

EEG-31



CHEMISTRY OF RUSTLER FLUIDS

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Environmental Improvement Division
Health and Environment Department
State of New Mexico**

July 1985

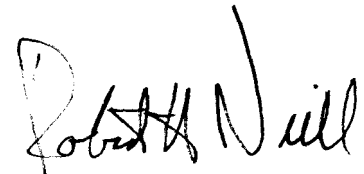
FOREWORD

The purpose of the Environmental Evaluation Group (EEG) is to conduct an independent technical evaluation of the potential radiation exposure to people from the proposed Federal radioactive Waste Isolation Pilot Plant (WIPP) near Carlsbad, in order to protect the public health and safety and ensure that there is minimal environmental degradation. The EEG is part of the Environmental Improvement Division, a component of the New Mexico Health and Environment Department -- the agency charged with the primary responsibility for protecting the health of the citizens of New Mexico.

The Group is neither a proponent nor an opponent of WIPP.

Analyses are conducted of available data concerning the proposed site, the design of the repository, its planned operation, and its long-term stability. These analyses include assessments of reports issued by the U. S. Department of Energy (DOE) and its contractors, other Federal agencies and organizations, as they relate to the potential health, safety and environmental impacts from WIPP.

The project is funded entirely by the U. S. Department of Energy through Contract DE-AC04-79AL10752 with the New Mexico Health and Environment Department.



Robert H. Neill
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EXECUTIVE SUMMARY

Water chemistry determinations were performed by the U. S. Geological Survey on water samples collected from the three fluid-bearing zones of the Rustler Formation from 20 testholes at and adjacent to the WIPP from 1976 to 1980. Analysis of the data demonstrates that the three fluid-bearing zones are chemically separate from one another at the WIPP site, but progressively merge towards the west into Nash Draw.

The fluids present at the Rustler-Salado contact approach saturation with respect to sodium chloride. Magnesium replaces sodium as the prevalent cation east of the WIPP site; this boundary may represent the approximate limit of salt dissolution in the Rustler Formation.

Three zones (areally) of differing predominant chemical constituents are present in the Culebra Dolomite. Groundwater flow paths cross these zones, changing the Culebra water from a sodium chloride brine to a moderately saline calcium sulfate water. The Culebra waters are undersaturated with respect to halite and have the capacity of dissolving more halite from the Rustler or the Salado formations.

The major ions present in the fluids in the Magenta Dolomite are predominantly sodium and chloride. A few wells have sulfate, rather than chloride as the predominant anion.

Additional work is needed to improve the degree of understanding of the chemical characteristics of the fluids in the Rustler Formation especially with regard to the Culebra Dolomite. More information is needed to understand the chemical changes that occur along proposed groundwater flow paths of the Culebra. It is important that the current groundwater chemistry sampling program obtain representative and replicable groundwater quality data.

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1. INTRODUCTION

The Waste Isolation Pilot Plant (WIPP) is a U. S. Department of Energy (DOE) facility for demonstrating the disposal of defense transuranic radioactive waste. The WIPP is located approximately 26 miles east of Carlsbad, New Mexico (Figure 1) and lies in the northern part of the Delaware Basin, an oval-shaped sedimentary trough nearly surrounded by the Capitan reef. The major formations of interest in the Delaware Basin, at the WIPP site are, in stratigraphically ascending order, the Bell Canyon, Castile, Salado, and Rustler Formations and the Dewey Lake Redbeds (Figure 2).

The Rustler Formation has been identified as a possible pathway for radionuclide migration and transport to the biosphere in the event of a breach of the WIPP repository (Weart 1983).

Therefore, hydrologic studies have been ongoing since 1976 in an attempt to characterize the major patterns and processes of water movement in the Rustler Formation. Physical and chemical data have been collected and evaluated to determine the stratigraphy, hydraulic potential, and water quality of the Rustler water-bearing units.

The three main water-bearing units contained in the Rustler

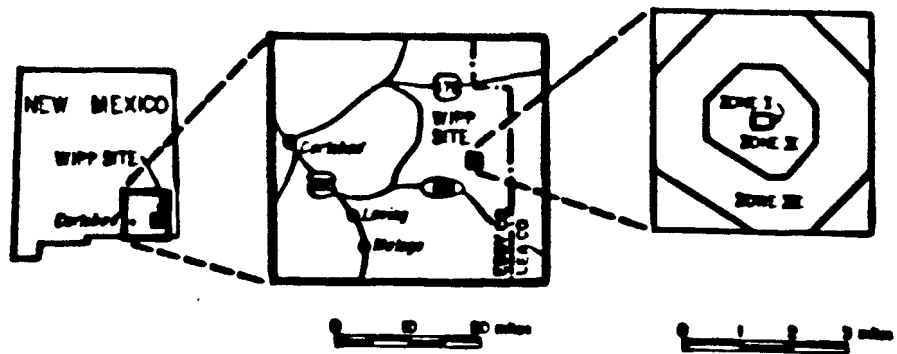
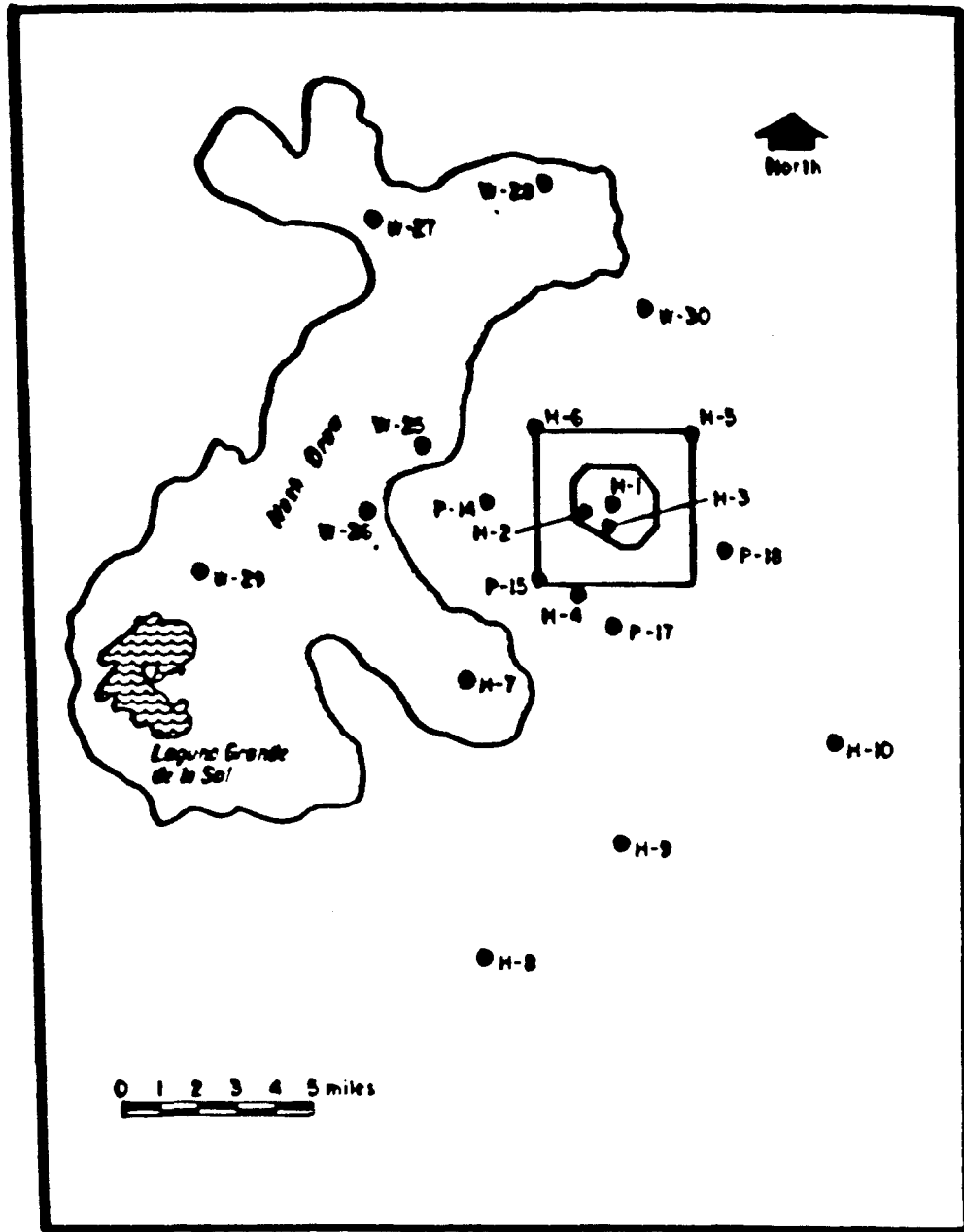


Figure 1. Location of WIPP site.

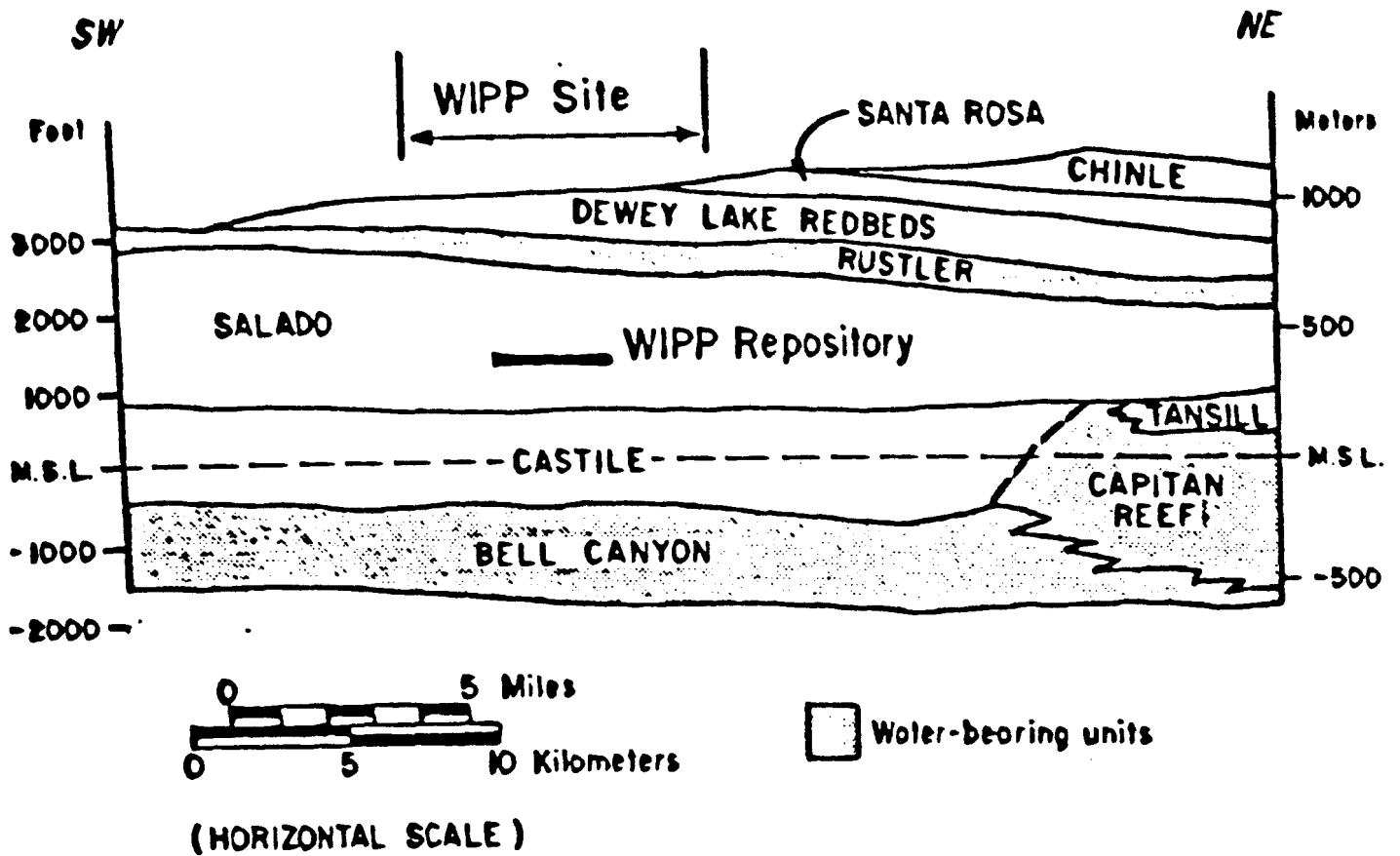


Figure 2. Geologic cross-section at the WIPP site.

Formation include in ascending order; Rustler-Salado contact, Culebra Dolomite, and Magenta Dolomite. The Culebra and Magenta Dolomites have been identified as the most significant units in hydrologic terms (Weart 1983), and consequently have been studied the most.

A comprehensive tabulation and analysis of water quality data at and near the WIPP has not been completed. The purpose of this report is to consolidate existing Rustler Formation water quality data, describe general water quality data trends, and evaluate the water quality testing program.

2. SOURCES OF DATA

The data contained herein are a compilation of chemical information collected by the U. S. Geological Survey. Water chemistry analyses were performed on water samples collected from 20 sites at and adjacent to the WIPP site from 1976 to 1980. Selected results of these chemical analyses are reported by Mercer and Orr, 1979; Mercer 1983; and Gonzalez 1983.

The availability of fluids, or in some cases the lack of fluids, for production from testholes necessitated variations in the methods of water sample collection. Depending on production capabilities, each testhole was bailed, swabbed or pumped for a period of time prior to water quality sampling. The guideline

used to determine whether representative formational fluid had been drawn into the hole was the stabilization of fluid temperature, conductivity, and density. Problems were encountered with the sampling techniques even though criteria had been formulated prior to sampling to ensure the collection of formational fluids. Bailing caused aeration of the borehole water which resulted in mineral precipitation and also flaking of corroded metal off the sides of the well casing (Mercer et al., 1981). More detailed discussion of the field methods used for data collection are available in other reports (Mercer and Orr, 1979; Mercer, Davis, Denneby, and Goetz, 1981; Mercer and Gonzalez, 1981; Denneby and Mercer, 1982; Mercer, 1983).

Additional water quality data from nearby wells collected from 1959 to 1975 by the U. S. Geological Survey during investigations of potash mining and the project Gnome Site have been included. (Cooper and Glanzman, 1971).

3. RUSTLER/SALADO CONTACT

The Rustler/Salado contact has been described as a layer of fine-grained clastic material with lesser amounts of anhydrite, halite, and polyhalite underlying the Rustler Formation and overlying the Salado Formation. Although the Rustler/Salado contact has been considered geologically to be part of the Salado Formation, for hydrological purposes, it has been grouped with

the Rustler Formation (Mercer 1983). The unit is quite variable in thickness, thinning to the east and thickening to the west from the site. The Rustler/Salado Contact reportedly outcrops in areas west of the site along the Pecos River (Mercer 1983).

The Rustler/Salado contact yields small amounts of water to a borehole. During geologic mapping of the waste handling shaft, no observable flow was noted for this zone. Transmissivities calculated for this unit under the WIPP site range from 1×10^{-4} to 3×10^{-4} ft²/day at testholes H-2 and H-1 respectively.

Transmissivities for the Rustler/Salado contact near the WIPP site in Nash Draw range from 0.4 to 8 ft²/day at test holes W-26 and W-29 respectively (Gonzalez 1983). The transmissivities calculated for the Rustler/Salado contact in Nash Draw are greater than those observed for the contact at the WIPP, but are low when compared to other water-producing zones in the Rustler Formation.

3.1 General Rustler-Salado Water Quality Description

Water chemistry determinations were conducted on water samples collected from 20 test holes during the period February 1977 through March 1980. Only one chemistry determination was completed for each borehole during this period, therefore the data base currently available for analysis is small. Sampling of

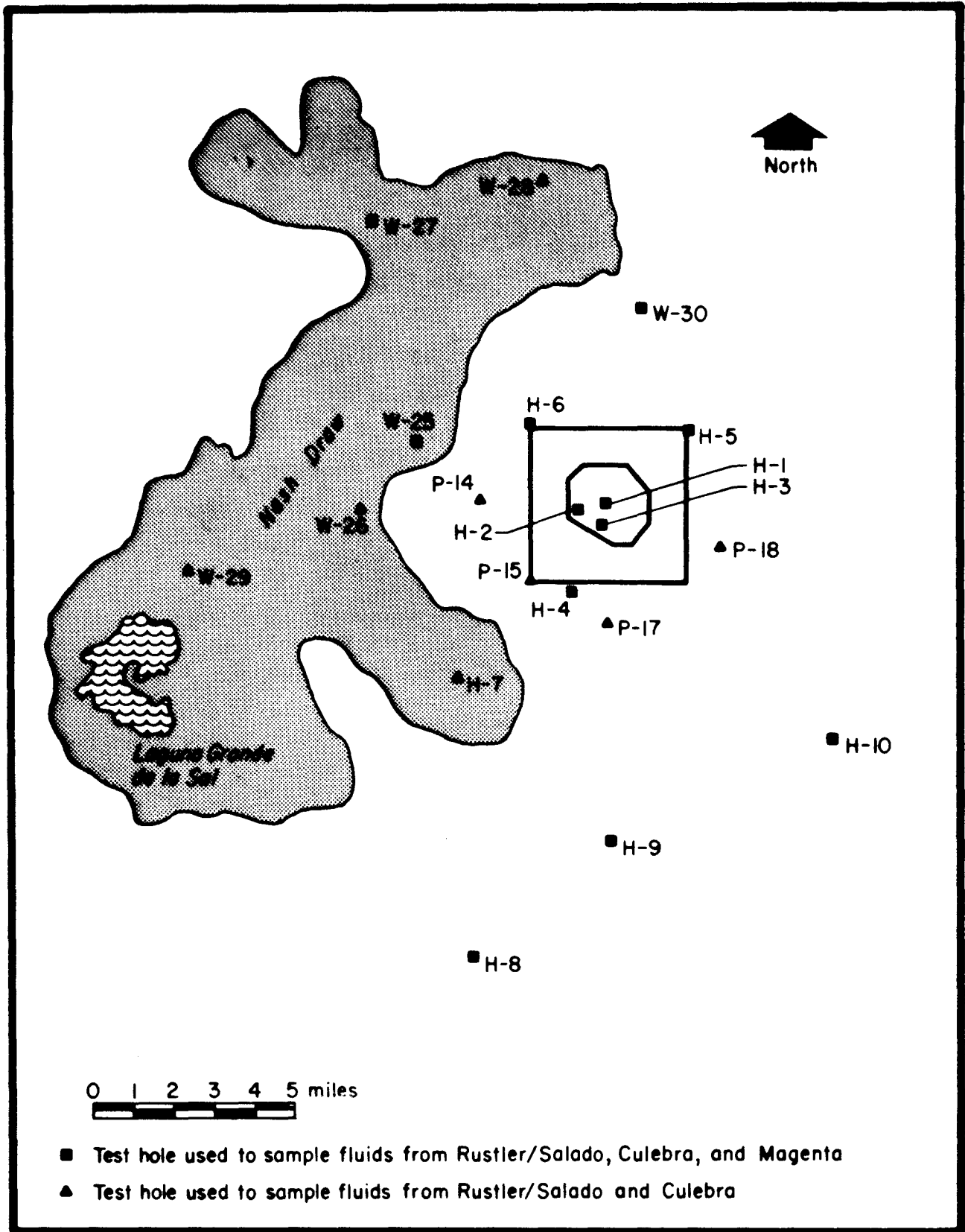


Figure 3. Water chemistry sampling locations.

the water in the Rustler/Salado contact was difficult because of the low water yield (Mercer and Orr 1979). Location of water sampling boreholes are illustrated in Figure 3 and chemistry results are reported in the Appendix.

Water samples from the Rustler/Salado contact have greater concentrations of dissolved solids than samples from either of the other two water-bearing units in the Rustler Formation at the WIPP site. Total dissolved solids (calculated) range from 70,000 mg/l in testhole H-7 southwest of the site to 411,000 mg/l in test hole H-5 northeast of the site. Waters with greater than 35,000 mg/l of total dissolved solids are classified as brines, thus these waters are considered briny (Hem 1970). The dissolved solids content increases from Nash Draw eastward (Figure 4).

The major dissolved ionic constituents of the briny waters are chloride, sodium, and magnesium with lesser amounts of sulfate, calcium, and potassium. The prevalent chemical characteristic, as determined by the highest milliequivalent percentages of the dominant anions and cations, changes from a sodium-chloride water west of the WIPP site, to a magnesium-chloride water to the east (Figure 5). The criteria used for the determination of the prevalent chemical characteristic is simply the cation and anion with the highest milliequivalent concentration. In those cases where two cations are nearly the same, both are designated as the

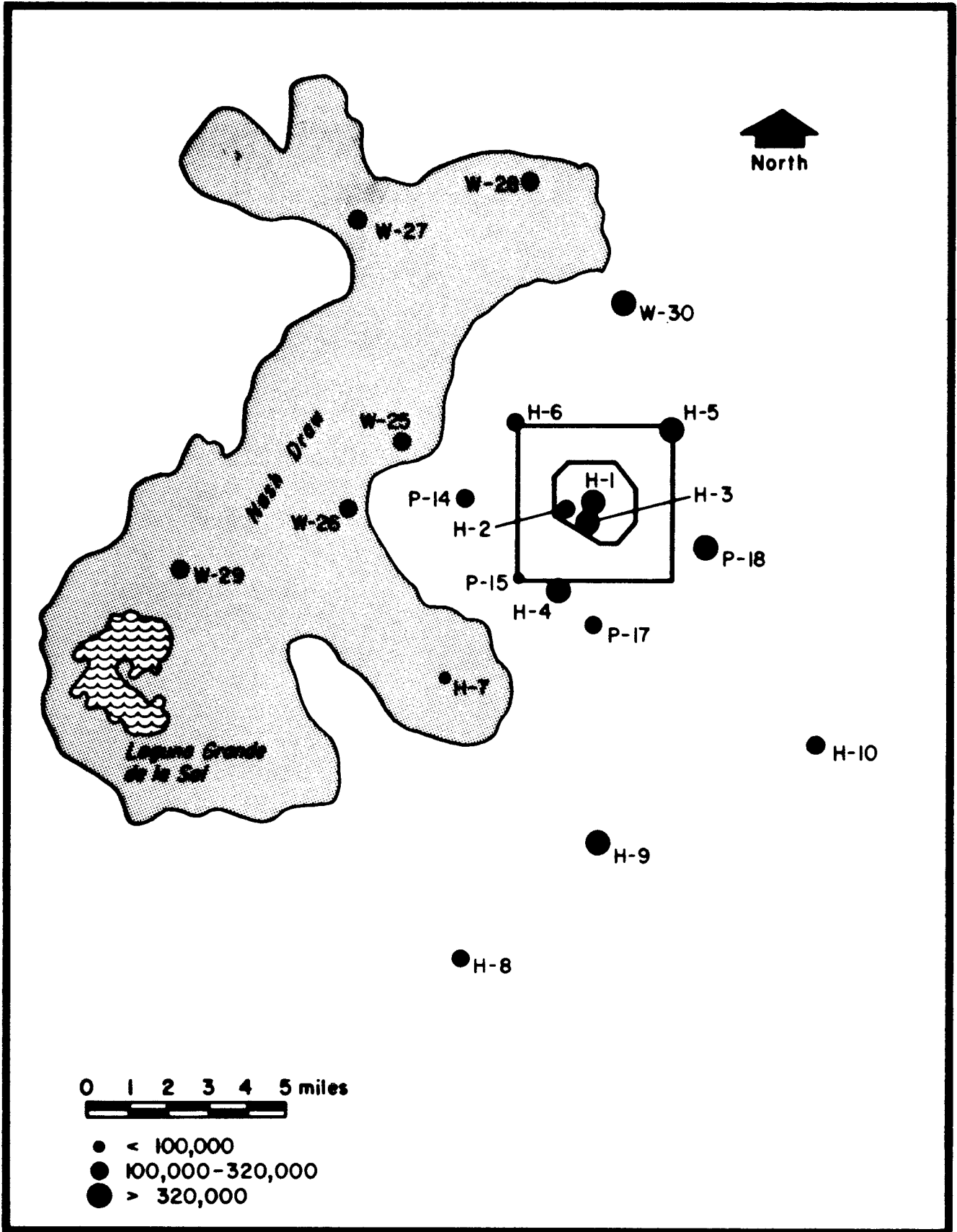


Figure 4. Total dissolved solids (calculated) content of Rustler/Salado contact water.

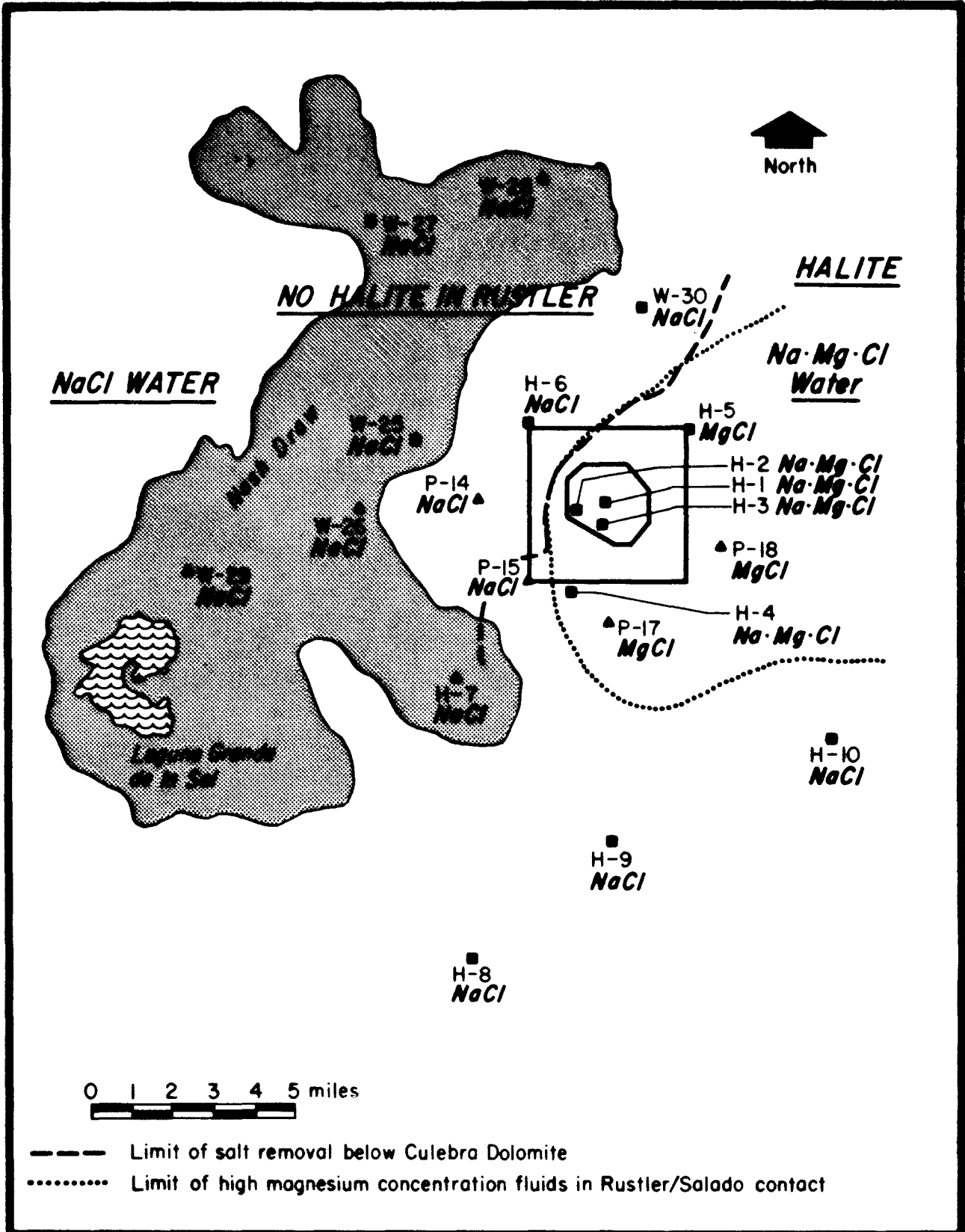


Figure 5. Major Rustler/Salado water types

prevalent cation. The source of magnesium may be the dissolution of polyhalite near the Rustler/Salado contact.

The area of change of the prevalent chemistry of the water approximates a zone that delineates higher and lower transmissivities. Higher transmissivities occur west of the site and are associated with sodium-chloride water, while lower transmissivities associated with the magnesium-chloride water occur east of the site. The area that roughly delineates the sodium and magnesium chloride waters also coincides with the extent of salt removal as defined by Snyder, 1983, from the base of the Rustler Formation (Figure 5).

Water saturated with pure halite (NaCl) at standard pressure and temperature contains approximately 318,000 mg/l dissolved NaCl. Rustler/Salado waters show the influence of dissolved minerals such as sylvite, which exhibits a "common ion" effect with halite and decreases the threshold of saturation. Therefore many of the samples appear to approach saturation with respect to halite, and thus the ability of these waters to dissolve more halite is greatly reduced, unless more water that is undersaturated with sodium chloride is added to the system.

4. CULEBRA DOLOMITE

The Culebra Dolomite Member of the Rustler Formation is a vuggy, finely crystalline dolomite. It is areally the most persistent unit of the three-water bearing zones. Water present in the Culebra east of Nash Draw and at the site is under confined conditions and moves along fractures and bedding planes (Rehfeldt 1984). Water-table conditions may occur in some areas of Nash Draw and south of Laguna Grande de la Sal.

The structural characteristics of the Culebra Dolomite have been related to the amount of halite dissolution that has occurred at the top of the Salado and bottom of the Rustler Formations (Mercer 1983). West of the WIPP site and in Nash Draw the dissolution and removal of halite has caused deformation of the Culebra Dolomite. The dolomite is highly fractured and in some areas slumped. Concomitant with this deformed area, the Culebra Dolomite exhibits high transmissivities ranging from approximately 10 to 1,250 ft²/day.

East of the WIPP site there has been less dissolution and removal of halite below the Culebra Dolomite. The eastward-advancing active dissolution front is thought to be approximately 1-1/2 miles west of the WIPP site (Snyder 1983). The dissolution mechanism, whether it be vertical or horizontal movement of fluids, has not yet been determined.

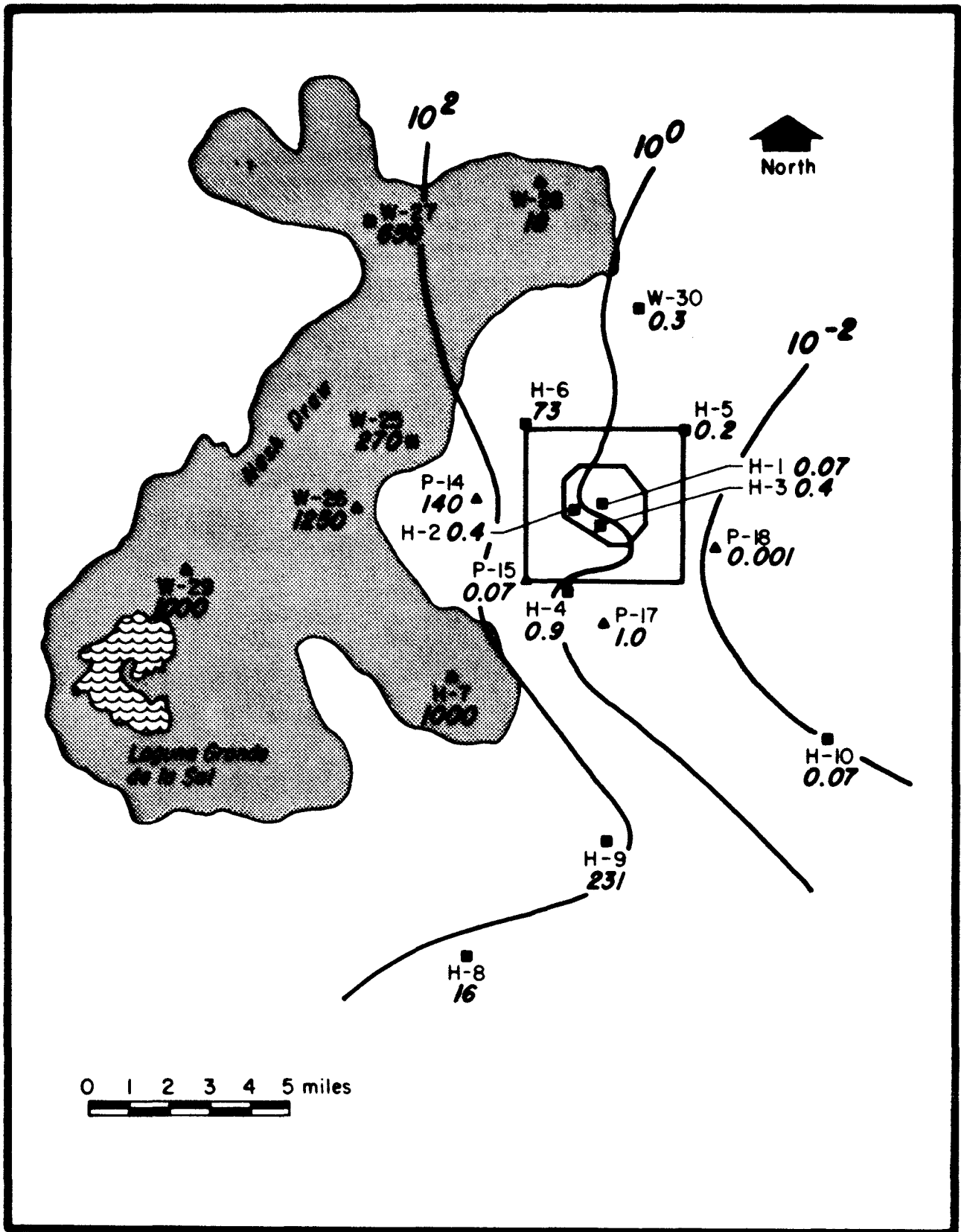


Figure 6. Transmissivity values at Culebra Dolomite testholes.

Fracturing of the dolomite in the area east of the site is not nearly as extensive as in Nash Draw, and large block deformation has not occurred. Due to the lack of dissolution deformation east of the WIPP site, the Culebra is fairly regular and the flow system is restricted. Transmissivities ranging from 1×10^{-3} to $1.0 \text{ ft}^2/\text{day}$ at testholes P-18 and P-17 respectively, reflect these restricting conditions. Transmissivities decrease from Nash Draw to east of the WIPP site (Figure 6). Although transmissivity data calculated for the WIPP area are based on porous-media equations and should be used with some reservation, the transmissivity gradient correlates with the degree of deformation that has occurred in the Culebra Dolomite.

4.1 General Culebra Water Quality Description

Chemical analyses were conducted on samples collected from 20 testholes during the period June 1976 through March 1980 (Figure 3). Only one sample was collected from each well during this period with the exception of hydroholes H-1 and H-2 which were sampled twice during 1976 and 1977. The chemical parameters analyzed for each water sample were not constant throughout the sampling period so that all chemical parameters are not reported for all wells. Water chemistry data for the Culebra Dolomite are listed in the Appendix. Three identifiable zones of differing prevalent water chemistry are readily apparent from the chemistry data (Figure 7). Zone A is an area east of the WIPP site

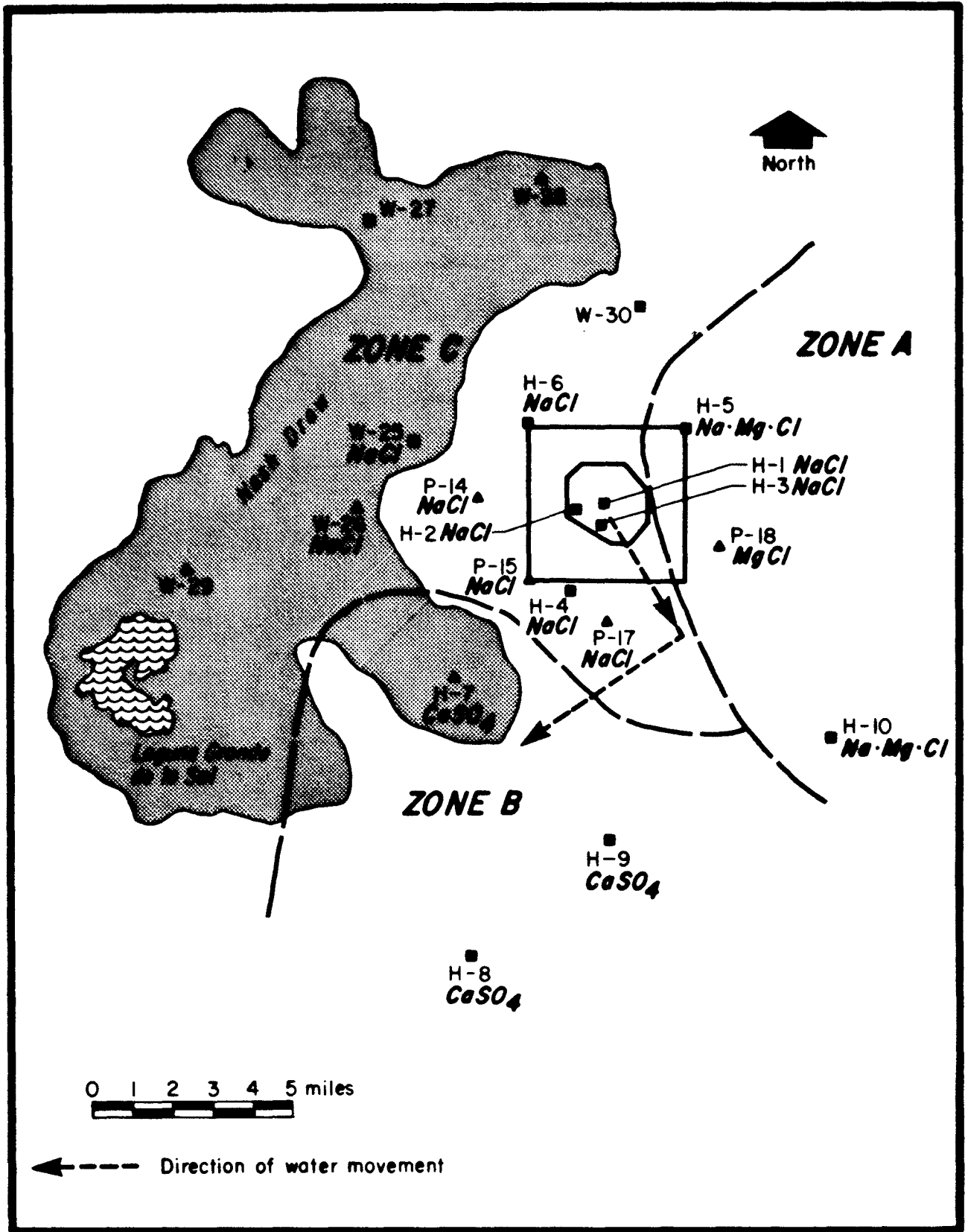


Figure 7. Major Culebra Dolomite water types

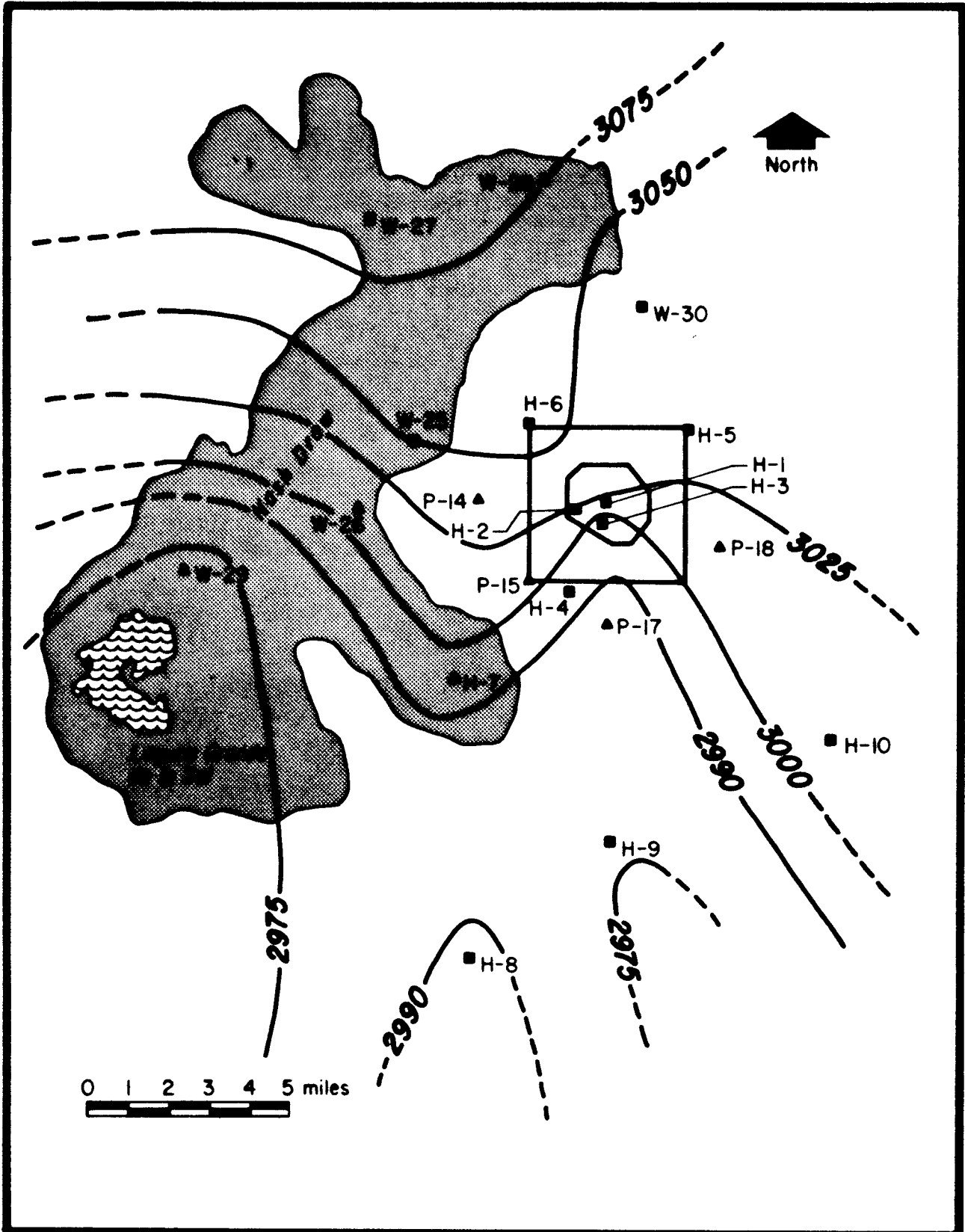


Figure 8. Potentiometric surface of the Culebra Dolomite (after Mercer, 1983).

including the eastern side of the site itself. This zone is characterized as predominantly a sodium-chloride type water with high concentrations of potassium and magnesium. Zone A is characterized hydraulically as having the lowest Culebra transmissivity values. Mercer (1983) suggested that the high concentrations of magnesium and potassium in this area indicate a long fluid residence time with little circulation. Total dissolved solids (TDS) for this area are typically high (greater than 60,000 mg/l).

Zone B lies south of the WIPP site and includes hydroholes H-7, H-8, and H-9. This zone is characterized as predominantly a calcium-sulfate water with relatively low concentrations of total dissolved solids (less than 3,500 mg/l). Wells in this zone contain the lowest concentrations of sodium, chloride, and dissolved solids of all Culebra wells and have transmissivities ranging from 16 to over 1,000 ft²/day. A potentiometric surface map (Figure 8), representing equivalent to freshwater heads, shows a possible groundwater high or ridge adjacent to H-8 in this zone (Mercer 1983). This groundwater high may imply some sort of recharge to the Culebra near or south of H-8, or may perhaps be a numerical artifact caused by the conversion of actual heads to freshwater heads.

Ground water samples collected during the 1950's, prior to the Gnome Project, south of the WIPP site, show the same chemical

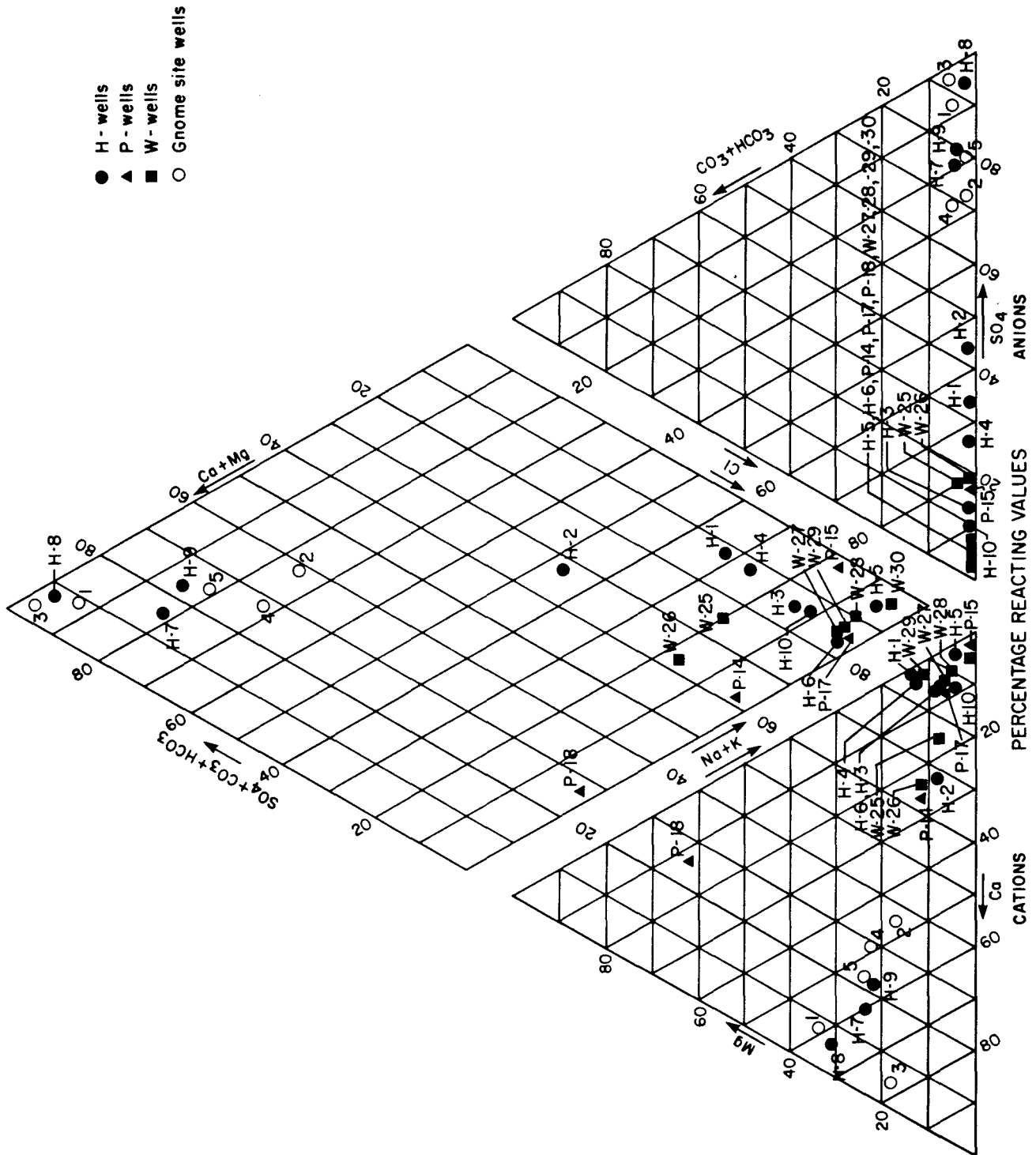


Figure 9. Trilinear diagram of Culebra Dolomite water

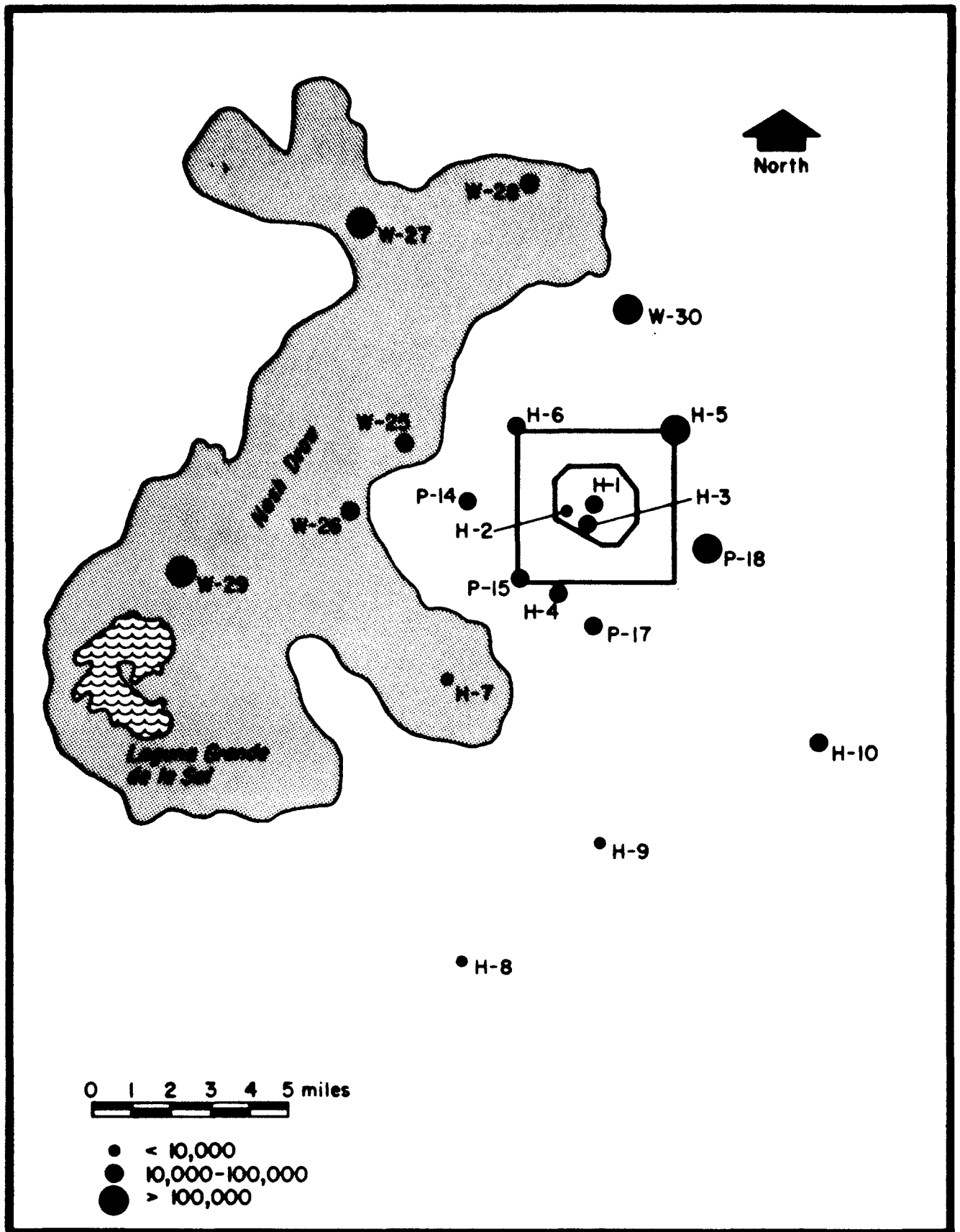


Figure 10. Total dissolved solids (calculated) content of Culebra Dolomite water.

pattern as is evident today in Zone B (Figure 9). Calcium and sulfate were the prevalent chemical ions in a water with a relatively low dissolved solids content.

Zone C (Fig. 7) includes most of the area north and west of the WIPP site. Sodium and chloride are the predominant chemical constituents, and based upon dissolved solids concentrations (9,000 to 239,000 mg/l) the waters are classified as saline to briny (Hem 1970). Potassium and magnesium concentrations are relatively low except at W-27 and W-29 which are located near potash mines and may be affected by these operations.

Wells located within Zone C exhibit considerable variations in the amount of dissolved constituents. A general trend of increasing TDS from west to east is evident (Figure 10). Wells such as W-25 and W-26, west of the site in Nash Draw, have TDS concentrations of 17,000 and 16,000 mg/l, compared to 52,000 and 97,000 mg/l at H-3 and H-1 respectively. The increase in total dissolved solids from west to east can be accounted for by the individual increases in sodium and chloride. Wells W-25 and W-26 are located in an area in which there is no halite present in the Hustler Formation, whereas Wells H-3 and H-1 are located in an area in which halite is present below the Culebra Dolomite (Figure 7). The increase in TDS, sodium and chloride may represent halite dissolution processes immediately adjacent to the Culebra Dolomite.

Considerable chemical variation exists between the hydroholes H-1, H-2, and H-3 which are the most proximate wells to the site. Total dissolved solids concentrations range from 9,000 to 52,000 mg/l between these wells, a difference of six times, and chloride ranges from 2800 to 29,600 mg/l, an order of magnitude difference. If one assumes that areas with restricted flow and low transmissivities would have longer periods of time for host rock-fluid interaction and should be characterized chemically as having high dissolved solids, then it would be expected that well H-1, which has the lowest transmissivity value, to have the highest dissolved solids content. In actuality, Well H-3 with the highest transmissivity value has the greatest concentrations of dissolved constituents. The reasons for the abrupt chemical changes within the one square mile area surrounding well H-1, H-2, and H-3 cannot be answered with the limited data currently available, and the wells should be considered for resampling during the upcoming water chemistry sampling period.

Marked differences are also evident in water chemistry results from samples collected from the same well during different sampling periods. Wells H-1 and H-2 were sampled for water chemistry determinations twice from the period June 1976 to March 1977. Results for well H-2 are reported by Mercer and Orr, (1979), as Culebra samples H-2B and H-2C. Comparison of the data for the major ions in the two H-2 samples indicates fairly good agreement between the concentrations of reported constituents

from one time period to the other. However, the values for dissolved metals such as copper, iron, and lead show significant differences between the two sampling periods. The metals data also show significant differences between dissolved and total values.

A wide discrepancy is also present between the two H-1 samples. The values for chloride, sodium, and total dissolved solids of the sample collected in 1977 are three to four times greater than values reported for the 1976 sample. Also as observed in the H-2 samples, there is a significant difference between the values reported for dissolved and total metals.

As discussed briefly in section 2 of this report (Sources of Data) and in other reports (Mercer and Orr, 1979; Mercer et al , 1981) sample perturbation and contamination was a major concern. The differences between the reported dissolved and total metals values suggests the influence or contamination of the water sample by corroding well casing. Also the differences in major ions between the two H-1 samples may suggest that the collection of representative formational fluid may not have been achieved.

Field geochemical studies conducted during 1980 using testholes in Nash Draw showed that, "any arbitrarily chosen sample from a pumped or bailed well cannot be shown as representative of the nearly unperturbed subsurface reservoir" (Lambert and Robinson

1984). Physiochemical measurements on Eh, pH, specific conductance, specific gravity, bicarbonate/carbonate, chloride, divalent cations, calcium, total iron, and hydrogen sulfide were conducted in the field to determine when representative formational fluids were being sampled. Lambert and Robinson stated that "the most useful indicators of steady state were divalent cations, chloride, and in some cases Eh," but that "criteria for determining a sample's significance are not absolute, but must instead be based on longterm observations of the well that include withdrawal of water and periodic measurements.

The length of time required and the amount of water produced from the Nash Draw testholes to achieve representative formational fluids may indicate that the differences in fluid chemistry observed in the samples collected from 1976 to 1980 may be the result of anthropogenic contamination. The amount or significance of contamination on these samples may not be determinable at this late date, and therefore it is of utmost importance that the present water chemistry sampling program be conducted in such a manner that representative formational fluids are collected and documented.

The differing water chemistries in Zones B and C present a problem for the currently assumed direction of flow in the Culebra. The presently preferred flow path is southeast from the

center of the site then turning westward towards Malaga Bend (Gonzalez 1983). The observed water chemistries for Zones B and C do not support this Culebra water movement pattern. Water in Zone C moving from the center of the site would have to decrease the amount of dissolved solids from approximately 30,000 mg/l to 3,000 mg/l along its flow path into Zone B. The major constituents would have to change from sodium and chloride to calcium and sulfate from Zone C to Zone B. At present, no mechanisms are known which could effect such a chemical change, other than the mixing of low TDS water with Zone C water and there does not appear to be a source of low TDS water available for the mixing.

The Culebra Dolomite is the most hydraulically conductive water-bearing unit above the repository and has been presented as the most likely transport medium for the movement of radionuclides in repository breach analyses. As such, in modeling the transport of solutes from the repository along Culebra flow paths, investigators have numerically simulated the movement of solute from Zone C to Zone B (Barr et al. 1983). Due to the credence given to these models (Weart 1983), and the marked inconsistencies of the chemical processes south of the WIPP site, it is of utmost importance to investigate further the chemical interaction of Culebra groundwater in this area.

4.2 Culebra Saturation Index Calculations

A common technique for evaluating the chemical characteristics of ground water is through the use of mineral saturation indices. The saturation index provides a method for comparison of mineral dissolution-precipitation reactions and describes fluid-host rock interactions.

The saturation index is the ratio of the ion activities of a given mineral to its equilibrium solubility product (KSP). For the case of the mineral halite in groundwater, the saturation index is:

$$SI = \frac{(\alpha Na^+) (\alpha Cl^-)}{K_{NaCl}}$$

Where SI is the saturation index, (αNa^+) is the activity of sodium for the chemical analysis, (αCl^-) is the activity of chloride and K_{NaCl} is the thermodynamic equilibrium constant for the mineral halite.

The ion activities in the numerator are referred to as the thermodynamic effective concentrations and can be calculated from chemical analyses of groundwater samples by using the following equation:

$$a_i = m_i \gamma_i$$

where a_i is the activity of solute species i , m_i is the molality, and γ_i is the activity coefficient (Stumm and Morgan, 1970). The activity coefficient for an ion in a given water chemistry analysis can be calculated by using the Davies equation:

$$\text{Log } \gamma_i = \frac{-Az_i^2 \sqrt{I}}{1 + Ba\sqrt{I}} + CI$$

where γ_i is the individual ion activity coefficient, A is a constant depending on pressure and temperature. I is the ionic strength of the solution, and z_i is the ionic charge (Plummer et al., 1976).

The activity coefficient of a given solute is the same in all solutions of the same ionic strength. Ionic strength (I) is defined by the following relation:

$$I = 1/2 \sum m_i z_i^2$$

Where I is the ionic strength, m_i is the molality of species i and z_i is the valence or charge that the ion carries (Stumm and Morgan 1970).

The equilibrium constant K_{NaCl} in the denominator of the saturation index equation can be calculated from free-energy data or read directly from equilibrium constant tabulations.

Computer programs have been written and documented that utilize the numerical formulation of saturation indices. These programs utilize experimentally determined thermodynamic properties of various minerals in low ionic strength solutions to predict the degree to which a given solution is in equilibrium with solid-phase minerals. The degree of equilibrium is expressed in terms of mineral saturation or undersaturation. A solution with a saturated mineral can be interpreted as being in a precipitation process or having no further dissolution potential and a solution with an undersaturated mineral can be viewed as a dissolving process, with dissolution potential.

The computer program used in this analysis is a descendant hybrid of the original U. S. Geological Survey program "WATEQ" (Plummer et al. 1976). The model code, "WATEQFC," has been altered to include 35 elements, approximately 440 aqueous species, and 380 minerals and compounds (Runnells, 1983). This model was used because of its availability and relative ease of usage.

Saturation calculations were performed by the EEG on Culebra Dolomite water chemistry analyses. The suspect nature of the groundwater samples at some testholes as discussed previously limits the degree to which interpretation of the modeling can be accomplished. In addition, a comprehensive investigation of the Rustler Formation mineralogy has not been completed, therefore lateral variations in water chemistry due to possible changes in

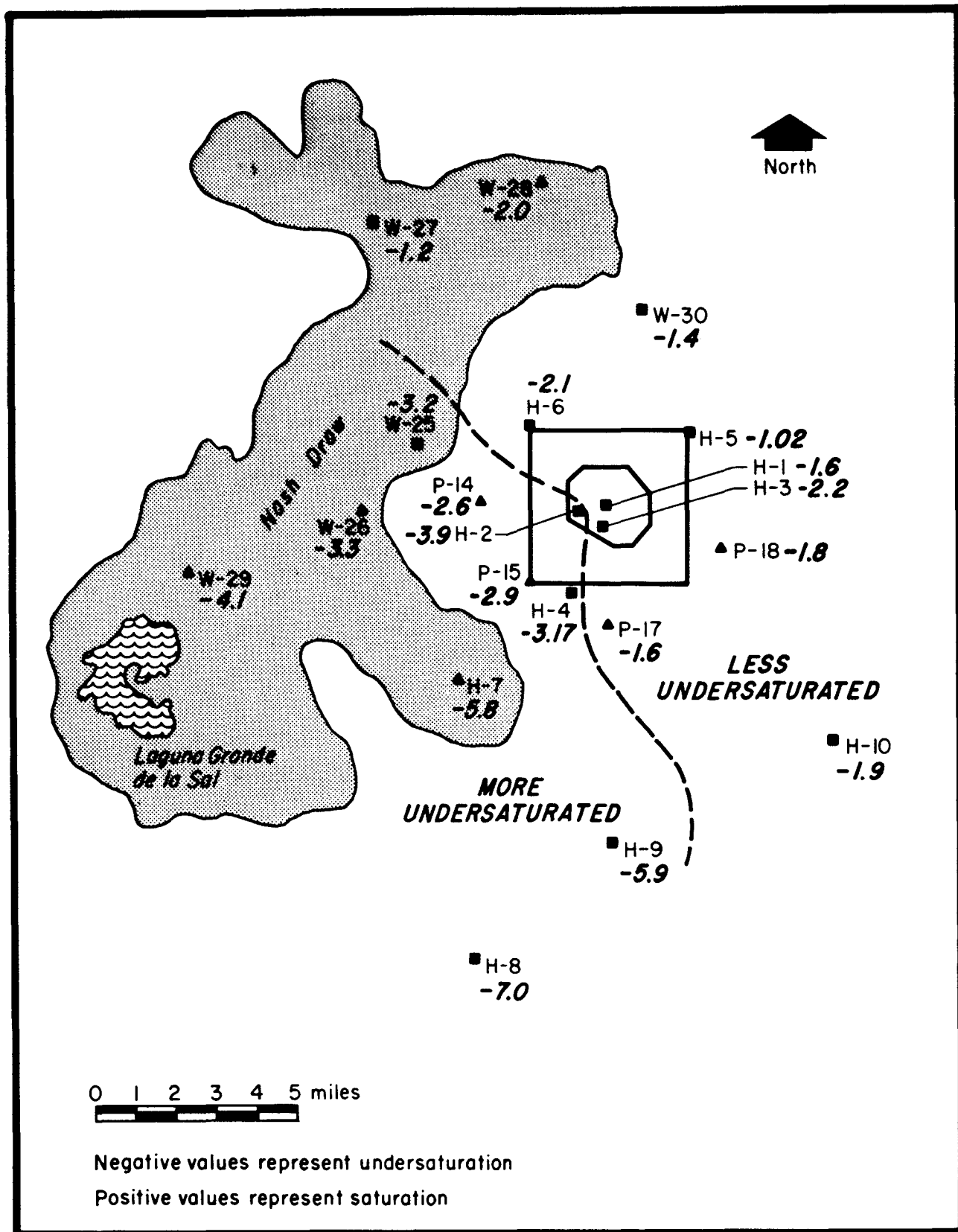


Figure 11. Halite saturation index for Culebra Dolomite water (reported as the Log_{10})

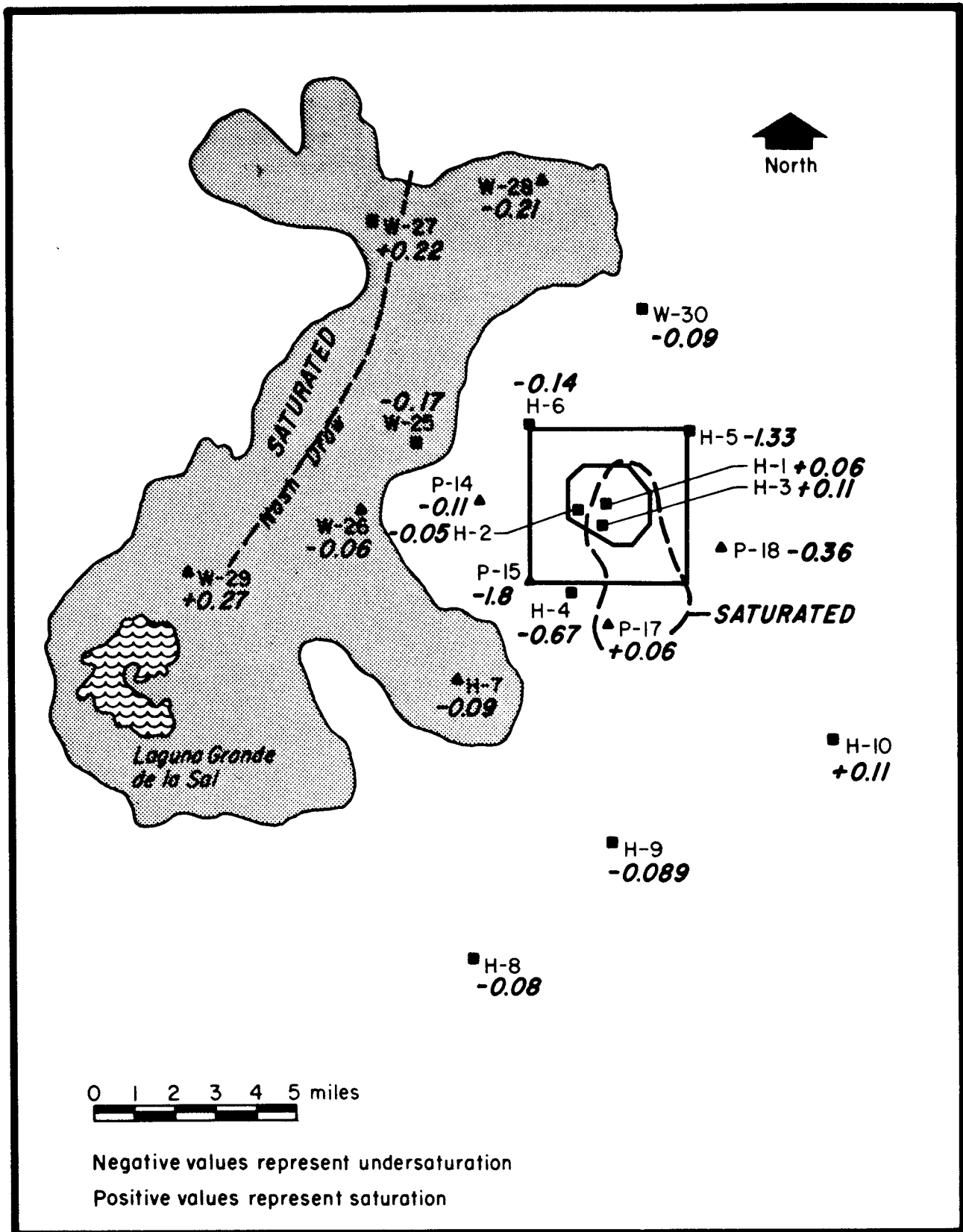


Figure 12. Anhydrite saturation index for Culebra Dolomite water (reported as the Log_{10})

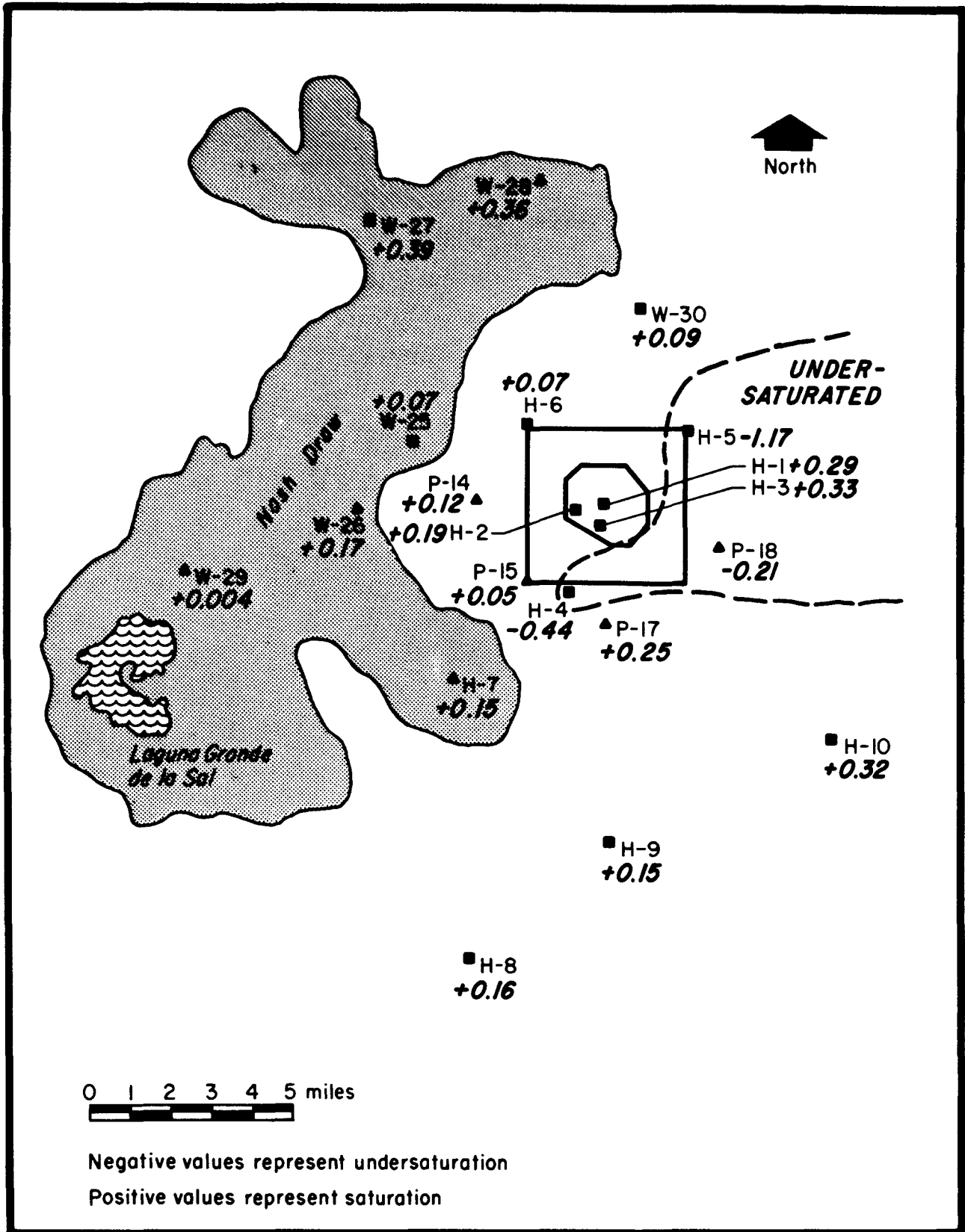


Figure 13. Gypsum saturation index for Culebra Dolomite water (reported as the Log₁₀)

major and minor mineralogy and host rock-fluid interactions cannot be documented. Also the solubility of various minerals, notably calcium sulfates, changes with variations in the salinity of the solution (Madgin and Swates, 1956). Finally, and most importantly, the calculation of an individual ion activity coefficient by the Davies equation becomes tenuous at high ionic strength (Stumm and Morgan 1970). In accord with these limitations the modeling results are interpreted in only the broadest sense.

Results of thermodynamic modeling are presented in Figures 11 to 15. Minerals of prime importance to the Rustler Formation include anhydrite, calcite, dolomite, gypsum, and halite. All fluid samples from Culebra testholes were undersaturated with respect to the mineral halite (Figure 11). Culebra Dolomite water has the capacity to dissolve more halite if it comes in contact with host-rock containing halite. In the breach scenarios where a connection is made between the Culebra Dolomite and the repository by a pair of boreholes (Event 2 - SAR) the Culebra Dolomite water has the capability to dissolve backfilled halite surrounding the waste containers, placing the containers in contact with the water.

Although all Culebra fluid samples were undersaturated with respect to halite, a general numerical divide between degrees of undersaturation is present (Figure 11). The eastern half of the

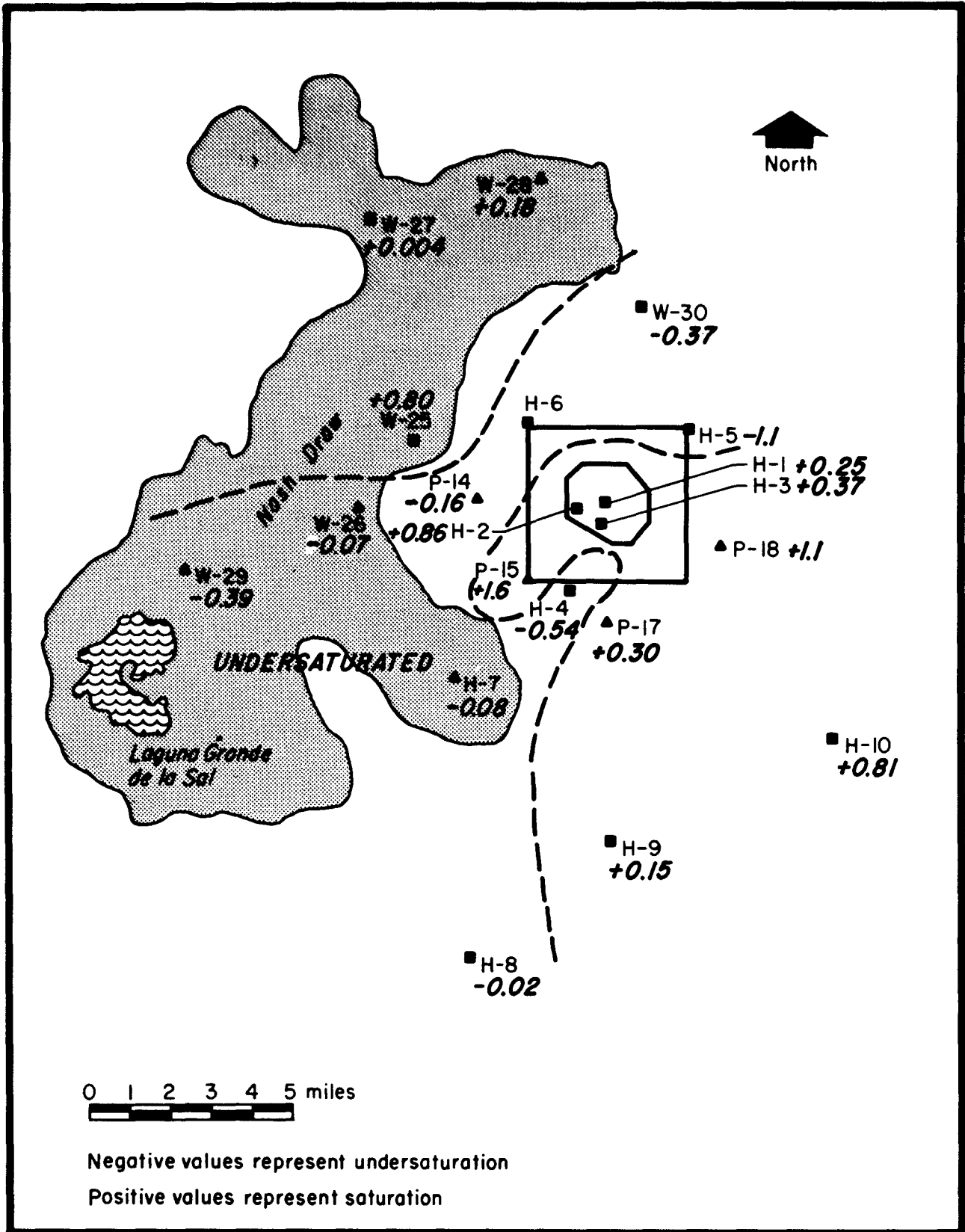


Figure 14. Calcite saturation Index for Culebra Dolomite water (reported as the Log₁₀)

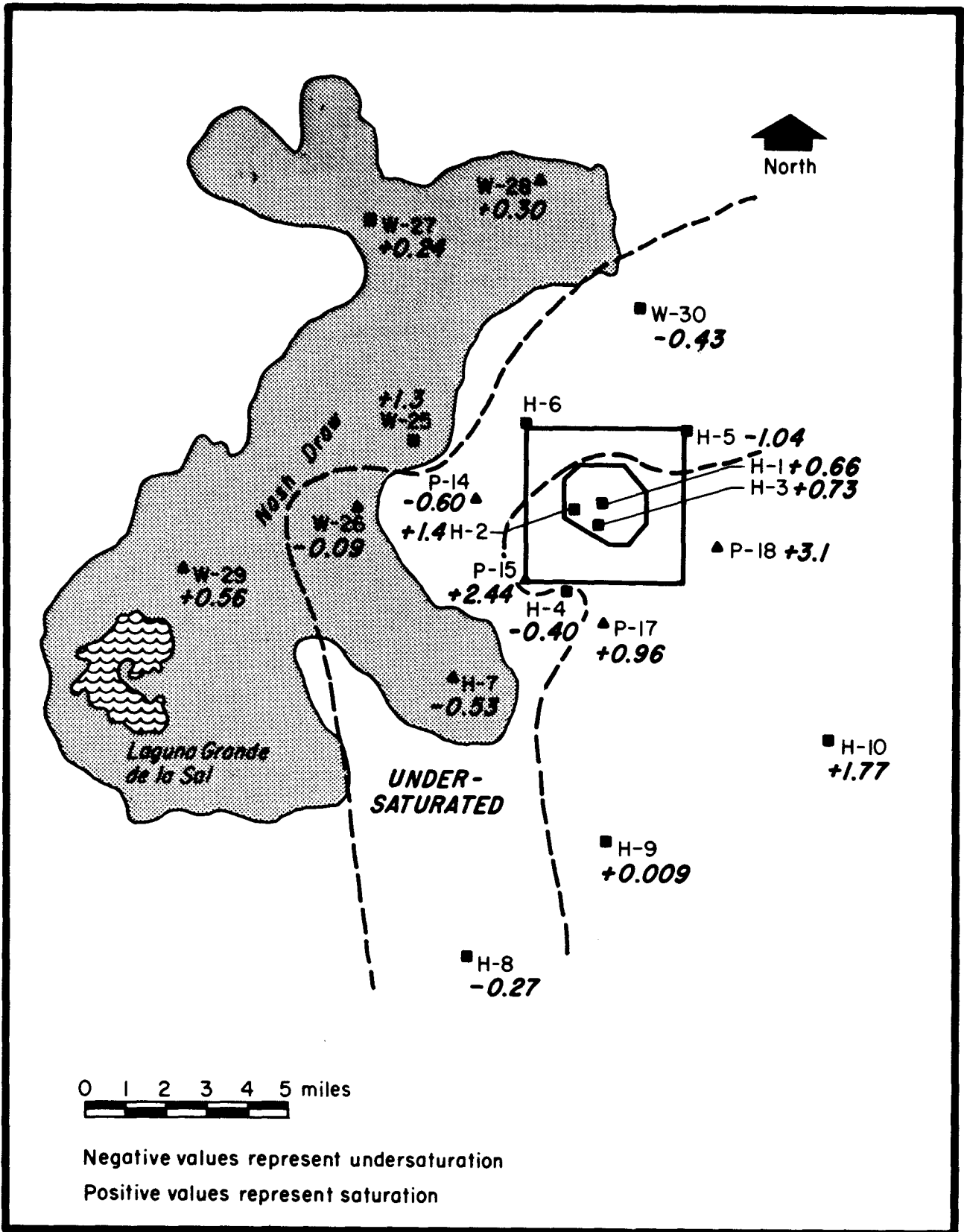


Figure 15. Dolomite saturation index for Culebra Dolomite water (reported as the Log₁₀)

study area is less undersaturated than the western half. This may reflect the presence of halite above and below the Culebra and the movement of dissolved salt from the halite into the Culebra.

Saturation indices of the minerals anhydrite and gypsum are presented in Figures 12 and 13. Culebra fluids are undersaturated with respect to anhydrite across nearly the entire study area. Two small areas, one near the potash mining region 10 miles to the northwest and the other east and south of the WIPP, are slightly saturated.

Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) saturation indices on the other hand are nearly the reverse of those for anhydrite (CaSO_4). Culebra waters are saturated with respect to gypsum across almost the entire study area (Figure 13). A small area east of WIPP site is undersaturated and is capable of dissolving gypsum. Saturation index calculations may indicate that anhydrite is being converted to gypsum and then dissolving in zones adjacent to the Culebra.

Water from testholes along the western and northern areas of Nash Draw are saturated with respect to both calcite and dolomite. The availability of CO_2 in this area may be increased due to the enhanced deformation of the Culebra Dolomite and overlying units. Rain water with large amounts of dissolved CO_2 in this area may

infiltrate rapidly through the fractures and thus provide a supply for bicarbonate and carbonate reactions.

A second area of calcite and dolomite saturation occurs east of the WIPP site (Figures 14 and 15). The reason for this area of calcite and dolomite saturation is not clear with the present data, although the low transmissivities in this area indicate a longer residence time allowing more host-rock fluid interaction. Additional water chemistry samples and a Rustler mineralogy study may provide data for an explanation.

5. MAGENTA DOLOMITE

The Magenta Dolomite member is a thin areally persistent clastic carbonate and is the uppermost water-bearing unit of the Rustler Formation. Water present in the Magenta Dolomite is under confined conditions except in outcrop areas in Nash Draw, and where extensive fracturing and alteration at testholes W-28, W-26, W-29, and H-7 has occurred, allowing water to percolate downward into underlying units (Mercer 1983). Water movement is within the silty dolomite and along any bedding planes or fractures.

Structurally, the Magenta Dolomite outcrops along the western edge of Nash Draw and dips gently eastward. In the central areas of Nash Draw near testhole W-29 and southward to Malaga Bend, the

Magenta Dolomite has been eroded away. In the vicinity of the WIPP site, the Magenta Dolomite has not been fractured as much as the Culebra and fracture flow is not as prevalent.

Values of transmissivity show considerable variation from area to area near the site. West of the site, in Nash Draw, transmissivity values range from 53 to 375 ft²/day in testholes W-27 and W-25 respectively. The transmissivity value reported from W-25 is the largest value recorded for the Magenta in the region. Mercer (1983) attributes this large value to increased permeability due to fracturing in the Magenta Dolomite, and to vertical leakage upwards from the Culebra. A comparison of the mole ratios of major chemical constituents in waters of the Culebra and Magenta Dolomites at W-25 indicates that the waters are very similar in the ratios of the constituents, although the actual concentrations vary.

Transmissivity values recorded for wells at or adjacent to the site are low, ranging from 4×10^{-3} ft²/day in testhole W-30 to 3×10^{-2} ft²/day at hydrohole H-6a. These low values reflect the restricted flow system of the Magenta at the site.

The Magenta water is unsaturated with respect to halite in testholes west and south of the WIPP site. Mercer reported that testholes W-26 and H-7a were unsaturated as a consequence of Magenta fractures allowing fluids to move vertically downward

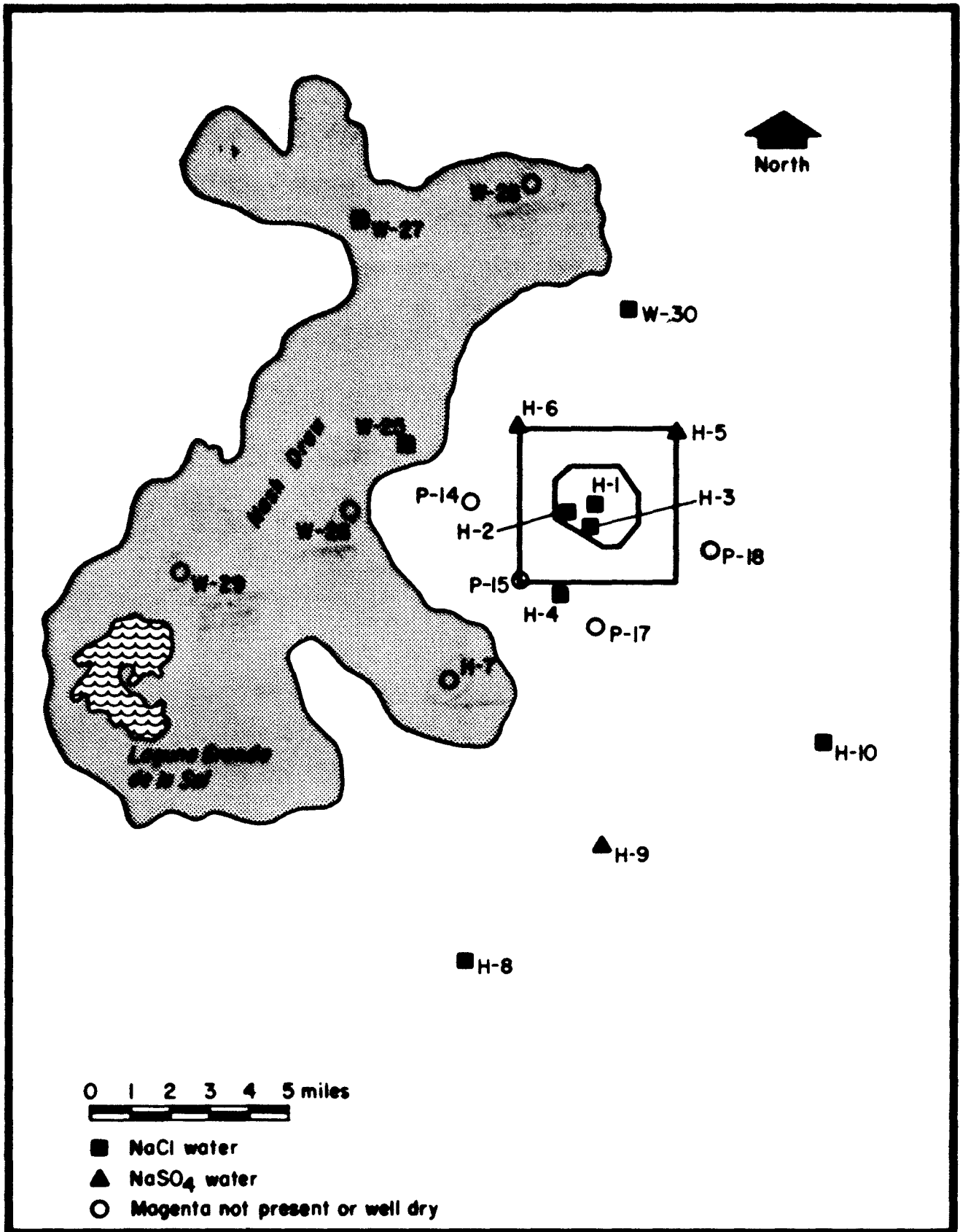


Figure 16. Major Magenta Dolomite water types.

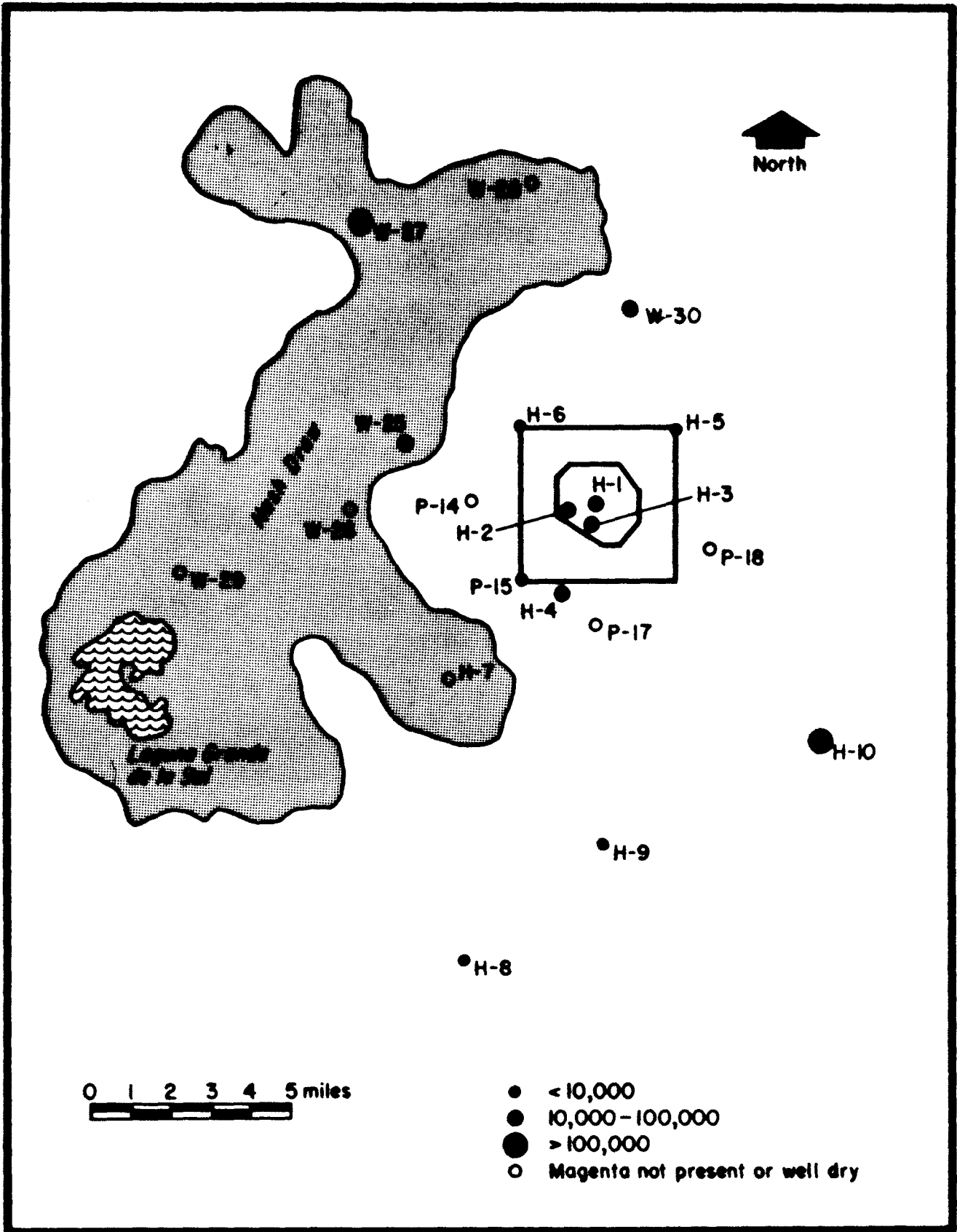


Figure 17. Total dissolved solids (calculated) content of Magenta Dolomite water.

into the Culebra. An inspection of the Culebra potentiometric surface (Figure 6) at these holes may reflect the higher heads associated with the vertical drainage. It has been proposed that a division of the higher and lower transmissivity zones within the Magenta can be approximated by an isocon line of 50 milliequivalents of potassium and magnesium (Mercer 1983). The flow system throughout the Magenta, except in or along Nash Draw, appears to be restrictive as indicated by the low transmissivity values. Also, only a single well, H-10a, east of the site has potassium and magnesium concentrations greater than 50 milliequivalents. Therefore it seems premature to relate the potassium and magnesium content of Magenta water to hydraulic conditions as has been done for the Culebra Dolomite.

5.1 General Magenta Water Quality Description

Water chemistry determinations were conducted on water samples collected from 12 testholes during the period June 1976 through September 1980. One sample was collected from each testhole during this period with the exception of testhole W-27, which was sampled twice during 1980. Locations of water sampling points are illustrated in Figure 1 and reported in Appendix 1.

The major dissolved chemical constituents of the Magenta Dolomite are chloride and sodium, except in testholes H-5a, H-6a and H-9a where sulfate replaces chloride as the most prevalent anion

(Figure 16). The total dissolved solids content ranges from 5,460 to 270,000 mg/l at testholes H-9a and H-10a, respectively, characterizing these waters as saline to briny (Figure 17). Total dissolved solids tend to increase from the northwest to the southeast with the exception of testhole W-27, located northwest of the site, which has an extremely high dissolved solids content.

6. CONCLUSIONS AND RECOMMENDATIONS

Water chemistry determinations were performed by the U. S. Geological Survey on water samples collected from the three fluid-bearing zones of the Rustler Formation from 20 testholes at and adjacent to the WIPP from 1976 to 1980. Analysis of the data demonstrate that the three fluid-bearing zones are chemically separate from one another and that little inter-zone interaction of fluids occurs.

The fluids present at the Rustler-Salado contact are characterized as sodium-chloride brines that approach saturation with respect to halite. Magnesium replaces sodium as the prevalent cation east of the WIPP; this area may represent the approximate limit of salt dissolution at the base of the Rustler Formation.

Chemical interpretation of the fluids present in the Culebra

Dolomite is a highly complex problem. Large chemical variations exist between testholes. The number of water chemistry samples collected and the degree to which they represent formational fluid may not be sufficient to summarize fluid and host-rock interactions.

Three zones of differing predominant chemical constituents are present in the Culebra Dolomite. These zones do not support previously reported directions of water movement and there appears to be an inconsistency between the apparent chemistry and the previously reported flow paths. The Culebra waters are undersaturated with respect to halite and have the capacity of dissolving more halite from the Rustler, or if a connection is produced, from the Salado or repository horizon.

The use of WATEQFC or other low ionic-strength ion-association models may lead to unacceptable errors in the calculation of saturation indices. Additional chemical thermodynamic modeling should be approached with models capable of handling high ionic strength solutions. The major ions present in the fluids in the Magenta Dolomite are predominantly sodium and chloride. A few wells have sulfate, rather than chloride, as the predominant anion.

Additional work is needed to improve the degree of understanding of the chemical characteristics of the fluids in Rustler

Formation especially with regard to the Culebra Dolomite. More information is needed to understand the chemical changes that occur along proposed ground water flow paths of the Culebra.

EEG offers the following recommendations to improve the understanding of the Rustler Formation water quality.

1. Collect additional water quality samples from fluid-bearing zones in the Rustler Formation. Emphasis should be placed on rigorous field and laboratory procedures to obtain representative and repeatable ground water quality data.
2. The water quality differences observed in Culebra Dolomite testholes near the middle of the site should be investigated.
3. The change in water quality from Culebra Zone C to Zone B (fig. 7) should be investigated to aid in the determination of ground water flowpaths.
4. A WIPP pre-operational data base should be initiated to define water levels and water quality for all constituents of interest.

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APPENDIX

Selected chemical and radiochemical analyses of water from testholes at and near the WIPP collected and analyzed by the U.S. Geological Survey (Mercer and Orr, 1979; Mercer, 1983).

Well	H-1	H-2C	H-3	H-4C	H-5C	H-6C	H-7C	H-8C	H-9C
Date Sampled	77-2-23	77-2-23	77-2-23	79-03-16	79-05-16	79-04-09	80-03-20	80-09-06	80-05-20
Geologic Unit	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S
pH (unite)	7.9	5.9	7.6	7.6	-	-	6.8	7.6	7.0
temperature (°C)	21	20.5	21.5	-	-	-	-	-	-
Total diss. solids									
(Calculated as mg/l)		311,000	326,000	320,000	411,000	315,000	70,000	124,000	326,000
Total diss. solids (residue, mg/l)	325,000	450,000	327,000	322,000	412,000	316,000	79,800	130,000	326,000
Hardness (mg/l as CaCO ₃)	160,000	130,000	150,000	130,000	340,000	97,000	10,000	4,800	6,800
Non-carbonate hardness									
(mg/l as CaCO ₃)	160,000	130,000	150,000	130,000	340,000	97,000	10,000	4,700	6,800
Total organic carbon (mg/l)	-	-	-	-	-	-	-	-	-
Sodium absorption ratio	-	-	-	-	-	-	-	-	-
Chloride (mg/l)	210,000	200,000	210,000	210,000	290,000	200,000	41,000	70,000	190,000
Fluoride (mg/l)	-	-	-	1.7	<0.1	1.0	0.8	0.4	0.1
Alkalinity (mg/l as CaCO ₃)	-	-	-	1	180	1	35	21	24
Bicarbonate (mg/l as CaCO ₃)	675	199	467	1	300	-	-	-	-
Carbonate (mg/l as CaCO ₃)	0	0	0	0	-	-	-	-	-
Sulfate (mg/l)	520	1,300	370	1,400	2,000	2,000	2,900	5,300	2,600
Sulfide (mg/l)	-	-	-	-	-	-	-	0.6	-
Nitrite & nitrate (mg/l)	0.29	1.1	0.77	0.27	-	-	-	0	1.1
Orthophosphate (mg/l)	0.00	0.00	0.00	-	-	-	-	-	-
Silica (mg/l)	0.0	2.0	1.0	1.3	1.6	1.4	7.2	0.8	3.8
Calcium (mg/l)	13,000	9,200	18,000	8,300	2,100	4,200	2,600	1,200	1,300
Magnesium (mg/l)	30,000	25,000	25,000	27,000	82,000	21,000	910	430	870
Sodium (mg/l)	56,000	66,000	59,000	66,000	14,000	80,000	22,000	46,000	130,000
Potassium (mg/l)	17,000	9,100	14,000	8,600	21,000	8,000	210	660	1,200
Gross Alpha as U. diss. (ug/l)	<6,300	<5,000	<6,000	<11,000	<19,000	<11,000	<1,400	<2,600	<8,000
Gross Alpha as U. sus. (ug/l)	290	190	68	4.9	1.1	1.3	-	-	-
Gross Beta as Cs diss. (pCi/l)	16,000	8,400	12,000	8,900	15,000	6,800	<580	<1,100	7,600
Gross Beta as Cs sus. (pCi/l)	160	91	26	<0.4	0.6	<0.7	-	-	-
Gross Beta as Sr/Y diss. (pCi/l)	12,000	6,700	9,600	8,100	14,000	6,200	<590	<1,100	<7,200
Gross Beta as Sr/Y sus. (pCi/l)	120	76	21	<0.4	0.6	<0.7	-	-	-
Diss. Radium (pCi/l)	64	4.8	51	340	310	280	65	18	0.31
Diss. Natural Uranium (ug/l)	-	-	-	-	-	-	-	-	-
Diss. Uranium	0.02	2.4	0.06	1.2	<0.04	<0.04	1.9	0.04	0.45

Well	H-1	H-2C	H-3	H-4C	H-5C	H-6C	H-7C	H-8C	H-9C
Date Sampled	77-2-23	77-2-23	77-2-23	79-03-16	79-05-16	79-04-09	80-03-20	80-09-06	80-05-20
Geologic Unit	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S
Arsenic, tot. (ug/l)	7	1	8						
Arsenic, diss. (ug/l)	0	0	0						
Boron, diss. (ug/l)	110,000	150,000	1,900	360,000	67,000	200,000	3,100	1,300	19,000
Cadmium, tot. (ug/l)	-	1	-						
Cadmium, diss. (ug/l)	1	1	12						
Chromium, tot. (ug/l)	<50	<50	<50						
Chromium, diss. (ug/l)	<50	<50	<50						
Cobalt, tot. (ug/l)	5	15	20						
Cobalt, diss. (ug/l)	2	4	4						
Copper, tot. (ug/l)	190,000	2.4	190,000						
Copper, diss. (ug/l)	500	1.6	16,000						
Iron, tot. (ug/l)	130,000	75,000	140,000						
Iron, diss. (ug/l)	1,500	2,500	1,500						
Lead, tot. (ug/l)	320,000	2,800	340,000						
Lead, diss. (ug/l)	15,000	2,800	29,000						
Manganese, tot. (ug/l)	52,000	110,000	30,000						
Manganese, diss. (ug/l)	52,000	78,000	3,800						
Mercury, tot. (ug/l)	0	0	0						
Mercury, diss. (ug/l)	0	0	0						
Selenium, tot. (ug/l)	0	0	1	< 1	1	1	-	-	-
Selenium, diss. (ug/l)	0	0	1						
Zinc, tot. (ug/l)	22	30,000	22,000						
Zinc, diss. (ug/l)	0.19	29,000	210						

Well	H-10C	P-14	P-15	P-17	P-18	V-25	V-26	V-27	V-28
Date Sampled	80-05-19	77-02-24	79-04-03	79-05-11	79-05-11	80-03-19	80-03-18	80-05-21	80-03-20
Geologic Unit	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S
pH (unite)	6.3	7.2	-	-	5.35	7.2	8.5	7.8	7.0
temperature (°C)	-	-	-	-	-	-	-	-	-
Total diss. solids (Calculated as mg/l)	310,000	313,000	6,700	268,000	327,000	267,000	153,000	266,000	103,000
Total diss. solids (residue, mg/l)	323,000	350,000	-	-	-	252,000	153,000	363,000	16,500
Hardness (mg/l as CaCO ₃)	49,000	6,400	3,400	200,000	-	15,000	12,000	-	-
Non-carbonate hardness (mg/l as CaCO ₃)	49,000	6,200	3,300	200,000	-	15,000	12,000	4,700	13,000
Total organic carbon (mg/l)	-	-	-	-	-	-	-	-	-
Sodium absorption ratio	-	-	-	-	-	-	-	-	-
Chloride (mg/l)	190,000	180,000	38,000	180,000	220,000	130,000	88,000	154,000	102,000
Fluoride (mg/l)	0.7	-	1.3	3.8	2.3	0.0	0.0	0.2	0.2
Alkalinity (mg/l as CaCO ₃)	53	182	45	650	400	80	160	-	-
Bicarbonate (mg/l as CaCO ₃)	-	220	-	-	-	-	-	-	-
Carbonate (mg/l as CaCO ₃)	-	0	-	-	-	-	-	-	-
Sulfate (mg/l)	3,300	10,000	2,800	1,200	480	12,000	7,600	5,190	11,000
Sulfide (mg/l)	-	-	-	-	0	-	-	-	-
Nitrite & nitrate (mg/l)	0.84	0.34	-	0.04	0.06	0.04	.05	-	-
Orthophosphate (mg/l)	-	-	-	-	-	-	-	-	-
Silica (mg/l)	3.2	2.0	1.3	15.0	0.4	2.6	2.5	0.1	6.0
Calcium (mg/l)	1,500	570	770	15,000	10,000	650	2,700	1,160	615
Magnesium (mg/l)	11,000	1,200	350	40,000	37,000	3,200	1,300	1,040	2,070
Sodium (mg/l)	100,000	120,000	24,000	23,000	48,000	90,000	52,000	102,000	65,000
Potassium (mg/l)	4,000	1,300	1,400	8,800	12,000	2,400	1,000	2,370	2,070
Gross Alpha as U. diss. (µg/l)	< 8,200	< 3,700	< 1,500	< 11,000	< 13,000	< 7,700	< 4,700	< 1,800	< 6,000
Gross Alpha as U. sus. (µg/l)	-	6.3	< 0.4	10	< 0.4	-	-	-	-
Gross Beta as Ca diss. (pCi/l)	7,200	< 2,000	1,300	13,000	9,800	< 3,600	< 1,700	< 7,100	< 2,700
Gross Beta as Cs sus. (pCi/l)	-	2.3	< 0.4	2.8	< 0.4	-	-	-	-
Gross Beta as Sr/Y diss. (pCi/l)	< 6,900	< 1,600	< 1,200	12,000	8,800	< 3,800	< 1,800	< 15,000	< 2,800
Gross Beta as Sr/Y sus. (pCi/l)	-	1.9	< 0.4	2.5	< 0.4	-	-	-	-
Diss. Radium (pCi/l)	10	15	0.59	340	11	2.7	12	2.4	3.6
Diss. Natural Uranium (µg/l)	0.37	1.3	0.08	< 0.02	0.05	0.29	5.2	< 0.07	2.7

Well	H-10C	P-14	P-15	P-17	P-18	V-25	V-26	V-27	V-28
Date Sampled	80-05-19	77-02-24	79-04-03	79-05-11	79-05-11	80-03-19	80-03-18	80-05-21	80-03-20
Geologic Unit	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S	R/S
Arsenic, tot. (ug/l)									
Arsenic, diss. (ug/l)									
Boron, diss. (ug/l)									
Cadmium, tot. (ug/l)									
Cadmium, diss. (ug/l)									
Chromium, tot. (ug/l)									
Chromium, diss. (ug/l)									
Cobalt, tot. (ug/l)									
Cobalt, diss. (ug/l)									
Copper, tot. (ug/l)									
Copper, diss. (ug/l)									
Iron, tot. (ug/l)									
Iron, diss. (ug/l)									
Lead, tot. (ug/l)									
Lead, diss. (ug/l)									
Manganese, tot. (ug/l)									
Manganese, diss. (ug/l)									
Mercury, tot. (ug/l)									
Mercury, diss. (ug/l)									
Selenium, tot. (ug/l)									
Selenium, diss. (ug/l)									
Zinc, tot. (ug/l)									
Zinc, diss. (ug/l)									
	120,000	1,700	3,700	880	160,000	35,000	30,000	1,300	54,000

Well	W-29	W-30
Date Sampled	80-03-18	80-03-19
Geologic Unit	R/S	R/S
pH (units)	7.3	7.0
temperature (°C)	-	-
Total diss. solids (Calculated as mg/l)	97,000	323,000
Total diss. solids (residue, mg/l)	129,000	302,000
Hardness (mg/l as CaCO ₃)	10,000	12,000
Non-carbonate hardness (mg/l as CaCO ₃)	10,000	11,000
Total organic carbon (mg/l)	-	-
Sodium absorption ratio	-	-
Chloride (mg/l)	49,000	170,000
Fluoride (mg/l)	0.9	0
Alkalinity (mg/l as CaCO ₃)	130	320
Bicarbonate (mg/l as CaCO ₃)	-	-
Carbonate (mg/l as CaCO ₃)	-	-
Sulfate (mg/l)	12,000	7,000
Sulfide (mg/l)	-	-
Nitrite & nitrate (mg/l)	0.23	0.04
Orthophosphate (mg/l)	-	-
Silica (mg/l)	3.5	3.5
Calcium (mg/l)	850	850
Magnesium (mg/l)	2,000	2,300
Sodium (mg/l)	32,000	120,000
Potassium (mg/l)	1,000	1,500
Gross Alpha as U. diss. (ug/l)	<1,600	<11,000
Gross Alpha as U. sus. (ug/l)	-	-
Gross Beta as Ca diss. (pCi/l)	740	<4,500
Gross Beta as Ca sus. (pCi/l)	-	-
Gross Beta as Sr/Y diss. (pCi/l)	730	<4,500
Gross Beta as Sr/Y sus. (pCi/l)	-	-
Diss. Radium (pCi/l)	1.2	98
Diss. Natural Uranium (ug/l)	-	-
Diss. Uranium	2.0	<.01

Well	W-29	W-30
Date Sampled	80-03-18	80-03-19
Geologic Unit	R/S	R/S
Arsenic, tot. (ug/l)		
Arsenic, diss. (ug/l)		
Boron, diss. (ug/l)		
Cadmium, tot. (ug/l)		
Cadmium, diss. (ug/l)		
Chromium, tot. (ug/l)		
Chromium, diss. (ug/l)		
Cobalt, tot. (ug/l)		
Cobalt, diss. (ug/l)		
Copper, tot. (ug/l)		
Copper, diss. (ug/l)		
Iron, tot. (ug/l)		
Iron, diss. (ug/l)		
Lead, tot. (ug/l)		
Lead, diss. (ug/l)		
Manganese, tot. (ug/l)		
Manganese, diss. (ug/l)		
Mercury, tot. (ug/l)		
Mercury, diss. (ug/l)		
Selenium, tot. (ug/l)		
Selenium, diss. (ug/l)		
Zinc, tot. (ug/l)		
Zinc, diss. (ug/l)		
	21,000	77,000

Well Date Sampled Geologic Unit	R-1 76-06-02 Culebra	R-1 77-3-17 Culebra	R-2B 77-2-22 Culebra	R-2C 77-3-16 Culebra	R-3 77-03-17 Culebra	R-4B 78-12-14 Culebra	R-5B 78-12-19 Culebra	R-6B 78-12-20 Culebra	R-7B 80-03-20 Culebra
pH (units)	7.6	7.3	8.4	8.2	7.4	7.6	6.8	7.3	7.0
temperature (°C)	-	22.5	21.5	20.5	21.5	-	-	-	-
Total diss. solids (Calculated as mg/l)	30,000	97,300	8,890	12,500	51,600	18,200	144,000	52,000	3,200
Total diss. solids (residue, mg/l)	30,100	-	-	-	-	18,100	144,000	52,600	3,610
Hardness (mg/l as CaCO ₃)	3,100	9,500	2,400	2,200	6,500	2,200	8,700	7,000	2,000
Non-carbonate hardness (mg/l as CaCO ₃)	3,000	9,400	2,300	2,100	6,400	2,200	8,700	6,900	1,900
Total organic carbon (mg/l)	-	-	-	-	-	-	-	-	-
Sodium absorption ratio	-	130	19	33	103	-	-	-	-
Chloride (mg/l)	12,000	49,000	2,800	4,700	29,600	7,500	86,000	28,000	390
Fluoride (mg/l)	5.1	0.8	2.0	1.6	0.5	1.9	1.4	1.5	1.4
Alkalinity (mg/l as CaCO ₃)	-	-	-	-	-	-	-	-	100
Bicarbonate (mg/l as CaCO ₃)	105	100	59	62	115	59	41	-	-
Carbonate (mg/l as CaCO ₃)	0	0	5	0	0	-	-	-	-
Sulfate (mg/l)	7,400	11,000	3,000	3,200	5,700	4,000	810	3,800	1,900
Sulfide (mg/l)	-	-	-	-	-	-	-	-	-
Nitrite & nitrate (mg/l)	-	0.03	0.01	0.16	0.07	0.02	0.01	0.02	0.40
Orthophosphate (mg/l)	-	-	0.03	0	0	-	-	-	-
Silica (mg/l)	2.7	0.06	1.7	3.5	1.2	5.2	2.1	8.5	39
Calcium (mg/l)	740	820	690	680	1,500	180	360	1,200	590
Magnesium (mg/l)	280	1,800	160	120	670	430	1,900	970	130
Sodium (mg/l)	9,400	29,000	2,100	3,600	19,000	5,800	53,000	18,000	210
Potassium (mg/l)	190	5,600	91	120	630	180	1,400	500	1.4
Gross Alpha as U. dis. (ug/l)	<200	2,100	330	360	<880	720	4,000	<1200	< 56
Gross Alpha as U. sus. (ug/l)	<0.3	<0.4	380	<0.4	<0.4	-	-	-	-
Gross Beta as Ca dis. (pCi/l)	410	6,000	120	230	850	310	1,100	<420	19
Gross Beta as Ca sus. (pCi/l)	<0.4	1.0	110	<4	<0.4	-	-	-	-
Gross Beta as Sr/Y dis. (pCi/l)	390	4,900	97	180	710	290	1,000	<390	19
Gross Beta as Sr/Y sus. (pCi/l)	<0.4	0.1	88	<0.4	<0.4	-	-	-	-
Diss. Radium (pCi/l)	1.7	78	4.6	19	57	67.0	290	6.6	0.98
Diss. Natural Uranium (ug/l)	<290	-	4.2	3.8	-	-	-	-	-
Diss. Uranium (ug/l)	0.16	0.1	-	-	0.09	2.9	1.0	4.3	9.7

Well Date Sampled Geologic Unit	H-1 76-06-02 Culebra	H-1 77-3-172 Culebra	R-2B 77-2-22 Culebra	R-2C 77-3-16 Culebra	R-3 77-3-17 Culebra	M-4B 78-12-14 Culebra	M-5B 78-12-19 Culebra	M-6B 78-12-21 Culebra	R-7B 80-03-20 Culebra
Arsenic, tot. (ug/l)	0	0	1	2	14				
Arsenic, diss. (ug/l)	0	0	0	0	0				
Boron, diss. (ug/l)	2,400	18,000	9,500	10,000	20,000	19,000	36,000	9,500	780
Cadmium, tot. (ug/l)		90	20	40	60				
Cadmium, diss. (ug/l)		2	0	14	2				
Chromium, tot. (ug/l)		0	130	0	0				
Chromium, diss. (ug/l)		0	10	0	0				
Cobalt, tot. (ug/l)		500	150	100	<50				
Cobalt, diss. (ug/l)		0	1	0	0				
Copper, tot. (ug/l)		8,400	220	32,000	12,000				
Copper, diss. (ug/l)		1,500	1	420	12,000				
Iron, tot. (ug/l)		71,000	110,000	180,000	84,000				
Iron, diss. (ug/l)		790	20	110	50				
Lead, tot. (ug/l)		13,000	800	40,000	17,000				
Lead, diss. (ug/l)		150	1	36	12				
Manganese, tot. (ug/l)		4,000	200	2,900	1,000				
Manganese, diss. (ug/l)		2,800	200	140	120				
Mercury, tot. (ug/l)		0	0.5	0.1	0				
Mercury, diss. (ug/l)		0	0	0	0				
Selenium, tot. (ug/l)		1	2	2	2				
Selenium, diss. (ug/l)		1	0	1	1				
Zinc, tot. (ug/l)	<1	900	1,700	3,100	1,000	<1	<1	5	
Zinc, diss. (ug/l)		140	20	30	90				

Well Date Sampled Geologic Unit	R-8B 80-02-11 Culebra	R-9B 80-02-05 Culebra	R-10B 80-03-21 Culebra	P-14 77-3-14 Culebra	P-15 77-5-10 Culebra	P-17 Culebra	P-18 77-5-10 Culebra	W-25 80-06-14 Culebra	W-26 80-06-18 Culebra
pH (unite)	7.3	7.3	8.3	6.0	10.2	7.4	7.2	7.3	6.9
temperature (°C)	-	-	-	21.5	21.5	22.5	24.5	-	-
Total diss. solids (Calculated as mg/l)	3,000	3,300	66,000	33,700	23,700	92,500	118,000	17,000	16,000
Total diss. solids (residue, mg/l)	3,200	3,590	69,200	38,000	24,000	97,000	420,000	22,100	23,800
Hardness (mg/l as CaCO ₃)	2,100	2,100	8,100	11,000	2,200	11,000	80,000	3,300	4,400
Non-carbonate hardness (mg/l as CaCO ₃)	2,100	2,000	8,100	11,000	2,100	11,000	80,000	3,000	43,000
Total organic carbon (mg/l)	-	-	-	32	64	125	14	-	-
Sodium absorption ratio	-	-	-	-	-	-	-	-	-
Chloride (mg/l)	57	320	36,000	20,000	11,000	54,000	80,000	8,300	8,200
Fluoride (mg/l)	2.4	3.0	1.3	0.9	1.2	1.5	1.2	1.4	1.5
Alkalinity (mg/l as CaCO ₃)	61	90	37	-	-	-	-	370	130
Bicarbonate (mg/l as CaCO ₃)	-	-	-	357	63	77	310	-	-
Carbonate (mg/l as CaCO ₃)	-	-	-	0	24	0	0	-	-
Sulfate (mg/l)	2,000	2,000	5,600	1,400	3,200	5,000	980	2,400	2,300
Sulfide (mg/l)	-	-	-	-	-	-	-	0.8	0
Nitrite & nitrate (mg/l)	0.95	0.13	0.01	0.01	0.04	0.06	0.81	0.67	3.5
Orthophosphate (mg/l)	-	-	-	0.02	0.03	0.11	0.40	-	-
Silica (mg/l)	19	26	1.5	33	1.6	1.0	1.0	29	20
Calcium (mg/l)	570	580	1,600	3,100	770	1,700	5,600	920	1,200
Magnesium (mg/l)	170	150	1,000	760	63	1,600	16,000	250	340
Sodium (mg/l)	82	210	21,000	7,600	6,900	30,000	9,200	5,100	3,600
Potassium (mg/l)	4.7	9.0	520	600	1,700	120	6,200	0.9	2.0
Gross Alpha as U. diss. (ug/l)	91	<100	<1,600	<390	2,000	2,900	<4,800	<290	<390
Gross Alpha as U. sus. (ug/l)	<0.04	-	-	<0.4	<0.4	<0.4	<0.4	-	-
Gross Beta as Cs diss. (pCi/l)	< 19	<25	<590	790	1,900	1,300	7,700	<170	<220
Gross Beta as Cs sus. (pCi/l)	<0.4	-	-	<0.4	<0.4	<0.4	0.5	-	-
Gross Beta as Sr/Y diss. (pCi/l)	< 18	<23	<610	620	1,600	1,000	6,100	<160	<210
Gross Beta as Sr/Y sus. (pCi/l)	<0.4	-	-	<0.4	<0.4	<0.4	<0.4	-	-
Diss. Radium (pCi/l)	3.4	7.3	29	68	23	84	190	17	18
Diss. Natural Uranium (ug/l)	-	34	-	-	2.3	-	-	-	-
Diss. Uranium (ug/l)	7.4	34	0.08	<0.01	-	0.10	0.33	6.1	12.0

Well	H-88	H-9B	H-10B	P-14	P-15	P-17	P-18	V-25	V-26
Date Sampled	80-02-11	80-02-05	80-03-21				77-5-10	80-08-16	80-08-18
Geologic Unit	Culebra	Culebra	Culebra	Culebra	Culebra	Culebra	Culebra	Culebra	Culebra
Arsenic, tot. (ug/l)				4	5	2	0		
Arsenic, diss. (ug/l)				2	0	0	0		
Boron, diss. (ug/l)				700	4,700	1,700	100,000	1,900	1,800
Cadmium, tot. (ug/l)	580	780	13,000	40	30	90	160		
Cadmium, diss. (ug/l)				1	0	1	2		
Chromium, tot. (ug/l)				0	80	100	180		
Chromium, diss. (ug/l)				0	80	100	130		
Cobalt, tot. (ug/l)				200	100	400	850		
Cobalt, diss. (ug/l)				3	0	0	0		
Copper, tot. (ug/l)				100	1,400	660	1,100		
Copper, diss. (ug/l)				4	190	250	330		
Iron, tot. (ug/l)				19,000	16,000	67,000	48,000		
Iron, diss. (ug/l)				17,000	100	1,200	540		
Lead, tot. (ug/l)				200	1,100	1,100	2,100		
Lead, diss. (ug/l)				8	10	6	2,100		
Manganese, tot. (ug/l)				560	190	4,000	44,000		
Manganese, diss. (ug/l)				500	20	3,000	4,500		
Mercury, tot. (ug/l)				0.1	0	0.1	0		
Mercury, diss. (ug/l)				0	0	0	0		
Selenium, tot. (ug/l)				1	0	1	0		
Selenium, diss. (ug/l)				1	0	1	0		
Zinc, tot. (ug/l)				120	400	1,700	6,300		
Zinc, diss. (ug/l)				120	400	400	6,200		

Well	W-27	W-28	W-29	W-30
Date Sampled	80-08-22	80-08-21	80-08-20	80-08-13
Geologic Unit	Culebra	Culebra	Culebra	Culebra
pH (units)	6.4	6.4	6.1	6.8
temperature (°C)	-	-	-	-
Total diss. solids (Calculated as mg/l)	126,000	56,000	239,000	109,000
Total diss. solids (residue, mg/l)	186,000	74,000	239,300	110,000
Hardness (mg/l as CaCO ₃)	16,000	4,900	26,000	6,300
Non-carbonate hardness (mg/l as CaCO ₃)	16,000	4,300	25,000	6,300
Total organic carbon (mg/l)	-	-	-	-
Sodium absorption ratio	-	-	-	-
Chloride (mg/l)	77,000	30,000	140,000	64,000
Fluoride (mg/l)	0.5	1.1	0.7	0.5
Alkalinity (mg/l as CaCO ₃)	150	670	210	74
Bicarbonate (mg/l as CaCO ₃)	-	-	-	-
Carbonate (mg/l as CaCO ₃)	-	-	-	-
Sulfate (mg/l)	3,900	3,200	13,000	5,050
Sulfide (mg/l)	0	10	0	0
Nitrite & nitrate (mg/l)	4.0	0.09	0.02	1.2
Orthophosphate (mg/l)	-	-	-	-
Silica (mg/l)	13	28	11	2.9
Calcium (mg/l)	3,100	1,200	810	1,100
Magnesium (mg/l)	2,000	470	5,700	870
Sodium (mg/l)	39,000	21,000	79,000	37,000
Potassium (mg/l)	714	4.0	150	888
Gross Alpha as U. diss. (pCi/l)	<2,600	<1,600	<11,000	<1,300
Gross Alpha as U. sus. (pCi/l)	-	-	-	-
Gross Beta as Cs diss. (pCi/l)	6,300	<1,100	18,000	< 660
Gross Beta as Cs sus. (pCi/l)	-	-	-	-
Gross Beta as Sr/Y diss. (pCi/l)	6,100	<1,000	17,000	<600
Gross Beta as Sr/Y sus. (pCi/l)	-	-	-	-
Diss. Radium (pCi/l)	79	40	17	64
Diss. Natural Uranium (ug/l)	-	-	-	-
Diss. Uranium (ug/l)	4.9	1.3	16	0.29

Well	W-27	W-28	W-29	W-30
Date Sampled	80-08-22	80-08-21	80-08-20	80-08-13
Geologic Unit	Culebra	Culebra	Culebra	Culebra
Arsenic, tot. (ug/l)				
Arsenic, diss. (ug/l)				
Boron, diss. (ug/l)	1,900	5,400	45,000	64,000
Cadmium, tot. (ug/l)				
Cadmium, diss. (ug/l)				
Chromium, tot. (ug/l)				
Chromium, diss. (ug/l)				
Cobalt, tot. (ug/l)				
Cobalt, diss. (ug/l)				
Copper, tot. (ug/l)				
Copper, diss. (ug/l)				
Iron, tot. (ug/l)				
Iron, diss. (ug/l)				
Lead, tot. (ug/l)				
Lead, diss. (ug/l)				
Manganese, tot. (ug/l)				
Manganese, diss. (ug/l)				
Mercury, tot. (ug/l)				
Mercury, diss. (ug/l)				
Selenium, tot. (ug/l)				
Selenium, diss. (ug/l)				
Zinc, tot. (ug/l)				
Zinc, diss. (ug/l)				

Well Date Sampled Geologic Unit	H-1 76-06-04 Magenta	H-1 77-05-10 Magenta	H-2A 77-02-22 Magenta	H-3 77-05-10 Magenta	H-3 79-05-10 Magenta	H-4A 78-12-14 Magenta	H-5A 78-12-14 Magenta	H-6A 78-12-20 Magenta	H-8A 80-02-12 Magenta
pH (units)	7.4	7.2	8.6	8.0	-	8.0	7.8	7.3	9.3
Temperature (°C)	-	22	-	-	-	-	-	-	-
Total diss. solids (Calculated as mg/l)	19,000	22,000	10,300	30,000	-	22,300	6,000	5,700	9,000
Total diss. solids (residue, mg/l)	18,900	22,200	12,000	32,000	-	22,300	-	-	9,410
Hardness (mg/l as CaCO ₃)	3,300	4,400	2,700	5,000	-	2,200	1,300	2,000	2,200
Non-carbonate hardness (mg/l as CaCO ₃)	3,300	4,300	2,700	4,900	-	2,100	1,300	2,000	2,200
Total organic carbon (mg/l)	-	-	-	-	-	-	-	-	-
Sodium absorption ratio	-	41	-	-	-	-	-	-	-
Chloride (mg/l)	8,000	10,000	4,100	15,000	-	7,500	880	1,200	3,500
Fluoride (mg/l)	2.8	2.0	-	1.8	-	2.5	2.8	1.4	0.7
Alkalinity (mg/l as CaCO ₃)	75	-	61	42	-	52	41	42	26
Bicarbonate (mg/l as CaCO ₃)	92	93	74	51	-	63	50	51	-
Carbonate (mg/l as CaCO ₃)	0	0	0	0	-	-	-	-	-
Sulfate (mg/l)	3,900	3,600	2,400	3,400	-	7,000	3,200	2,700	2,100
Sulfide (mg/l)	0	-	-	-	-	-	-	-	-
Nitrite & nitrate (mg/l)	-	0.04	0.04	0.08	-	0.01	0.01	0.03	0.06
Orthophosphate (mg/l)	-	0.03	-	-	-	-	-	-	-
Silica (mg/l)	1.3	1.7	6.0	6.4	-	6.4	9.0	7.7	0.9
Calcium (mg/l)	890	1,000	820	1,200	-	210	240	520	870
Magnesium (mg/l)	270	460	170	480	-	410	170	160	17
Sodium (mg/l)	5,700	6,200	2,700	9,300	-	7,000	1,500	1,100	2,400
Potassium (mg/l)	70	840	81	250	-	130	53	46	84
Gross Alpha as U. diss. (ug/l)	<400	<400	<160	<550	<620	<320	160	110	<200
Gross Alpha as U. sus. (ug/l)	<0.4	<0.4	12	<0.4	0.4	-	-	-	<0.4
Gross Beta as Ca diss. (pCi/l)	940	940	69	330	1,300	<100	53	43	130
Gross Beta as Ca sus. (pCi/l)	<0.4	<0.4	2.6	<0.4	0.4	-	-	-	<0.4
Gross Beta as Sr/Y diss. (pCi/l)	790	790	55	260	1,200	<92	48	39	130
Gross Beta as Sr/Y sus. (pCi/l)	<0.4	<0.4	2.0	<0.4	0.4	-	-	-	<0.4
Dis. Radium (pCi/l)	170	170	6.1	44	10	9.3	17	11	1.9
Dis. Natural Uranium (ug/l)	-	-	-	-	-	-	-	-	-
Dis. Uranium (ug/l)	0.6	0.6	0.8	-	0.24	0.08	1.0	6.7	0.08

Well Date Sampled Geologic Unit	W-1 76-06-04 Magenta	H-1 77-05-10 Magenta	H-2A 77-02-22 Magenta	H-3 77-05-10 Magenta	H-3 79-05-10 Magenta	H-4A 78-12-14 Magenta	H-5A 78-12-14 Magenta	H-6A 78-12-20 Magenta	H-8A 80-02-12 Magenta
Arsenic, tot. (ug/l)		21							
Arsenic, diss. (ug/l)		0							
Boron, diss. (ug/l)	2,200	3,300	220	13,000		13,000	11,000	2,500	3,100
Cadmium, tot. (ug/l)		50							
Cadmium, diss. (ug/l)		1							
Chromium, tot. (ug/l)		600							
Chromium, diss. (ug/l)		100							
Chromium, diss. (ug/l)		350							
Cobalt, tot. (ug/l)		0							
Cobalt, diss. (ug/l)		27,000							
Copper, tot. (ug/l)		3							
Copper, diss. (ug/l)		660,000							
Iron, tot. (ug/l)		220							
Iron, diss. (ug/l)		27,000							
Lead, tot. (ug/l)		0							
Lead, diss. (ug/l)		9,600							
Manganese, tot. (ug/l)		950							
Manganese, diss. (ug/l)		0.1							
Mercury, tot. (ug/l)		0							
Mercury, diss. (ug/l)		1							
Selenium, tot. (ug/l)		0							
Selenium, diss. (ug/l)	1	0	1	7	1	< 1	< 1	1	-
Zinc, tot. (ug/l)		36,000							
Zinc, diss. (ug/l)		400							

Well Date Sampled Geologic Unit	H-9A 80-02-05 Magenta	H-10A 80-03-21 Magenta	W-25 80-09-04 Magenta	W-27 80-07-24 Magenta	W-27 80-09-20 Magenta	W-30 80-09-24 Magenta
pH (units)	8.5	7.1	7.5	6.6	6.5	8.8
temperature (°C)	-	-	-	-	-	-
Total diss. solids (Calculated as mg/l)						
Total diss. solids (residue, mg/l)	5,100	261,000	12,000	109,000	147,000	18,500
Hardness (mg/l as CaCO ₃)	5,460	270,000	18,700	106,000	173,000	19,000
Non-carbonate hardness (mg/l as CaCO ₃)	2,100	17,000	3,300	11,000	17,000	2,400
Total organic carbon (mg/l)	2,000	17,000	3,100	11,000	17,000	2,400
Sodium absorption ratio	-	-	-	-	-	-
Chloride (mg/l)	750	160,000	5,600	61,000	85,000	8,700
Fluoride (mg/l)	1.8	1.3	1.5	0	0.4	1.9
Alkalinity (mg/l as CaCO ₃)	35	0	150	57	180	62
Bicarbonate (mg/l as CaCO ₃)	-	-	-	-	-	-
Carbonate (mg/l as CaCO ₃)	-	-	-	-	-	-
Sulfate (mg/l)	2,700	2,700	1,900	9,400	2,900	3,200
Sulfide (mg/l)	-	-	1.2	-	1.8	0
Nitrite & nitrate (mg/l)	0.02	0.03	0.64	0.32	0.4	0
Orthophosphate (mg/l)	-	-	-	-	-	-
Silica (mg/l)	3.3	1.9	25	1.7	13	0.7
Calcium (mg/l)	550	2,500	910	1,100	3,600	690
Magnesium (mg/l)	170	2,600	240	1,900	2,000	170
Sodium (mg/l)	800	93,000	3,100	34,000	43,000	5,500
Potassium (mg/l)	28	510	0.8	1,800	10,000	190
Gross Alpha as U. diss. (µg/l)	<150	<7,800	<230	-	<2,900	<440
Gross Alpha as U. sus. (µg/l)	-	-	-	-	-	-
Gross Beta as Ca diss. (pCi/l)	<38	<3,500	<140	1,900	6,000	<200
Gross Beta as Ca sus. (pCi/l)	-	-	-	-	-	-
Gross Beta as Sr/Y diss. (pCi/l)	<35	<3,600	<130	1,800	5,800	<190
Gross Beta as Sr/Y sus. (pCi/l)	-	-	-	-	-	-
Diss. Radium (pCi/l)	9.4	480	12	12	24	26
Diss. Natural Uranium (µg/l)	-	-	-	-	-	-
Diss. Uranium (µg/l)	0.15	<0.10	8.4	-	5.8	0.02

Well	H-9A	H-10A	W-25	W-27	W-27	W-30
Date Sampled	80-02-05	80-03-21	80-09-04	80-07-24	80-09-20	80-09-24
Geologic Unit	Magenta	Magenta	Magenta	Magenta	Magenta	Magenta
Arsenic, tot. (ug/l)						
Arsenic, diss. (ug/l)						
Boron, diss. (ug/l)	2,600	3,900	1,900	26,000	230	12,000
Cadmium, tot. (ug/l)						
Cadmium, diss. (ug/l)						
Chromium, tot. (ug/l)						
Chromium, diss. (ug/l)						
Cobalt, tot. (ug/l)						
Cobalt, diss. (ug/l)						
Copper, tot. (ug/l)						
Copper, diss. (ug/l)						
Iron, tot. (ug/l)						
Iron, diss. (ug/l)						
Lead, tot. (ug/l)						
Lead, diss. (ug/l)						
Manganese, tot. (ug/l)						
Manganese, diss. (ug/l)						
Mercury, tot. (ug/l)						
Mercury, diss. (ug/l)						
Selenium, tot. (ug/l)						
Selenium, diss. (ug/l)						
Zinc, tot. (ug/l)						
Zinc, diss. (ug/l)						