

**INFLUENCE OF GEOLOGIC STRUCTURE ON FLOW  
PATTERNS OF GROUNDWATER IN THE VICINITY OF  
YUCA MOUNTAIN — PROGRESS ON REVIEW OF  
SELECTED LITERATURE**

*Prepared for*

**Nuclear Regulatory Commission  
Contract NRC-02-88-005**

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**September 1992**

# **INFLUENCE OF GEOLOGIC STRUCTURE ON FLOW PATTERNS OF GROUNDWATER IN THE VICINITY OF YUCCA MOUNTAIN — PROGRESS ON REVIEW OF SELECTED LITERATURE**

## **1.1 INTRODUCTION**

The purpose of this report is to document progress on a review of literature being conducted to determine the state of knowledge about and availability of data pertaining to control of groundwater flow by structural geologic features, especially faults, fracture zones, and structural juxtaposition of aquifer units. The objective of the literature review is to provide initial bases for combined modeling of structural and groundwater system evolution. Significant technical uncertainties exist concerning the relationship between a region of relatively high potentiometric gradient at the north end of Yucca Mountain and the role of faults as potential barriers to local-scale flow (Czarnecki, 1989b; Sinton, 1989). Concern also exists as to the potential for continued fault displacement to create fault-controlled conduits of flow from the region of high gradient (Ahola and Sagar, 1992; Sinton, 1989).

Existing analyses and scientific/technical investigations considering structural control of groundwater flow at Yucca Mountain occur in four basic classes: (i) models of flow and transport in natural fracture systems, (ii) local-scale field oriented investigations and models of flow around faults and fault zones, (iii) models of sub-regional flow in the immediate Yucca Mountain area, and (iv) regional scale models of interbasin flow. Dynamic effects of neotectonic processes, such as historic and near-future earthquakes and magmatism, are not directly considered here.

This literature review is focused on two classes of investigations: (i) control of regional-scale groundwater flow by regionally extensive geologic fault systems and resultant geometric complexity of the hydrogeologic stratigraphy, and (ii) field investigations directly concerned with determining the hydrogeologic/hydraulic characteristics of faults and fault zones within the ash flow tuff sequence at Yucca Mountain.

Both classes of studies are necessary to determine the fate of radionuclides released from a potential high-level radioactive waste (HLW) repository at Yucca Mountain and to assess groundwater travel time from a repository to the accessible environment. Classification of fault zones as strictly either conduit or barrier is certainly an over-simplification. Designation as a conduit infers that all flow affected by the fault is contained, or restricted, within a discrete zone. Conceptually, faults, fault zones, and fracture zones should be considered as having hydrogeologic properties that vary depending on effective time and space scales, and that evolve over time.

Some general guidelines are being followed in conducting this review. Literature reviewed to date pertains primarily to flow in the saturated zone. Rather than inferring the hydrogeologic implications of tectonic features by correlating separate work on regional tectonics and regional groundwater flow, this review is restricted to work done specifically to investigate structural geologic control on groundwater flow. Accordingly, certain important aspects of the issue are used as points of focus to identify key papers. Aspects of structural geologic influence on groundwater flow that are of specific concern for this review are:

- Imposition of strong anisotropy on flow (conductivity and velocity) fields at various spatial scales
- Juxtaposition of aquifer and aquitard units
- Geometric complexity of aquifer and aquitard units (e.g., complexly folded and displaced mountain-scale blocks)
- Fault-controlled geomorphology and surface drainage patterns

## 1.2 REGIONAL TECTONIC FEATURES AND STRUCTURAL COMPLEXITY OF THE LOWER CARBONATE AQUIFER

That regional-scale tectonic features, such as faults, shear zones, and displaced blocks of the crust, exert considerable influence on patterns and rates of interbasin and intrabasin groundwater flow is not much in debate. Indeed, because late Cenozoic extensional tectonism [about 17 millions of years ago (Ma) to present] is the cause of the first order geomorphology of the Basin and Range physiographic province, tectonic fabric can be considered to control the regional flow field. Hydrologically closed alluvial basin and sub-basin domains are essentially defined by the girding fault-bounded mountain ranges. However, just as uplift, rotation, and erosion due to tectonism act to reveal the geologic underpinnings of the region, associated deformation and subsequent deposition of orogenic sediments and volcanic rocks complicate and obscure the geologic view. So it is not the concept, but the details that are elusive. The literature reflects this reality. There has been little definitive work focused exclusively on tectonic and structural geologic control of groundwater flow. Benchmark work on this problem requires a tremendous amount of effort to compile and integrate the myriad geological and hydrological data needed, and then to assimilate the necessary multidisciplinary analytical, interpretive, and modeling work. Add to this the problems inherent in attempting to understand processes operating simultaneously across a broad range of time and space scales. Therefore, conclusions drawn from this review are quite general and can be fairly well summed up: regional tectonic features are an important influence on groundwater flow, but pathways and rates of interbasin flow are not well resolved.

In general, the primary pathway required to accommodate interbasin transfer of water resident in the Cenozoic sedimentary and volcanic rocks is for flow to be established between the Cenozoic valley-fill rocks and the underlying lower carbonate aquifer. Two basic geologic mechanisms can be suggested that may result in interconnection of these stratigraphically separated water-bearing units. The first is an erosional-depositional unconformity where the underlying, older units have been uplifted and eroded, and the younger sedimentary and volcanic units were subsequently deposited directly onto the exposed outcrop area. The second is fault juxtaposition, where younger strata are displaced into contact with the underlying aquifer unit by slip along a normal fault or fault zone.

Regional hydrostratigraphic units and associated hydrogeologic properties are extensively described by Bedinger et al. (1989), Waddell et al. (1984), Winograd and Thordarson (1975 and 1968), and Naff et al. (1974). Two general hydrogeologic units are of primary importance for this review. The first is the total sequence of alluvial and pyroclastic valley fill and ash flow tuff deposited over about the last 20 million years (20 Ma). Regionally, the water table resides primarily in this part of the section. The second is the so-called "regional lower carbonate aquifer." The regional carbonate aquifer is composed of a thick sequence of limestones and dolomites. Groundwater flow in the lower carbonate

aquifer is dominated by fracture transmissibility (Winograd and Thordarson, 1975). The regional carbonate aquifer is confined above by a tuff aquitard composed of mostly Miocene (23 Ma-5 Ma) volcanoclastic flows, and confined below by a "lower clastic aquitard" composed of lower Paleozoic quartzite sandstones (Winograd and Thordarson, 1975).

Coupling of the regional carbonate aquifer to overlying, relatively shallow water table and perched aquifers in alluvial and pyroclastic valley fill, or within aprons of ash flow tuff, is of prime concern for intrabasin transport. Galloway et al. (1991) report a difference in hydraulic head between the Tertiary volcanic (tuff) beds and the underlying lower carbonate aquifer of about 14 m in the vicinity of Yucca Lake at the south end of Yucca Flat. They suggest that water perched within the tuff section flows northward from Yucca Lake for a short distance (less than 5 km) to a sink created by juxtaposition of the Cenozoic tuffs against the lower carbonate aquifer by normal offset along the Yucca fault zone. Galloway et al. (1991) also suggest that surface fissures in the southern Yucca Flat area may be important contributors to influx of perched or pluvial water into the regional aquifer. The fissures may be tectonic in genesis, caused by propagation of fault displacement upward through the valley fill sediments (Carr, 1974); however, Galloway et al. (1991) suggest differential compaction as at least an equally likely cause.

Winograd and Thordarson (1968) maintain that regional-scale tectonic features, such as faults and shear zones, exert considerable influence on interbasin flow paths and are the primary mechanism for compartmentalization of the regional carbonate aquifer system. Contractional shear and extensional deformation most often result in highly fractured, and probably long-lived, dilatant zones within the carbonate aquifer. Offset along these fault zones may place the regionally extensive clastic aquitard section into fault contact with the carbonate aquifer, resulting in regional scale barriers to flow (Bedinger et al., 1989).

Devils Hole is described by Riggs (1991) to be essentially a "tectonic window" into the regional groundwater flow system in the Ash Meadows area, and interpreted by Carr (1988) to be the result of pull-apart extension of a fault zone, rather than a karst process.

Sinton et al. (1989) indicate that major tectonic lineaments, which may be fault or fracture zones, exert strong control on regional groundwater flow patterns. They identify extensional, perhaps dilatant, zones trending northeast-southwest coincident with Fortymile Wash, and northwest-southeast shear zones coincident with Amargosa Valley. Their conclusion is that models of regional groundwater flow that include these tectonic pathways will yield substantially different regional travel times than models that do not consider tectonic features.

Naff et al. (1974) maintain that regional groundwater flow in the southern Great Basin is strongly influenced by tectonic fabric. They conclude that the influence of contractional structures (thrust faults) is little understood, but significant, and that the influence of normal fault zones is primarily expressed by localization of spring outflow along fault trends.

### **1.3 HYDROGEOLOGIC CHARACTERIZATION AND MODELING OF FLOW AROUND FAULT ZONES AT YUCCA MOUNTAIN**

Because tectonic faulting, often including Quaternary (< 1.64 Ma) (Harland et al., 1990) slip, has been a common process within the Yucca Mountain region, it is important to determine the extent to which faults serve as either conduits or barriers to regional flow. Some of the key geologic questions

are: (i) what measurable geologic parameters can be correlated to the hydrogeologic characteristics of fault zones? (ii) does total slip (finite strain) substantially influence development of impermeable gouge? (iii) what is the effect of rock type on impermeable gouge development? (iv) under what conditions do fault zones change hydrogeologic character (i.e., change from barrier to conduit, or the converse)? (v) to what extent do hydrogeologic properties of faults vary laterally along the fault zone (i.e., can a fault zone be a barrier in some areas while being permeable, or a conduit, in another)? (vi) what types of field hydraulic experiments would be most effective in assessment of hydrogeologic properties of known fault zones of appropriate scale? (vii) what type of mathematical modeling approach might be most appropriate to utilize results from such field experiments?

Influence of faults on local-scale flow is similar in process to regional-scale effects. For example, Czarnecki (1989b) suggests that a buried fault zone coincident with Yucca Wash strongly influences both the anomalously high potentiometric gradient in the area and the geomorphically controlled surface drainage. Sinton (1989) also suggests a fault or fault zone as a potential barrier to flow and, thus, a significant contributor to the gradient. Fridrich et al. (1991) suggest that the gradient is the result of local groundwater response to a regionally cross-cutting, deeply buried fault zone. Their hypothesis is that the fault zone provides a conduit for local flow from the volcanic aquifer into the underlying regional carbonate aquifer and that the apparent gradient is the result of laterally variable capture of volcanic aquifer flow across the fault zone. Ahola and Sagar (1992) model disruption of a low permeability barrier coincident with the steep hydraulic gradient. As a result, they calculate a water table rise of about 275 m in the immediate vicinity of Yucca Mountain. A particularly interesting result is the change in calculated flow direction in the vicinity of Yucca Mountain from south-southwest, with the barrier intact, to south-southeast after the permeability of the barrier area is increased. Flow through the Yucca Mountain area increases substantially if this barrier is removed. Calculated flow velocities increase from about 10.0 m/yr with the barrier intact to as much as 40 m/yr without the barrier.

Ervin and Downey (1991) report that water levels west of the Solitario Canyon fault are about 45 m higher than levels east of the fault, and attribute variation in stratigraphic level of the saturated zone to fault and fracture controlled transmissivity as reported by Waddell et al. (1984). Fridrich et al. (1991) suggest that there is limited hydraulic coupling between the volcanic cover rocks and the underlying regional carbonate aquifer; however, the lateral extent, stratigraphic relationships, and structural configuration of the carbonate aquifer below Yucca Mountain are not well known (Winograd and Thordarson, 1975).

Sinnock and Lin (1989) include the Ghost Dance fault in realizations of a probabilistic model of Yucca Mountain, but do not treat the fault as a zone of distinct hydrogeologic character. Wang and Narisimhan (1988) model the Ghost Dance fault as a "seepage face" which causes saturation to increase on the west (up flow) side of the fault under the assumed flux conditions, but does not allow water influx into the fault zone. They conclude that assessment of the hydrologic effect of faults is important. In the case that faults are primarily barriers, studies should be focused on flow within the blocks. For models that include faults as conduits, studies, at least in the saturated zone, should focus on fault contribution to the total flow field.

## 1.4 CONCLUSION

This is a progress report on review of literature that is focused on structural control of groundwater flow. There are few definitive studies that focus specifically on resolution of pathways and

rates of regional-scale flow in the structurally complex Great Basin region. Most workers agree that tectonic features strongly control flow in the lower carbonate aquifer and that flow through the lower carbonate aquifer is the primary mechanism of natural interbasin transfer of water. Therefore, improved understanding of regional flow will only come from study of this aquifer system. However, resolution of detailed flow patterns in the complexly deformed regional aquifer system is not likely in the short term.

There are few focused modeling studies or field investigations of hydrogeologic and hydraulic properties and effects of local-scale faults at Yucca Mountain. The studies reviewed do not go much beyond suggestions that faults are important.

It is recommended that this literature review continue as a "background" task related to development and assessment of alternative tectonic models of the Yucca Mountain region. Information derived from this activity will be important to development of compliance determination methods (CDMs) for hydrogeologic requirements of 10 CFR 60.122 [especially 60.122(c)(11)], and to appropriate consideration of structural and stratigraphic influence of groundwater flow and transport in performance models.

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