomite, two in Forty-Niner gypsum, and one in Dewey Lake siltstone. WIPP-33 is the westernmost of a chain of four sinkholes, all of which DOE now concedes to be karst features (EPA Docket, A-93-02, Item # II-H-46, p. 31); they are almost perfectly aligned with WIPP-13, where open fractures were found in the Magenta. The response time between WIPP-13 and WIPP-25 was extraordinarily rapid – a delay in maximum drawdown of only 26 hours between test wells nearly four miles apart. There was also a measurable response at the WIPP exhaust shaft, 1.50 miles southeast of WIPP-13 (CCA, Appendix SUM, Table 4.7), which suggests an existent karstic flow path from the WIPP repository all the way to Nash Draw.

DOE admits to the existence of karst at the WIPP site in the CCA, Appendix DEF (p. DEF-30): "Only a few small clusters of shallow dolines on the Mescalero caliche have been identified on the Los Medaños plateau east of Livingston Ridge." DOE refers the reader to Figure DEF-7, where the karst features are depicted with three black dots: at WIPP-33, WIPP-13, and WIPP-14.