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Radionuclide Transport from Yucca Mountain and Inter-basin Flow in Death Valley

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ABSTRACT

Hydrodynamics and the U.S. Geological survey conducted studies to evaluate far-field issues related to potential transport, by ground water, of radionuclide into Inyo County from Yucca Mountain, including Death Valley, and the evaluation of a connection between the Lower Carbonate Aquifer (LCA) and the biosphere. Our oversight and completed Cooperative Agreement research, and a number of other investigators research indicate that there is groundwater flow between the alluvial and carbonate aquifers both at Yucca Mountain and in Inyo County. The specific purpose of our research was to acquire geological, subsurface geology, and hydrologic data to:

1. Establish the existence of inter-basin flow between the Amargosa Basin and Death Valley Basin,
2. Characterize groundwater flow paths in the LCA through Southern Funeral Mountain Range, and
3. Evaluate the hydraulic connection between the Yucca Mountain repository and the major springs in Death Valley through the LCA.
4. Evaluate the hydraulic connection between the Yucca Mountain repository and Franklin Lake Playa.

The hydraulic characterization of the LCA is of critical interest to Inyo County and the U.S. Department of Energy because:

1. The upward gradient in the LCA at Yucca Mountain provides a natural barrier to radionuclide transport,
2. The LCA is a necessary habitat resource for the endangered Devil's Hole pup fish, and
3. The LCA is the primary water supply and source of water to the major springs in Death Valley National Park.

This paper presents the results of our study program to evaluate if inter-basin flow exists between the Amargosa and Death Valley Basins through the LCA. The study presents the results of our structural geology analysis of the Southern Funeral Mountain range, geochemical source analysis of spring waters in the region, and a numerical groundwater model to simulate inter-basin flow in the Southern Funeral Mountain range.

INTRODUCTION

The United States is engaged in the licensing of the Yucca Mountain high-level nuclear waste repository, just to the west of the Nevada Test Site. The repository will be sited in the unsaturated volcanic tuffs beneath the mountain.

Underlying the Tertiary tuffs that make up the upper parts of the mountain is a sequence of Paleozoic carbonate rock that is a significant aquifer. Winograd and Thordarson (1) working at the Nevada Test Site in the 1950s hypothesized that the Paleozoic carbonate aquifer underlies a large area of southern and eastern Nevada and integrates the groundwater hydrology of a number of valleys in the area.

The original Winograd and Thordaerson (1) hypothesis was based upon the observation that the water chemistry of carbonate groundwater from wells at the Nevada Test Site were similar to the water chemistry of groundwater from the major springs that are associated with the carbonate aquifer to the south—Devils Hole, Ash Meadows, and the springs at Furnace Creek in Death Valley. Based upon this evidence they suggested that groundwater that flowed beneath Yucca Mountain and the Nevada Test Site discharges in the large spring complexes to the south. Flowing groundwater in the Paleozoic carbonate aquifer is one potential pathway by which contaminants from the proposed repository could reach the biosphere.

Wionograd and Thordarson (1) were slow to publish their definitive U.S. Geological Survey (USGS) Professional Paper. Even so, other investigators quickly adopted the Winograd/Thordarson Paleozoic carbonate aquifer hypothesis; one of the earliest was Mifflin (2). Since the 1960s the conceptual idea of a large carbonate aquifer integrating much of the groundwater hydrology of eastern and southern Nevada has become something more than a hypothesis; it has taken on the air of the prevailing doctrine. The USGS did a Regional Aquifer System Analysis (RASA) of the Paleozoic carbonate aquifer province; this study included a groundwater model of the entire province (3).

Working on behalf of Inyo County, California, our concern is the potential for contaminants from the Yucca Mountain Repository to reach the Paleozoic carbonate aquifer and then be transported to the biosphere. Should the contaminants reach the carbonate aquifer they will almost certainly be moved to the discharge area of the aquifer in Death Valley. This paper is concerned with the potential for contaminant transport from Yucca Mountain to discharge area in Death Valley. It is our intent to draw heavily upon the work of the USGS and others in examining how readily contaminants could potentially move through the carbonate aquifer.

DEATH VALLEY REGIONAL GROUNDWATER MODEL

Concern about the potential transport of contaminants from both the Nevada Test Site and from Yucca Mountain led to groundwater flow models being developed for both sites. Initially two separate models were developed—one for the Test Site by IT/GeoTrans and a second for Yucca Mountain by the USGS. Initially this was a duplication of effort. It was decided to merge the two efforts into a single model under the leadership of the USGS (4).

A groundwater flow model of the area poses unique problems. The area is broken up into mountain ranges and intervening valleys. In addition the area was at the continental margin during much of its geologic history; the facies of many of the stratigraphic units change in the area of the model. While there are outcrops of the rocks in the mountain ranges, there are few drill holes in the valleys that penetrate the Paleozoic carbonate aquifer. Creating the model is a challenging problem.

The final USGS model design is unusual. The model consists of 16 layers that are created based loosely upon elevation—they are more or less horizontal slices of rock. Superimposed on the layers is the usual horizontal finite difference grid—cells are 1500 m by 1500 m in the east-west and north south-direction. Using this grid system the rocks that underlie the region can be assigned into the grid cells within the model (5).

This modeling system has both strengths and weaknesses. Its strength is that it readily accommodates the rapid horizontal changes in lithology that occur within the region—all the differing rocks are readily accommodated. The scheme has the disadvantage that it is hard to follow a given aquifer through the model. For example, one has to search for all the cells in each layer that contain Paleozoic carbonate. One then has to aggregate the information from the layers to obtain a picture of the total carbonate rock at any location. If several layers at any given location contain Paleozoic carbonate the head representing the aquifer at that location has to be interpreted from the head in each of the model layers (6).

Geology in the Model

There are few drill holes in the area of the Death Valley flow system model that reach the Paleozoic carbonate aquifer beneath the valleys. Outcrops of the various stratigraphic units, including Paleozoic carbonate rocks occur in the mountain ranges. However, in order to fully populate the model it is necessary to interpret the geology, especially the geology beneath the valleys. Geologists constructed a series of cross-sections through the area of the model that depicted their interpretation of the geology.

Geologic mapping in the mountain ranges where the rocks are exposed is a more or less straightforward procedure. However, interpreting the geology beneath the valleys is a much more subjective endeavor, even when it is guided by regional geophysics. There is the further problem that the data must be interpolated from the cross-sections to the model grid; errors in input can occur in this procedure (7).

In summary, the USGS Death Valley Regional Flow System Model has the advantage that the laterally discontinuous nature of rocks in the region are accommodated. The model has the disadvantage that it is difficult to extract information of interest. It is our intent to extract form the USGS as much information as possible that pertains to the Carbonate aquifer.

THE PALEOZOIC CARBONATE AQUIFER

Our particular concern is the Paleozoic carbonate aquifer. We extracted from the USGS Death Valley Regional Flow Model the data pertaining to the Paleozoic carbonate aquifer. Figure 1 is a distribution map for the carbonate taken from the USGS Regional model area.

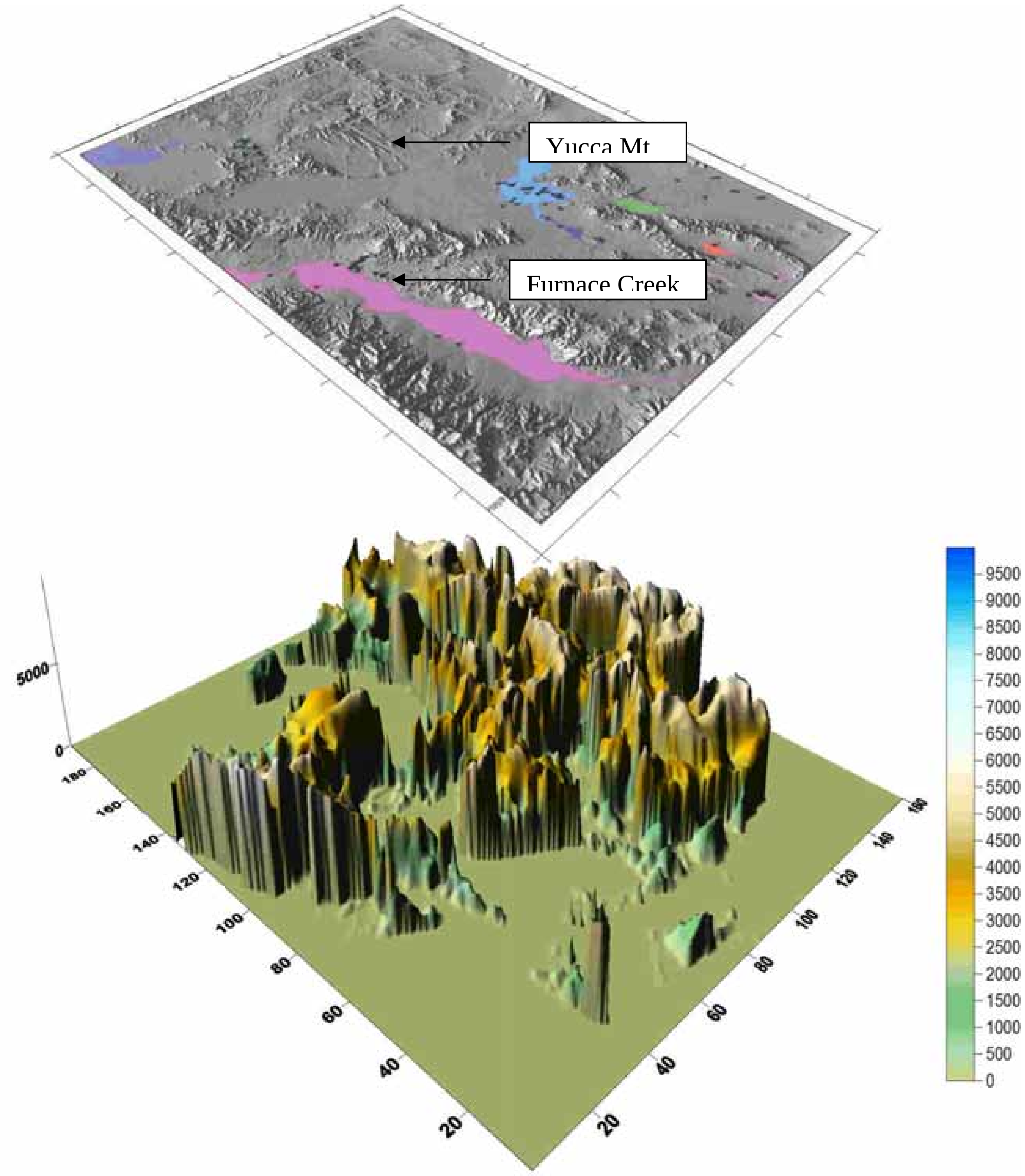

Figure 1. Distribution of carbonate rocks in the Death Valley Regional Flow System Model.

As Figure 1 illustrates, the carbonate rocks are discontinuous across the region. In places they are very thick, reaching more than 5000 m in thickness. A large mass of carbonate rock underlies Yucca Mountain and the Amargosa Valley that extends through the Southern Funeral Mountains.

The potentiometric surface for the area indicates an area of low gradients over the Amargosa Valley that is bounded by an area of high gradients through the Southern Funeral Mountain Range to the southwest to a spring discharge area in Death Valley. Within the area of low gradients discharge occurs at Ash Meadows, and to a lesser amount in Pahrump Valley, Shoshone and Tecopa.

Amargosa Valley Sub-Region

Our focus is on Yucca Mountain, the Amargosa Valley, and the Southern Funeral Mountains. It is through this area that the Paleozoic carbonate aquifer provides a potential pathway for contaminants to be transported from the Yucca Mountain Repository to the biosphere.

We extracted from the USGS regional model the thickness of the Paleozoic carbonate rock in the sub region. Figure 2 is an isolith map for the Paleozoic carbonate rock within the sub-region. Not all of the sub-region contains carbonate. Beneath the Amargosa Valley the Paleozoic carbonate rocks are greater than 5000 m thick. In this area, even extensional basin and range faults with large vertical throws would juxtapose carbonate rocks against carbonate rocks across the faults. With such large thickness of carbonate rock one can understand why the aquifer integrates the subsurface flow at depth.

Each researcher working on the hydrogeology of the Paleozoic carbonate aquifer has a somewhat different conceptual image of what forms the interconnected pore space of the Paleozoic carbonate aquifer. The brittle carbonate rocks are broken up by the tectonics of the basin and range. Joints and faults in the rock have been enlarged by subsequent dissolution of the rock. Caverns are known to occur—Devils Hole is a good example. The question arises: can one drill anywhere in the carbonate rock terrain and obtain a reasonable productive water well—a well producing several hundred gallons a minute or more? Experienced Nevada ground-water hydrologists believe this is possible, provided that one drills a “sufficient” thickness of carbonate rock.

Recently the Southern Nevada Water Authority (SNWA) (8) proposed to pump groundwater from valleys to the south and east of Ely, Nevada and pipe it to Las Vegas. Estimates vary for their proposed withdrawal; but they talk in terms of 190 million cubic meters annually (150,000 acre-feet). One of their early requests to the Nevada State Engineer is for a water right to pump 110 million cubic meters (90,000 acre-feet) annually from Spring Valley. SNWA’s contractor, Durbin & Associates, assembled hydraulic conductivity values for the entire Paleozoic carbonate region as input for a model of Spring Valley (8). Figure 3 illustrates a cumulative distribution of tramsmissivity taken from the SNWA data.

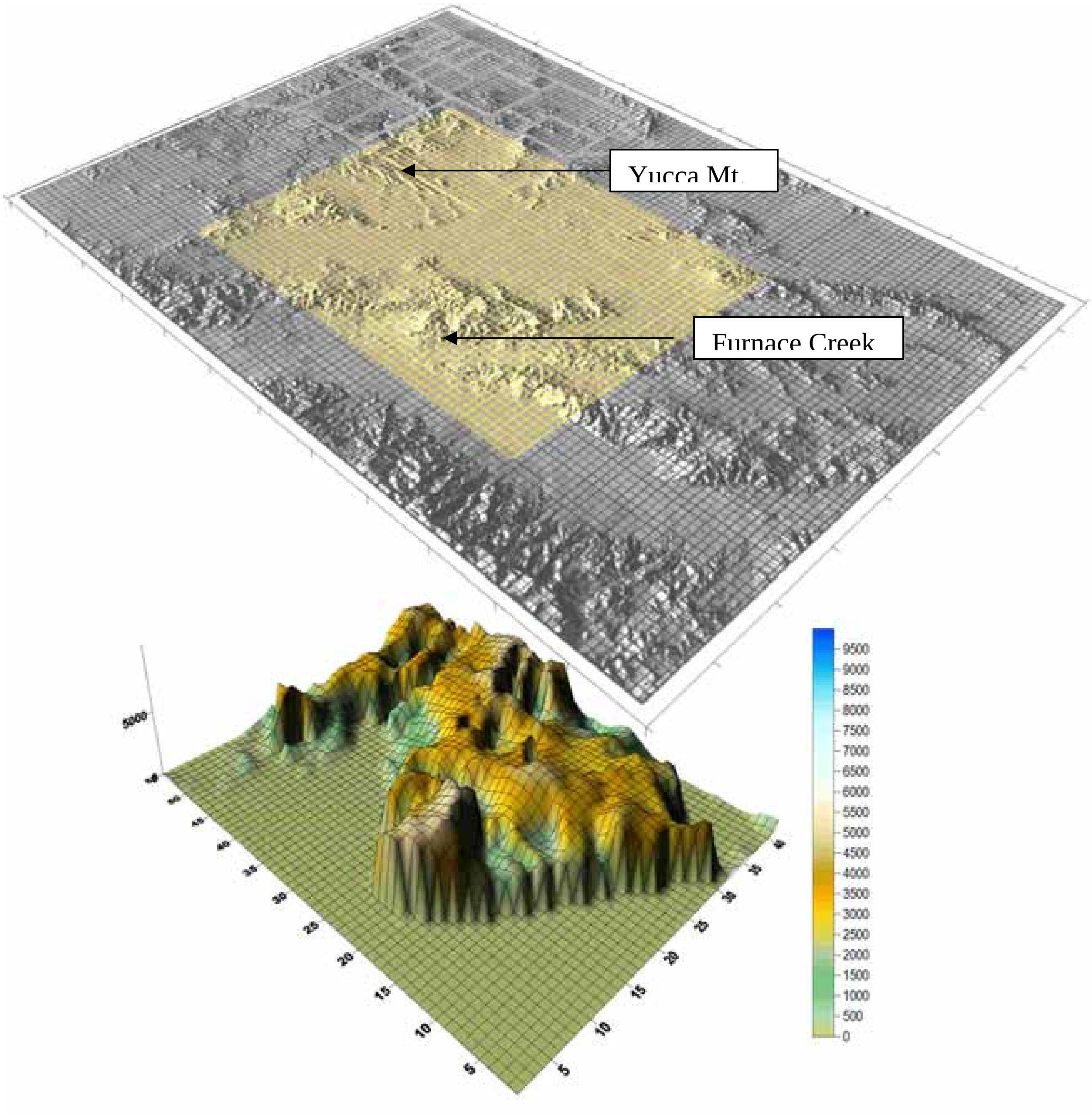

Figure 2. Thickness of the Paleozoic carbonate rocks in the sub-region.

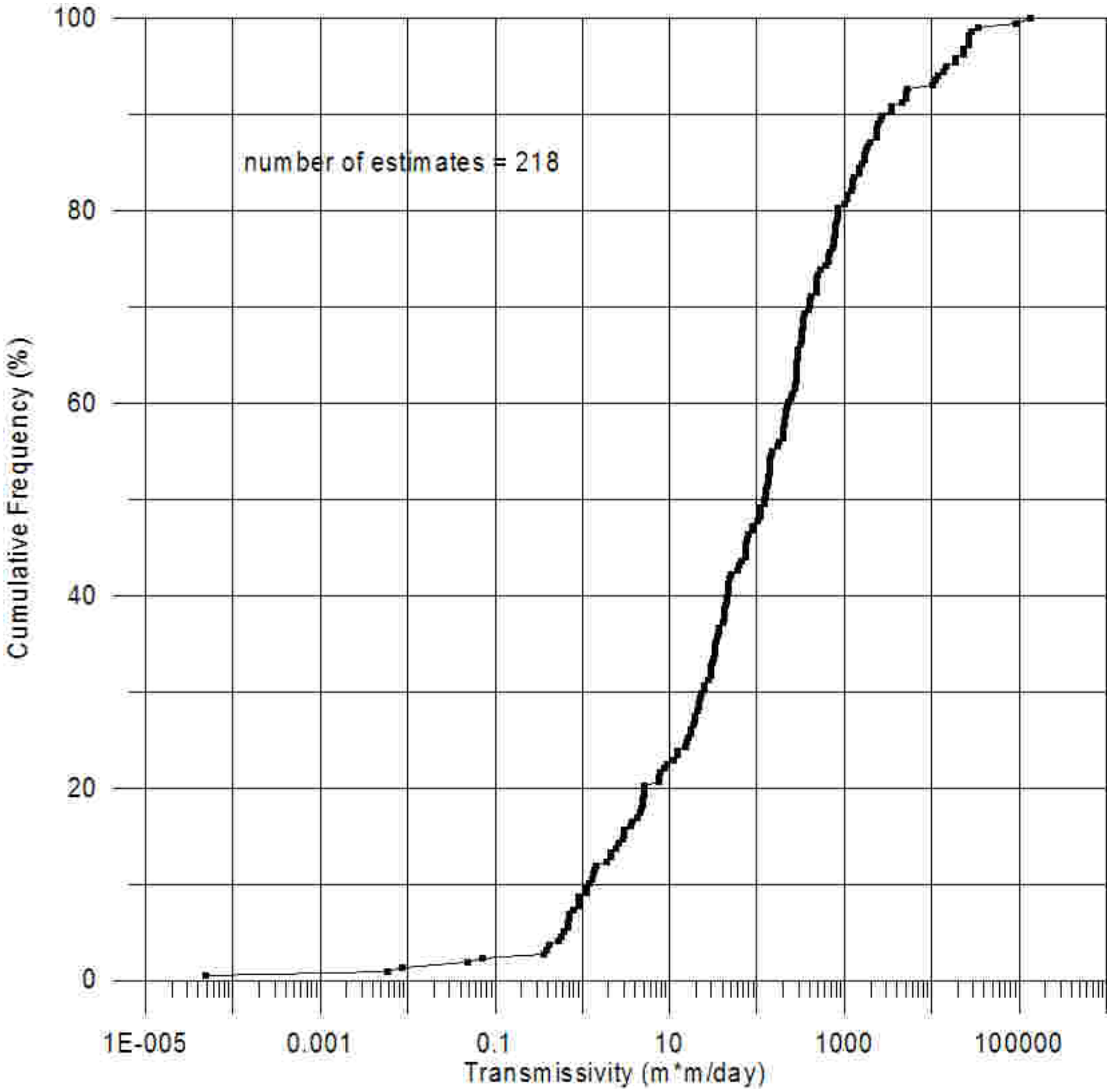

Figure 3. Cumulative distribution of Transmissivity from SNWA data (SNWA, 2006).

These data suggest that there is approximately an 85% chance of obtaining a well that yields 0.4 cubic meters per minute with 30 meters of drawdown (100 gpm with 100 feet of drawdown). It also indicates that there is approximately a 10% chance that a well with 30 meters of drawdown will yield approximately 8 cubic meters per minute (2000 gallons per minute with 100 feet of drawdown).

One can calculate a hydraulic conductivity from the Transmissivity data. The usual assumption is that the screened interval, or the open-hole section of the portion of the well tested should be divided into the transmissivity to obtain a local estimate of the hydraulic conductivity. If one compares the cumulative ratio of the cumulative distributions you see that the hydraulic conductivity generally represents approximately 30 meters of tested well section. This suggests that there is about an 85% chance that if one drills a sufficiently thick section of Paleozoic carbonate rock one will find a 30 meter, or smaller zone that is sufficiently permeable to yield a good well (defined as more than 100 gpm with 100 feet of drawdown).

In other words, our simple conceptual model of the hydraulic conductivity in the aquifer is—the aquifer contain at least a permeable zone, maybe 10 meters, or several tens of meters thick, more or less everywhere where the Carbonate rocks are more than several hundred meters thick. The permeability is enhanced where it is associated with recent faulting within the carbonate units. Barriers to flow seem to occur where the carbonate is juxtaposed against less permeable rock. Caves are known in the carbonate rock; for example, Devils Hole is a known cave.

There is some suggestion in the carbonate data that the hydraulic conductivity decreases with depth; however, the data very scattered—noisy. Some workers explain that this scatter is due to burial; on the other hand, the temperature rises with depth making the water less viscous, increasing the hydraulic conductivity. Researchers seem to assume a depth of burial beneath which the hydraulic conductivity does not decrease further. This seems questionable, given the noisy nature of the data, that correcting the hydraulic conductivity for depth adds much to the precision of the analysis.

The conceptual model may not be all that important when one’s concern is only the movement of water. However, when you begin to transport chemical constituents the nature of the conduit for flow becomes all-important—more on the permeability/porosity conceptual model below.

A Simple Flow Model

One simple way to investigate the system is to assume that the principal pathway for flow is mostly through the Paleozoic carbonate aquifer. With this thought in mind one can construct a model for flow through only the carbonate rock; this is a simplistic, first-order approximation for the system; but it provides insight. The USGS in their RASA study used a two-layer idealized model—this model is even simpler.

In the Ash Meadows/Amargosa area the largest amount of recharge comes from the Spring Mountains. The big discharge areas are in Ash Meadows, Pahrump Valley, in the area of Shoshone and Tecopa, and in Death Valley. Approximately 75% of the recharge comes from the Spring Mountains.

We created a one-layer model of the Paleozoic carbonate aquifer. As suggested above, this is a kind of zero-order model that provides insight into how contaminants might move through the carbonate aquifer. In this model the aquifer is decoupled from the overlying Tertiary deposits. Where the Paleozoic carbonate aquifer has been penetrated in the area a good low-permeability confining layer overlies the aquifer. We know that this isolates the aquifer, not totally, but certainly to a great degree. So the simple model is only useful in that it provides an estimate of how contaminants might move. Figure 4 is a computed steady-state potentiometric surface generated from the one layer model. Flow is continuous in the aquifer from the area of Yucca Mountain to the discharge area in Death Valley.

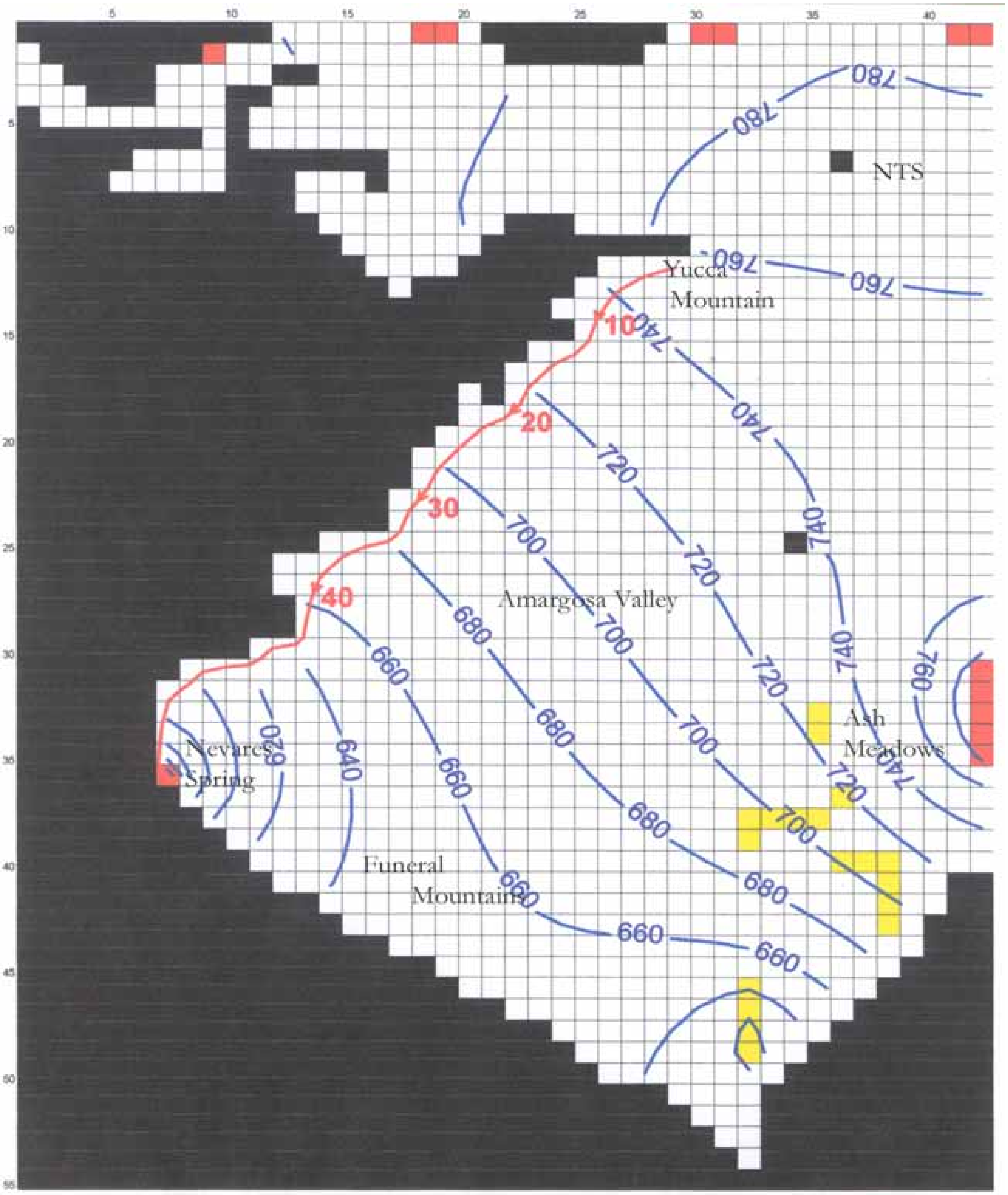

Figure 4. Map of steady state hydraulic head from the one layer carbonate aquifer model.

The yellow areas are spring discharge areas. The red line is a particle track for a particle introduced in the vicinity of Yucca Mountain that exits in Death Valley—the red numbers are estimates in years of the time of travel for the particle.

Potential for Contaminant Travel Through the Carbonate Aquifer

One common way to estimate the time of travel of a chemical constituent is to assume that the constituent moves with the velocity of the water. In groundwater flow, Darcy’s Law defines the groundwater velocity as:

$$v = K/\varepsilon\ (\partial h/\partial l)$$

Where v is the groundwater velocity, K is the hydraulic conductivity, ε is the porosity, and $(\partial h/\partial l)$ is the gradient in hydraulic head. The question becomes what is the appropriate porosity to apply to the calculation? This again raises the issue of how one conceives of the connected pore space in the aquifer. There are several investigations that shed some information on this issue.

Winograd and Pearson (9) investigated the isotopic content of major springs in the Ash meadows complex. They focused particularly on carbon 14 that varied greatly between individual springs. They concluded that the carbon 14 content of the springs was best explained by what they termed “mega scale channeling” within the aquifer.

One hole in the vicinity of Yucca Mountain, UE 25p1, penetrated approximately 500 m of the Paleozoic carbonate aquifer. Galloway and Rojstaczer (10) studied earth tide signals in the carbonate aquifer. They concluded that the aquifer was well confined, and that the storage coefficient derived from their analysis indicated porosity less than 1%. Craig and Robison (11) estimated from a pumping test that the transissivity of the carbonate aquifer penetrated by the hole was 59 m^2/day this is approximately mid-range in the transmissivity distribution (see Figure 3).

The evidence suggests that the porosity one assigns to the carbonate aquifer to estimate the velocity of groundwater flow should be less than 1%. This is consistent with a fractured zone in the thick carbonate sediments that is highly permeable.

The particle path line, shown on Figure 4, is calculated using a permeable zone 100 meters thick, with a porosity of 0.1%. With this calculation it takes less than 50 years for the particle to travel though the aquifer from vicinity of Yucca Mountain to Death Valley. If the porosity were 1% the travel time would be 500 years.

What Protects the Carbonate Aquifer at Yucca Mountain

Borehole UE 25p1 had a hydraulic head in the Paleozoic carbonate aquifer that was 15 m higher than the hydraulic head in the overlying Tertiary volcanic rocks (12). This higher head has the potential to move groundwater upward from the carbonate into the overlying volcanic sequence of rocks. As long as the head relationship remains as presently observed the carbonate is protected from contamination moving downward from the repository to the carbonate aquifer.

Hydraulic head is one of the more ephemeral of hydrologic conditions. Changes within the groundwater basin can change the hydraulic head. The head is probably most subject to change by development of groundwater for water supply in the Amargosa Valley. The population of southern Nevada is growing rapidly. Local groundwater is looked to for at least a large portion of the water supply. Both the valley fill deposits and the Paleozoic carbonate aquifer are the target for development. Groundwater development by lowering the hydraulic head could eliminate the upward hydraulic head gradient as a barrier to contaminate movement into the carbonate aquifer at Yucca Mountain.

SUMMARY AND CONCLUSIONS

The Paleozoic carbonate aquifer in the Death Valley flow system has been the site of intensive investigation since the 1950s. Conventional wisdom, that has become doctrine, has the carbonate aquifer integrating the ground water flow in the area. The investigations have intensified as the U.S. has embarked on building a nuclear repository at Yucca Mountain. One of the more ambitious of the projects has been the construction of the USGS Death Valley Regional Ground-Water Flow Model.

The intent of this paper was to create a homogeneous picture of the Paleozoic carbonate aquifer from the detailed data in the USGS regional model. From a coherent view of the carbonate aquifer, we constructed a very simple model in an effort to estimate potential contaminant movement through the carbonate aquifer.

Any model of contaminant transport through the carbonate aquifer depends heavily upon how one pictures the connected pore space in the carbonate rocks. Our conceptual model is of a thick carbonate sequence that contains a zone ten to several tens of meters thick where the rocks are fractured and provide a permeable pathway for flow. The information suggests that everywhere there is a reasonable thickness of carbonate rock one can obtain a reasonably good water well, provided he/she drills a sufficient thickness of the rock. One can enhance his/her chances of getting a really good well by going to places where recent tectonics movements in the region have further disturbed the carbonate rocks.

Finally with this model in mind transport through the carbonate aquifer from a location near the site of the Yucca Mountain Repository to the biosphere in Death Valley will be relatively rapid. Our calculation with a permeable zone 100 m thick and porosity of 0.1% indicates a transit time of less than 50 years; if the porosity is of the order of 1% the time is of the order of 500 years.

The ultimate conclusion from our study is that the Paleozoic carbonate aquifer is a good pathway for contamination to the biosphere. Every effort should be made to keep contaminants out of the carbonate aquifer that may include protection of the upward hydraulic gradient in the Paleozoic carbonate aquifer.

REFERENCES

(1) Winograd, I.J. and W. Thordarson (1975) *Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada-California, with special reference to the Nevada Test Site:* U.S. Geological Survey Professional paper 712-C, 126 p.

(2) Mifflin, M.D. (1968) *Delineation of ground-water flow systems in Nevada:* Technical University of Nevada, Desert Research Institute, Report Series H-W, Publication No.4, 109 p.

(3) Prudic, D.E., J.R. Harrill, and T.J. Burbey (1995) *Conceptual evaluation of regional ground-water flow in the carbonate rock province of the Great basin, Nevada, Utah, and adjacent states:* U.S. geological survey Professional paper 1409-D, 102 p.

(4) Belcher, W.R., F.A. D'Agnese and G.M. O'Brien (2004) *Chapter A: Death Valley regional ground-water flow system, Nevada and California—hydrogeologic framework and transient ground-water flow model:* (edited by W.F. Belcher) U.S. Geological Survey Scientific Investigation Report 2004-5205.

(5) Faunt [a}, C.C, F.A. D'Agnese, and G. O'Brien (2004) *Chapter D. Hydrology:* in *Death Valley Regional Ground-Water Flow System—Hydrogeologic Framework and Transient Ground-Water Flow Model:* (edited by W.F. Belcher) U.S. Geological Survey Scientific Investigation Report 2004-5205.

(6) Faunt [b}, C.C, J.B. Blainey, M.C. Hill, F.A. D'Agnese, and G. O'Brien (2004) *Chapter F. Transient numerical model:* in *Death Valley Regional Ground-Water Flow System—Hydrogeologic Framework and Transient Ground-Water Flow Model:* (edited by W.F. Belcher) U.S. Geological Survey Scientific Investigation Report 2004-5205.

(7) Sweetkind, D.S., W.F. Belcher , C.C. Faunt , and C.J. Porter (2004) *Chapter B. Geology and hydrogeology:* in *Death Valley Regional Ground-Water Flow System—Hydrogeologic Framework and Transient Ground-Water Flow Model:* (edited by W.F. Belcher) U.S. Geological Survey Scientific Investigation Report 2004-5205.

(8) Southern Nevada Water Authority (2006) *Aquifer-properties data compilation and evaluation, Volume 1:* presentation to the Office of the Nevada State Engineer.

(9) Winograd, I.J. and F.J. Pearson (1976) *Major carbon 14 anomaly in a regional carbonate aquifer: possible evidence for megascale channeling, south central Great Basin:* Water resources research, v. 12, p. 1125-1143.

(10) Galloway, D. and S. Rojstaczer(1988) *analysis and frequency response of water levels in wells to earth tides and atmospheric loading:* paper presented at 4th Canadian/American Conference on Hydrogeology, National Ground Water Association, Baniff, Alberta.

(11) Craig, R.W. and J.H. Robison (1984) *Geohydrology of the rocks penetrated by well uE-25 P!, Yucca Mountain area, Nye county, Nevada:* U.S. geolofgical Survey Water resources Investigation Report 94-4248, 57 p.

(12) Bredehoeft, J.D. (1997) *Fault permeability near Yucca Mountain:* Water Resources Research, v. 33, p. 2459-2463.