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SIGNIFICANCE OF WATER FLUXES IN A DEEP ARID-REGION VADOSE ZONE TO WASTE DISPOSAL STRATEGIES

K.R. Johnejack[a], L.G. Dever[b], L.J. O'Neill[b], D.O. Blout[a], M.J. Sully[a], S.W. Tyler[c], J. Chapman[d], D.F. Emer[a], and D.P. Hammermeister[a]

[a]Reynolds Electrical & Engineering Co., Inc., Las Vegas, Nevada
[b]DOE Nevada Operations Office, Waste Management Division, Las Vegas, Nevada
[c]Desert Research Institute, Water Resources Center, Reno, Nevada
[d]Desert Research Institute, Water Resourses Center, Las Vegas, Nevada,

ABSTRACT

Recently collected subsurface site characterization data have led to the development of a conceptual model of water movement beneath the Area 5 Radioactive Waste Management Site (RWMS) at the Nevada Test Site (NTS) that differs significantly from the conceptual model of water movement inherent in Resource Conservation and Recovery Act (RCRA) regulations. At the Area 5 RWMS, water fluxes in approximately the upper 75 m (250 ft) of the vadose zone point in the upward direction (rather than downward) which effectively isolates this region from the deep (approximately 250 m (820 ft)) uppermost aquifer. Standard RCRA approaches for detection and containment (groundwater monitoring and double liners/leachate collection/leak detection systems) are not able to fulfill their intended function in this rather unique hydrogeologic environment.

In order to better fulfill the waste detection and containment intentions of RCRA for mixed waste disposal at the Area 5 RWMS, the Department of Energy, Nevada Operations Office (DOE/NV) is preparing a single petition for both a waiver from groundwater monitoring and an exemption from double liners with leachate collection/leak detection. DOE/NV proposes in this petition that the containment function of liners and leachate collection is better accomplished by the natural hydrogeologic processes operating in the upper vadose zone; and the detection function of groundwater monitoring and the leak detection system in liners is better fulfilled by an alternative vadose zone monitoring system. In addition, an alternative point of compliance is proposed that will aid in early detection, as well as limit the extent of potential contamination before detection. Finally, special cell design features and operation practices will be implemented to limit leachate formation, especially while the cell is open to the atmosphere during waste emplacement.

INTRODUCTION

Proposed Mixed Waste Disposal Units (MWDUs) and the unused portion of an existing pit at the Area 5 RWMS located in Frenchman Flat at the Nevada Test Site (NTS) will be operated under facility standards specified by the Resource Conservation and Recovery Act (RCRA). In a future draft of Section E of the Part B Permit application under RCRA, the DOE/NV will pursue a waiver from groundwater monitoring and an exemption from double liners with leachate collection/leak detection. A previous petition for a groundwater monitoring waiver and liner exemption at the Area 5 RWMS suffered from a lack of site specific characterization data (U.S. DOE, 1987, 1992) and the State of Nevada subsequently deferred a decision (State of Nevada, 1987).

Based on recently collected site characterization data, the hydrologic conditions at the Area 5 RWMS differ significantly from the conceptual model of water movement inherent in RCRA regulations. Thus standard RCRA approaches are not able to provide their intended detection and containment functions. The purpose of this paper is to show that the combination of favorable location characteristics and alternative design and operations, under a RCRA groundwater monitoring waiver and liner exemption, respond to the hydrologic conditions at the Area 5 RWMS and better fulfill the intent of the regulations than the standard RCRA approaches.

SITE DESCRIPTION

The NTS is a DOE facility occupying approximately 3,500 km^2 (1,350 mi^2) in southern Nevada, approximately 95 km (60 mi) northwest of Las Vegas, Nevada (Figure 1). The site is bordered to the north, west, and east by the Nellis Air Force Range, a government-owned restricted access area. Activities at the NTS include a variety of nuclear and non-nuclear projects and experiments. The Area 5 RWMS encompasses approximately 3 km^2 (1.1 mi^2) within the Frenchman Flat basin of which only 0.37 km^2 (0.14 mi^2) is currently developed as a waste disposal site. A total of 17 cells are used for disposal of low-level radioactive waste; no cells currently are used for hazardous waste disposal. One of the existing cells (Pit 3) and the proposed MWDUs, consisting of 10 cells, are intended for mixed waste disposal. "Place Fig. 1 here."

The Frenchman Flat basin (approximately 1,290 km^2 (500 mi^2)) is typical of valleys in the Basin and Range Physiographic Province. The Area 5 RWMS is located north of the Frenchman Flat playa on an alluvial fan at an elevation of approximately 970 m (3,179 ft). Alluvial deposits ranging in thickness from 365 to 460 m (1,200 to 1,500 ft) underlie the Area 5 RWMS with Tertiary tuffs and Paleozoic carbonates underlying the alluvium, respectively (Dozier and Rawlinson, 1991). The NTS is in a transition zone between the Mojave Desert and Great Basin Desert ecosystems and although six major vegetation associations have been identified in Frenchman Flat, the creosote bush association (Larrea tridenta) predominates at the Area 5 RWMS (O'Farrell and Emery, 1976). Average daily temperatures range from 24°C (75°F) in August to 2°C (36°F) in January, but daily extremes may fluctuate between 17 to 36°C (63 to 97°F) in summer to -3 to 12°C (27 to 54°F) in winter (Patton et al., 1986). Prevailing winds are from the southwest (U.S. DOE, 1992). Precipitation is low and highly variable with an annual average of approximately 13 cm (5 in) at a nearby station with 19 years of record (French, 1986). Potential evaporation estimated at the playa, that varies from 0.1 cm/day (0.04 in/day) in the winter to 16.3 cm/day (6.4 in/day) in the summer, exceeds the annual precipitation (U.S. DOE, 1992). No perennial surface water bodies exist within the hydraulically closed Frenchman Flat basin (U.S. DOE, 1992).

REGULATORY OVERVIEW

RCRA regulations provide for a groundwater monitoring waiver under 40 CFR 264.90(b)(2) and the exemption from double liners with leachate collection/leak detection under 40 CFR 264.301(b) (Table I). The primary requirement of both the waiver and exemption is a demonstration that hazardous constituents will not migrate via the liquid pathway to the uppermost aquifer. The same site characterization data support both the waiver and exemption. "Place TABLE I here."

The groundwater monitoring waiver relies on containment provided by engineered barriers and leak detection to remove the need for groundwater monitoring, whereas the liner exemption relies on containment provided by a combination of location characteristics and alternative design and operation to remove the need for a liner. These contradictory approaches seemingly prohibit a joint waiver and exemption. However, if containment and detection can be provided by the alternative design and operations under the liner exemption, then the integration of the two may be possible.

RCRA CONCEPTUAL MODEL OF WATER MOVEMENT AND THE RESULTING APPROACHES FOR ITS CONTROL

Although no RCRA regulations explicitly state a conceptual model for water movement to the uppermost aquifer beneath a disposal site, an inherent model is clear in reports and manuals (U.S. EPA, 1986; Aller et al., 1989, Nielsen, 1991) and can be summarized as follows: precipitation exceeds evapotranspiration resulting in a net downward flux to a shallow water table with a significant horizontal gradient and lateral flow. This is indeed the case for humid regions and Figure 2 depicts this simple conceptual model. Although often complicated by heterogeneity and anisotropy of the porous media, the basic conceptual model remains the same. "Place Fig. 2 here."

Based on this common conceptual model of water fluxes, the EPA and industry have developed standard approaches to detect and prevent groundwater contamination. For new units, the RCRA regulations for groundwater monitoring are contained in 40 CFR 264.97 through 264.100; additional requirements for the post-closure period are covered in 40 CFR 264.112 and 264.117. Groundwater monitoring is required at specific intervals and locations, as well as for specific parameters and constituents. At a minimum, one upgradient well and three downgradient wells to the uppermost aquifer are required. The sampling interval is quarterly for the first year and semi-annually or annually thereafter, depending on the parameter. The point of compliance is a vertical plane located at the hydraulically downgradient limit of the waste management area that extends down to the uppermost aquifer underlying the regulated unit(s). The intent is to determine the impact on groundwater and to provide early detection of groundwater contamination (U.S. EPA, 1986; Federal Register, 1988; Aller et al., 1989).

These groundwater monitoring requirements clearly respond to the conceptual model inherent in RCRA regulations. That is, precipitation sufficiently exceeds evapotranspiration to cause a net downward flux and the regulated unit, vadose zone, and uppermost aquifer are hydraulically connected. Once percolating water reaches the uppermost aquifer, the gradient is large enough that its direction and magnitude can be determined for the purpose of siting monitoring wells and locating the point of compliance. Furthermore, statistical methods used to analyze water quality data strictly assume that each observation is an independent random sample from the parent population (Nielsen, 1991). The seepage velocity in the uppermost aquifer must be large enough to ensure that quarterly samples are independent in time.

Double liner requirements, including leachate collection and leak detection, are contained in 40 CFR 264.301 through 264.312. The intent is to "ensure that leaks are detected at the earliest practicable time" and to "provide for the containment and isolation of the hazardous waste" (Federal Register, 1992). The leachate collection system is sized primarily for the active period of the cell, during which the quantity of leachate is presumably greatest (Bagchi, 1990). These measures control the downward liquid pathway which again clearly responds to the conceptual model inherent in RCRA regulations.

Early detection of leaks or contamination is the intent of both the groundwater monitoring and liner requirements. The Groundwater Monitoring Technical Enforcement Guidance Document (U.S. EPA, 1986) uses "immediate" rather than "early". In the context of groundwater movement, which is generally slow, "immediate" may be years to tens of years. At best, immediate detection is quarterly given the prescribed minimum time interval for sampling. For liners, this intent derives from statute Section 3004(o)(4) of RCRA: "an approved leak detection system means a system or technology capable of detecting leaks at the earliest practicable time." The minimum time interval for monitoring of the leak detection system is weekly while a cell is active and monthly after closure.

Although "early" is subjective, compliance is made objective by adherence to prescribed design standards. For groundwater monitoring, "immediate" detection may be met by the prescribed placement and screening of monitoring wells. Specifically, wells must be located adjacent to the waste management area and screened intervals must be placed to intercept the most probable contaminant pathways. Leak detection in a liner, "at the earliest practicable time" is met by following design standards for the drainage layer and sump.

CONCEPTUAL MODEL FOR THE AREA 5 RWMS AT THE NTS

Since 1987, the Area 5 Site Characterization Program has endeavored to establish a conceptual model for the subsurface at the Area 5 RWMS. Three major subsurface investigations, the Existing Excavations Project (REECo, 1993a), the Science Trench Boreholes Project (REECo, 1993b), and the Pilot Wells Project (REECo, 1993c), have established the properties and conditions in the vadose zone and uppermost aquifer. In situ measurements as well as laboratory analyses of core and cutting samples have provided a picture of the water fluxes from the near surface to the uppermost aquifer. Only selected results with implications for waste disposal strategies are presented herein; the reader is referred to Ginanni et al., (1993) for a summary of the program and the three above referenced data reports for the details of the program.

Physical and hydrologic properties from both trenches and boreholes demonstrate that the thick vadose zone at the Area 5 RWMS is homogenous and isotropic (Ginanni et al., 1993). Although the sediments are layered as a result of the depositional environment, physical properties such as particle size distribution, porosity, and bulk density vary little throughout the profile. Hydrologic properties, such as saturated hydraulic conductivity, moisture retention curves, and water content, also vary little throughout the profile. Ambient water content is low, varying from approximately 5 to 15 percent (volumetric) and porosity is approximately 40 percent. Moreover, inorganic and organic carbon concentrations are nearly constant throughout the profile, thus eliminating caliche and humus soil layers as a source of heterogeneity, respectively. Vertical and horizontal cores collected from trenches indicate no anisotropy in either physical or hydrologic properties. Based on these data, the conceptual model with respect to water fluxes for the Area 5 RWMS is uncomplicated by layering, preferential flow paths, or anisotropy.

Using a hydrodynamic approach, the energy potential of water as measured from core samples can be used to infer flow direction in the vadose zone. The two most important energy potentials affecting liquid water flow are matric and gravitational potentials. Gravitational potential is the elevation above some reference datum, generally the water table. Matric potential results from capillary and adsorption forces and is equal to water potential (measurements made on core samples from the RWMS), minus osmotic potential. Since osmotic potentials for the Area 5 RWMS are negligible (REECO, 1993b,c), matric potentials are approximately equal to water potentials.

The direction of water fluxes in the vadose zone can be identified by plotting the water potential against the height above the water table (Koorevaar et al., 1983). Under steady state conditions, the equilibrium line indicates the total potentials that would exist if water potential equals the gravitational potential; that is, flux is neither upwards nor downwards. Water potentials plotted to the right of the equilibrium line indicate downward flux. Conversely, those plotted to the left indicate upward flux.

Three hydrologic zones are shown in Figure 3 by the water potential data from one deep well to the water table and four shallow boreholes. The near surface data plot to the left of the equilibrium line indicate an upward flux from approximately 0 to 75 m (0 to 250 ft) below ground surface and suggest long term evaporation and drying. From approximately 75 to 180 m (250 to 600 ft) below ground surface the data plot to the right of the equilibrium line suggest a downward flux. This downward flux has been estimated at approximately 3 m/1,000 yr (10 ft/1,000 yr) (O'Neill et al., 1993). The data above the water table (approximately 180 to 250 m (600 to 820 ft) below ground surface) plot on the equilibrium line indicate a balance of forces and no significant flux. "Place Fig. 3 here."

Environmental tracers provide another method, independent of the hydrodynamic approach, for defining the hydrologic zones below the Area 5 RWMS. The basic premise of this method is that precipitation and run-off contain dissolved natural and anthropogenic tracers that travel with the infiltrating water. Plots of these tracers with depth can confirm that the short term picture provided by the hydrodynamic approach has persisted over the long term. Chloride ions and the stable isotopes of hydrogen (^{1}H and D) and oxygen (^{16}O and ^{18}O) are commonly used as environmental tracers.

Chloride ions move readily with water in geologic formations because their negative charge discourages sorption on negatively charged mineral surfaces at solution pH values commonly found in soils and alluvium. Precipitation, run-off, and windblown dust contribute chloride to the soil profile. Chloride accumulates in the soil as water evaporates. Therefore, zones of low chloride concentration suggest that evaporation rates were low compared to infiltration. An example of the chloride profiles from the Pilot Well Project (REECo, 1993c) is shown on Figure 4 and, despite the variation between profiles, the zones of high chloride concentrations near the surface indicate an evaporative setting. The low chloride concentrations at depth imply that this water entered the profile via a different pathway or under a different climate. Using a chloride mass balance approach, Conrad (1993) estimated the age of the soil water at the bottom of the profile in UE5PW-1 to be over 100,000 yr. These data support the case that recharge at the Area 5 RWMS has been negligible for at least several thousand years and perhaps longer. "Place Fig. 4 here."

The stable isotopes of hydrogen and oxygen are part of the water molecule itself and therefore are excellent tracers of water movement. Evaporation and condensation concentrate the heavier isotopes (D and ^{18}O) in water and the lighter isotopes (^{1}H and ^{16}O) in water vapor. Thus, an enrichment of heavy isotopes in soil water of the vadose zone indicates evaporation. An example of stable isotope data from the Area 5 RWMS, in the standard δ notation, is shown in Figure 5 with reference to the meteoric water line (MWL) (REECo, 1993c). Data falling on the MWL have undergone little evaporation since originally condensing as precipitation suggesting that infiltration and recharge dominate, whereas points to the right of the MWL indicate that soil water is subject to evaporation (Drever, 1988). The points along the dashed line in Figure 5 represent samples from approximately the upper 40 m (130 ft) of the vadose zone and clearly show evaporative enrichment. Therefore, stable isotopes also support the hypothesis that the upward flux (evaporation) is high relative to the downward flux (infiltration) in the near-surface vadose zone. "Place Fig. 5 here."

Measurements of water table elevations showed approximately a 0.25-m (0.75-ft) maximum difference between the three Pilot Wells. However, the uncertainty in the measurements is ± 0.15 m (± 0.5 ft) and the measured elevation differences are within the uncertainty. To complete the conceptual model at the Area 5 RWMS, the uppermost aquifer is virtually horizontal.

Figure 6 illustrates this conceptual model for the Area 5 RWMS. Scanlon et al. (1991) and Fischer (1987) have found similar hydrologic zones, especially the upward flux in the near surface, at arid sites in the Chihuahuan Desert and the Mojave Desert, respectively. Although the conceptual model is not unique to the Area 5 RWMS, it may not apply at all locations within the Frenchman Flat basin (e.g., mountain fronts), much less at all arid sites. "Place Fig. 6 here."

IMPLICATIONS FOR WASTE DISPOSAL STRATEGIES

The conceptual model inherent in RCRA regulations and the conceptual model for the Area 5 RWMS differ radically. At the Area 5 RWMS, evapotranspiration greatly exceeds precipitation resulting in an upward flux in the near surface. Unlike the RCRA conceptual model, the near-surface vadose zone and the uppermost aquifer are disconnected -- there appears to be no hydraulic communication between the surface, deep vadose zone, and water table under the current climate. Even if the upward flux did not separate the uppermost aquifer from the surface, travel times to the uppermost aquifer approaching 80,000 years (O'Neill et al., 1993) lead to a separation for all practical purposes. Finally, the water table is horizontal within the error of measurement, thus invalidating the notion of a horizontal pathway in the uppermost aquifer and confounding definitions of upgradient and downgradient.

These differences suggest that the standard RCRA approaches to detect and control contamination, which are based on a humid region conceptual model, will not fulfill their intended functions in arid regions such as the Area 5 RWMS. Groundwater monitoring in this context clearly lacks early detection capability. Even if contamination were to reach the uppermost aquifer, the vadose zone is so thick and the flux is so slow that the vadose zone would could act as a contaminant reservoir for decades. Besides the hydraulic separation of the near surface and the uppermost aquifer, the lack of a significant horizontal gradient in the saturated zone would further prolong travel times to a monitoring well. Upgradient and downgradient comparisons of water chemistry are also confounded by the negligible horizontal gradient. If standard groundwater monitoring is inappropriate, the standard point of compliance is equally inappropriate. When the water table is virtually horizontal, a vertical plane cannot be defined that will intersect the ground surface and the uppermost aquifer at the downgradient limit of the waste management unit.

Liners are considered unnecessary in an arid environment and may even be detrimental. Under the standard RCRA approach, liners are intended to capture infiltrating water that would otherwise be committed on a downward pathway. With an upward flux in the near surface vadose zone, the need to contain infiltrating water is questionable. Evapotranspiration naturally recycles infiltrating water; the vadose zone itself is an effective barrier to recharge. Moreover, liners may be detrimental to the extent that they block upward fluxes and could cause water to accumulate below them, although no studies have yet documented this possible effect.

The "bathtub effect" has been of sufficient concern to the Nuclear Regulatory Commission (NRC) that it has concurred with the State of California that liners are not only unnecessary but also counterproductive at the Southwestern Compact's proposed disposal facility (NRC, 1990). Although this recommendation has no regulatory bearing on RCRA permitting at the Area 5 RWMS, the technical issues are identical. In order to demonstrate that liners would be productive, the downward flux through a cover must be less than the downward flux through a liner over the post-closure period. A successful demonstration is unlikely given the limited operational experience with the long-term performance of covers and liners in extremely arid areas. Liners may be detrimental if for any reason water accumulates and is allowed to remain above a liner ("bathtub") while a cell is open during operation. Arguably, accumulated water in a liner can be pumped out, but any increase in soil moisture above the liner may increase corrosion rates and the potential for releases (Case et al., 1992).

ALTERNATIVE DESIGN AND OPERATION

Given that standard RCRA approaches for detection and containment are inappropriate at the Area 5 RWMS, alternatives must respond to the new conceptual model so that the combination of design/operations and location characteristics provides containment and detection equivalent or superior to the standard RCRA approaches. Natural processes in the near surface vadose zone, in conjunction with special operating practices, vadose zone monitoring, and alternative groundwater monitoring will furnish the functions normally provided by complete groundwater monitoring and double liners with leachate collection/leak detection.

Special design and operations will limit leachate formation, especially during the critical period while a cell is open. Waste acceptance criteria do not allow wastes with more than 0.5 percent free liquids by volume (U.S. DOE, 1992), thus eliminating direct infiltration of liquid constituents. By steepening side slopes as much as safely possible, sloping the temporary earthen cover to drain away from the open portion of the cell, and controlling run-on, the amount of precipitation that collects will be minimized. Moreover, contact of water with waste will be minimized by a cell floor that slopes away from emplaced waste, as well as containerization of the waste itself. An approximately 2.5 m (8 ft) thick temporary earthen cap will prevent most if not all infiltration from reaching the waste. With these measures, water that does pond will most likely not contain any contaminants and, in any case, the quantity of ponded water will be minimized.

The upward flux in the near-surface vadose zone substitutes for containment of the downward pathway usually provided by a double liner with leachate collection. Containment by natural processes runs contrary to the general notion that engineered structures are more effective than natural processes. However, the liner exemption acknowledges the importance of natural processes by requiring that location characteristics contribute to containment in conjunction with alternative design and operation. In the case of some arid sites, the emphasis should be on enhancing, or at least not inhibiting, favorable natural processes, rather than relying on engineered structures.

Vadose zone monitoring substitutes for the early detection capability otherwise provided by groundwater monitoring and leak detection in a double liner system. The proposed vadose zone monitoring system at the Area 5 RWMS consists of three components: soil gas sampling for organic vapors, neutron logging to monitor soil moisture, and gamma spectroscopy to monitor radionuclides. All monitoring will occur in angle boreholes that start at the perimeter of a unit and extend at a minimum to the centerline below the cell. Boreholes will be in pairs with one used for soil gas sampling and the other used for neutron logging and gamma spectroscopy.

Although it cannot provide early detection capability, alternative groundwater monitoring will be included in order to continue the baseline established by ongoing monitoring under RCRA interim status. Ongoing monitoring under interim status is conducted quarterly for the first year and annually or semi-annually thereafter, depending on the parameter, until the Part B Permit is finalized. The proposed alternative groundwater monitoring under the waiver will simply consist of annual monitoring for indicator parameters for groundwater contamination (40 CFR 264.92(b)(2)).

This alternative approach reflects recent thinking by several EPA officials (Durant et al., 1993). These researchers acknowledged that effective vadose zone monitoring may allow a reduction in the scope of groundwater monitoring in arid environments where the uppermost aquifer is deep. For land treatment facilities, which are typically unlined, the EPA has indicated that vadose zone monitoring serves in a capacity similar to a leak detection system in a liner (U.S. EPA, 1982). Presumably these EPA positions are based on the conceptual model inherent in RCRA wherein water flux is predominantly downward, except that the uppermost aquifer is deep instead of shallow. In cases where the near-surface vadose zone and uppermost aquifer are hydraulically separated, the case for vadose zone monitoring is even stronger.

The conceptual model of water fluxes at the Area 5 RWMS suggests logical upper and lower bounds for an alternative point of compliance. Above an approximate depth of 75 m (250 ft), water flux is clearly upward; below that approximate depth, water flux is downward. Between these two hydrologic zones, there must exist a zone with no movement of water, the "static zone" or "zero flux zone" (Jackson et al., 1973; Sharma et al., 1990). Water that passes this "zero flux zone" will be committed downward, albeit at an extremely slow rate. Hence, it is a logical lower limit for the point of compliance. The upper limit for the point of compliance accepts that some precipitation will infiltrate, especially while an unlined cell is open. The point of compliance should be set deep enough below the unlined cell floor so that the wetting front from a chosen design storm will not trigger any regulatory action. That storm might be the 25-yr, 24-hr event in order to parallel guidance for control of run-on and run-off. Figure 7 illustrates these upper and lower bounds for an alternative point of compliance for a single cell.

The shape of the point of compliance may be a shell around an individual unit, a shell around several units, or a horizontal plane. A shell, either around one or several cells, would account for lateral water movement, whereas a horizontal plane would only account for downward movement. In any case, the proposed point of compliance fulfills the intent of early detection and is more restrictive than the standard RCRA point of compliance. Because it is much closer to the cell than the standard point of compliance at the uppermost aquifer, the volume of alluvium that could potentially be contaminated before detection is greatly reduced. Relative to the great depth to the uppermost aquifer, most of the thick vadose zone remains as a natural barrier to water movement towards the uppermost aquifer. *Place Fig. 7 here.*

CONCLUSIONS

Recently collected site characterization data at the Area 5 RWMS demonstrate that the near-surface vadose zone is effectively isolated from the uppermost aquifer with respect to water fluxes. A zone of upward flux from approximately 0 to 75 m (0 to 250 ft) is the primary reason for this isolation, although an equilibrium zone near the uppermost aquifer (approximately 180 to 250 m (600 to 820 ft)) below ground surface) also contributes to this separation. Between the zone of near-surface upward flux and the deep equilibrium zone lies an intermediate zone approximately 105 m (350 ft) thick where the extremely slow downward flux, approximately 3 m/1000 yr (10 ft/1000 yr), further protects the uppermost aquifer.

This conceptual model differs significantly from the conceptual model for water movement inherent in RCRA regulations and implies that detection and containment measures prescribed in RCRA regulations are inappropriate. Alternative design/operations in conjunction with natural processes will fulfill the intent of RCRA regulations. Vadose zone monitoring provides the detection functions of groundwater monitoring and leak detection in a double liner, and given the hydraulic isolation of the uppermost aquifer, is the only method that will provide early detection of releases. An alternative point of compliance also will aid early detection of releases, as well as limit the extent of potential contamination before detection. The upward flux in the near-surface vadose zone provide containment of liquids usually provided by a double liner with leachate collection.

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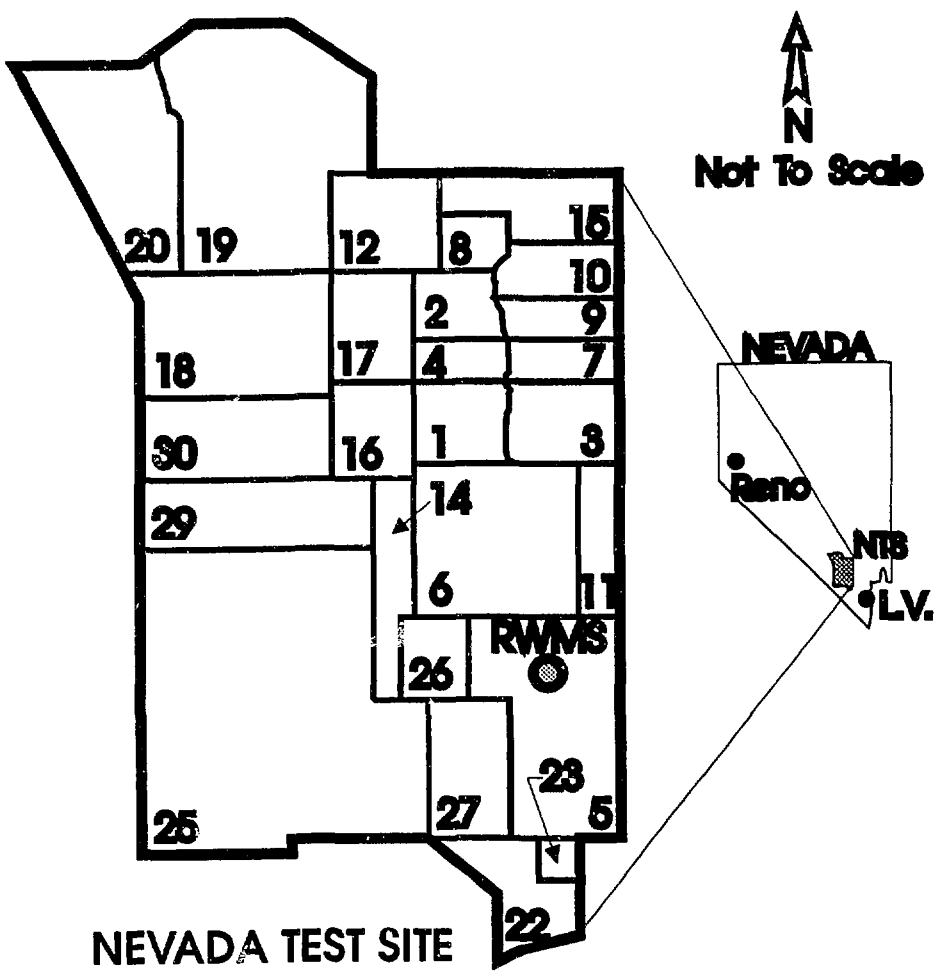

Fig. 1. Location of the Area 5 RWMS.

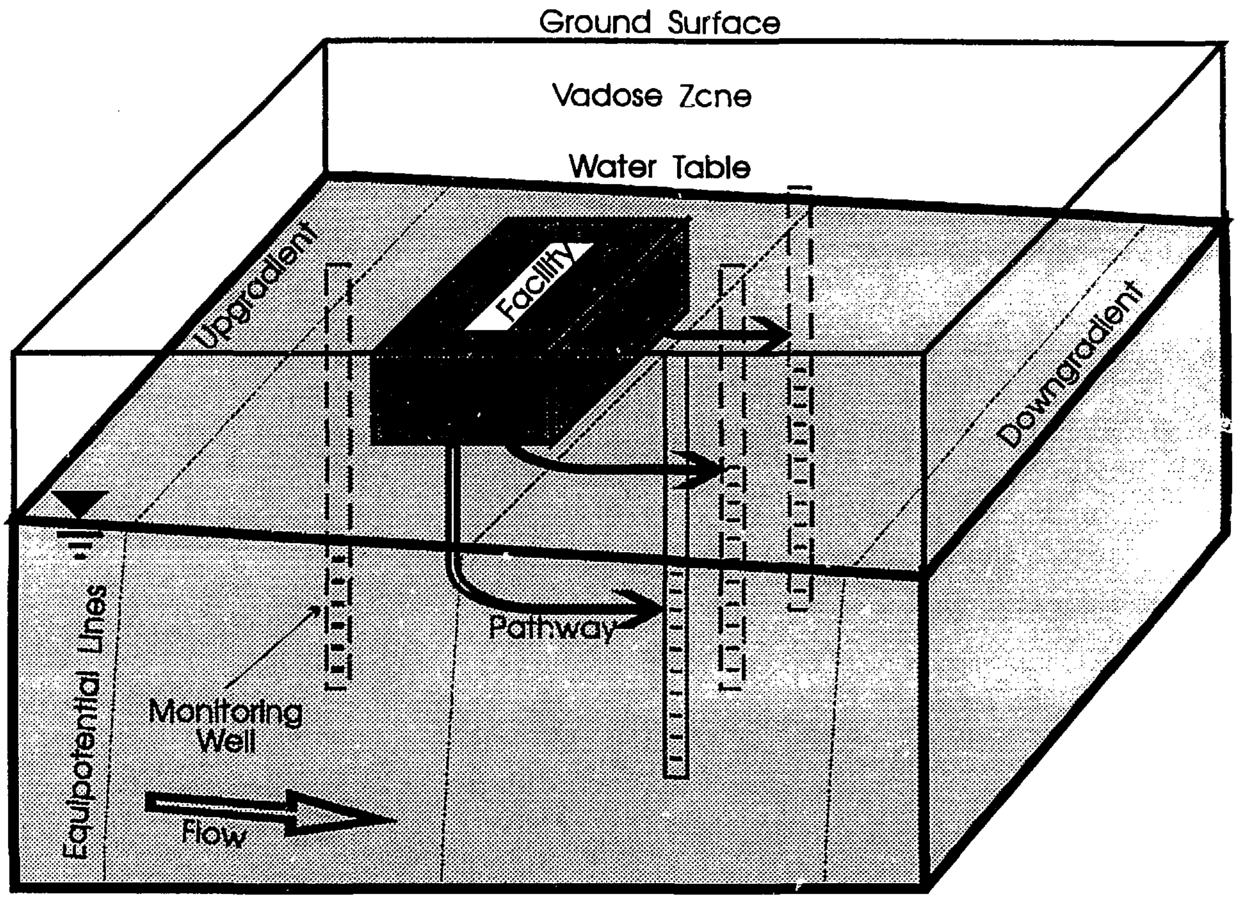

Fig. 2. Conceptual model inherent in RCRA.

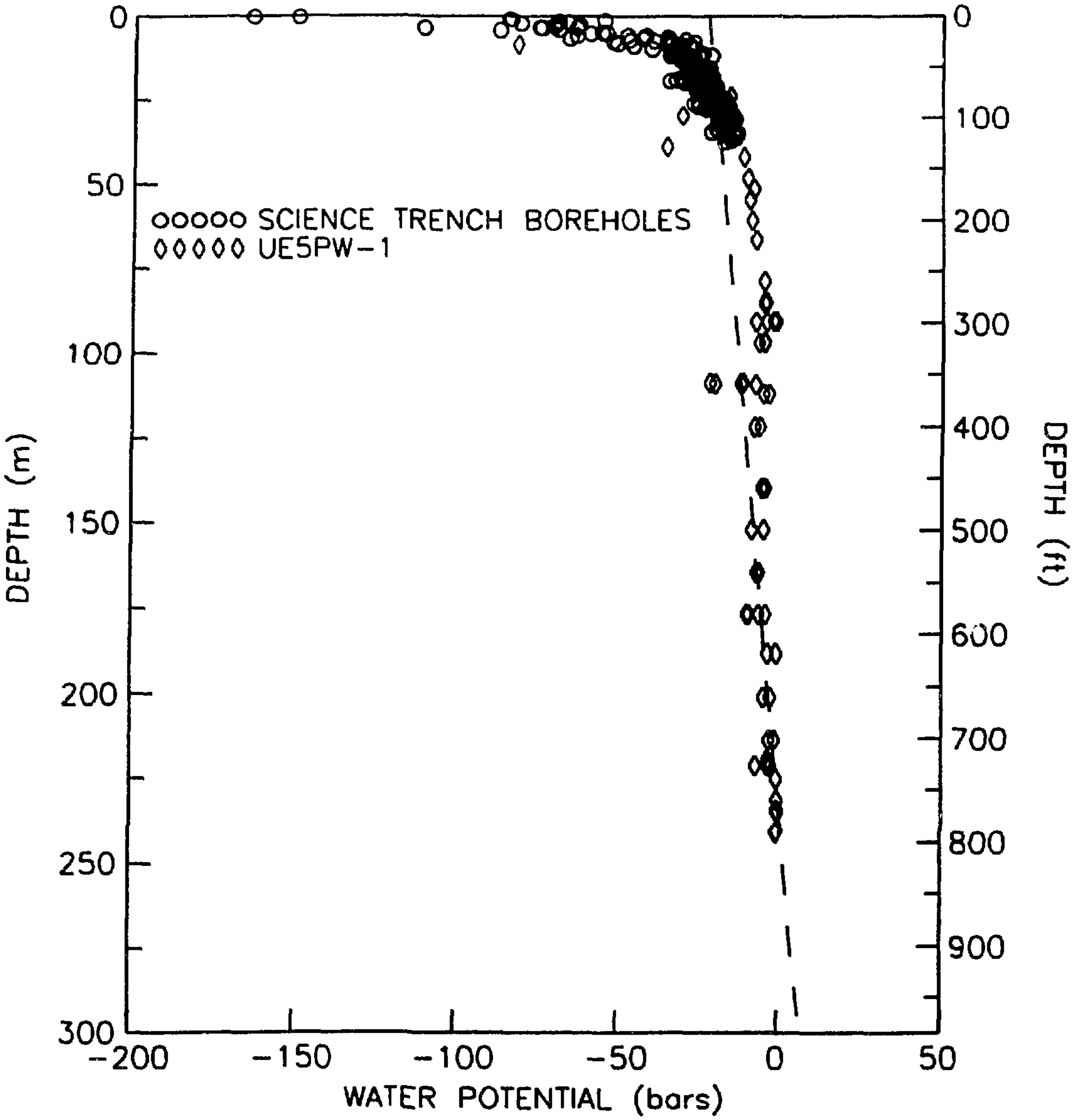

Fig. 3. Water potential data from Area 5 RWMS boreholes. Data to the left of the 1:1 line indicate upward liquid flow.

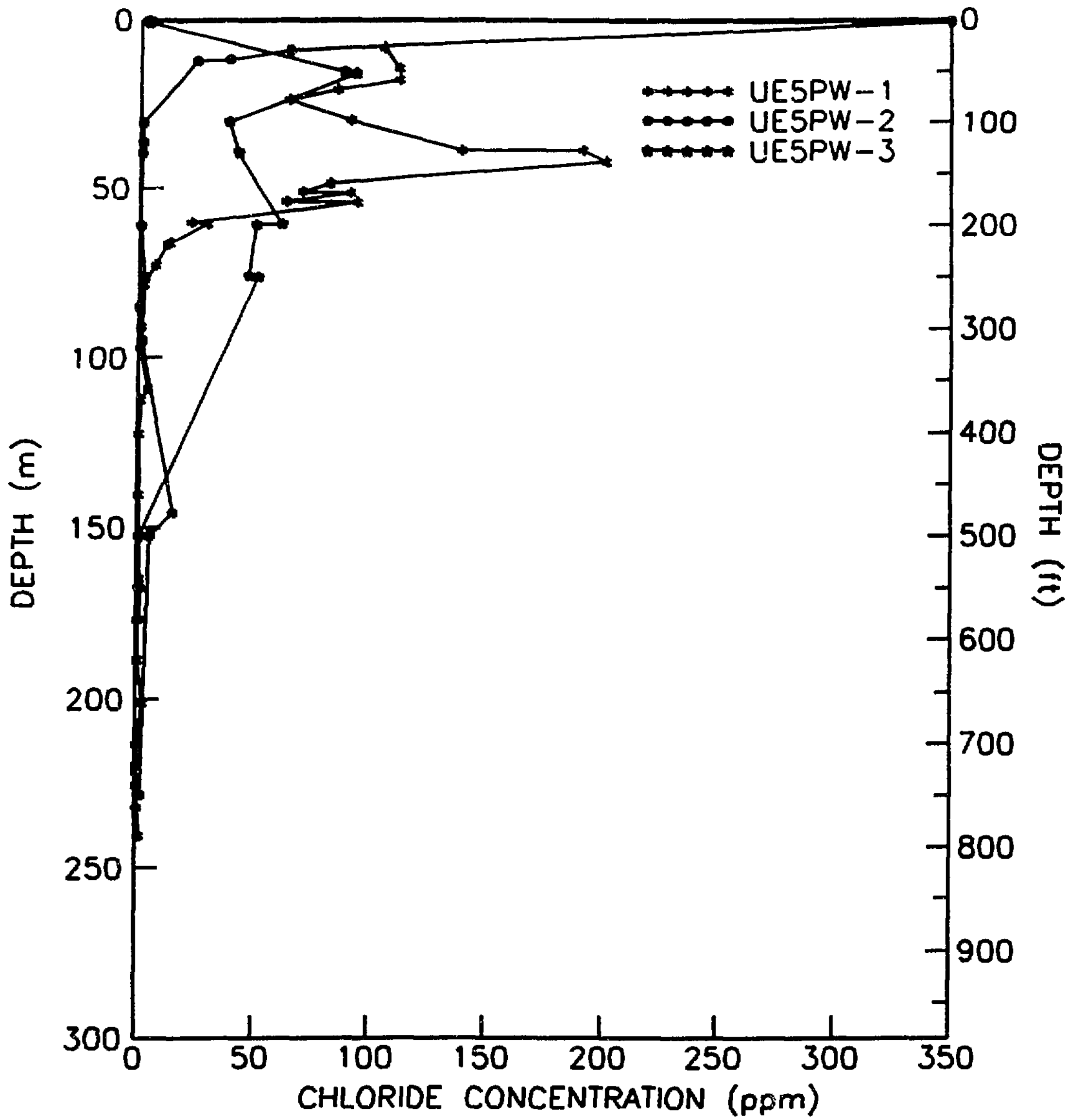

Fig. 4. Depth profiles of dry soil chloride concentrations for core samples from the Pilot Wells.

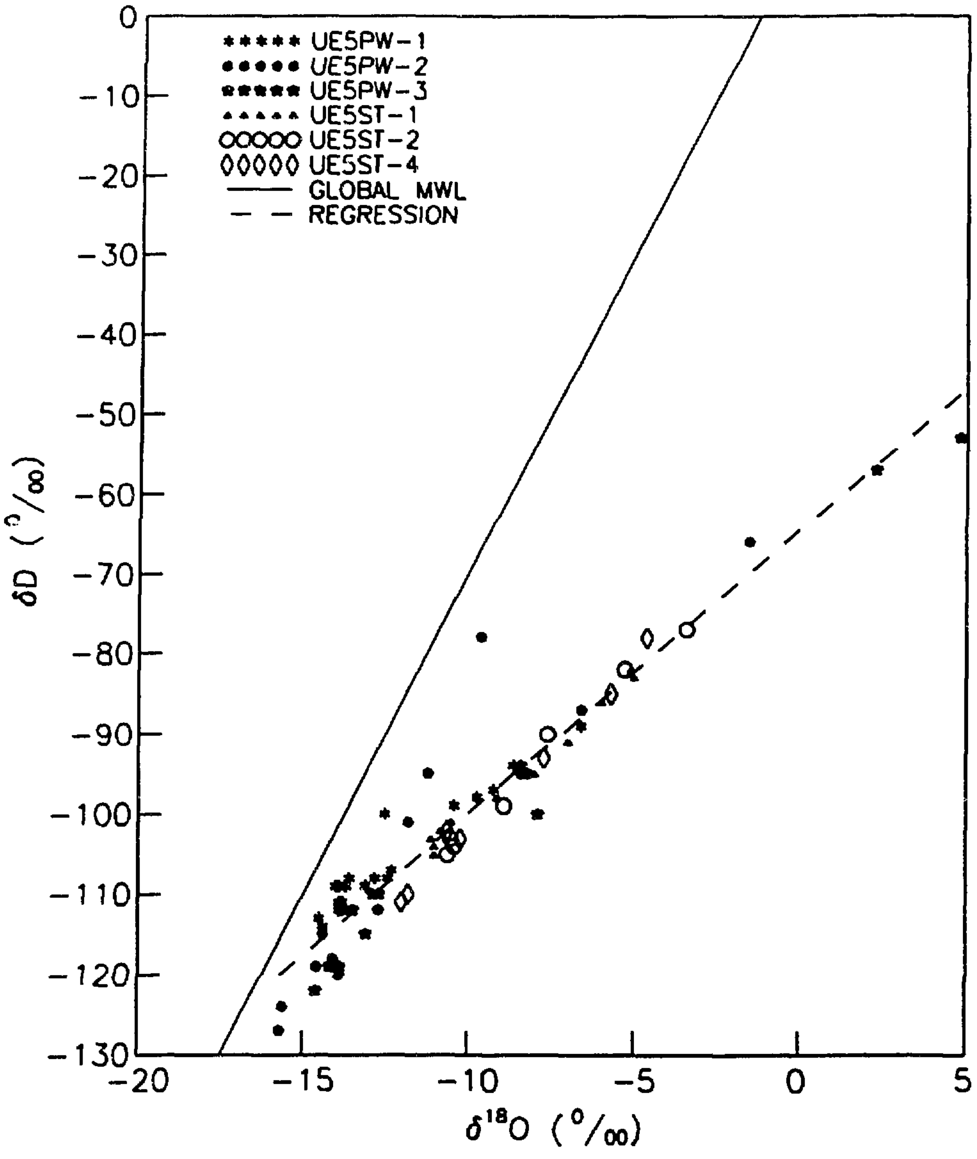

Fig. 5. Comparison of measured stable isotopes for core samples from the Science Trench Boreholes and Pilot Wells with stable isotope data for the global Meteoric Water Line.

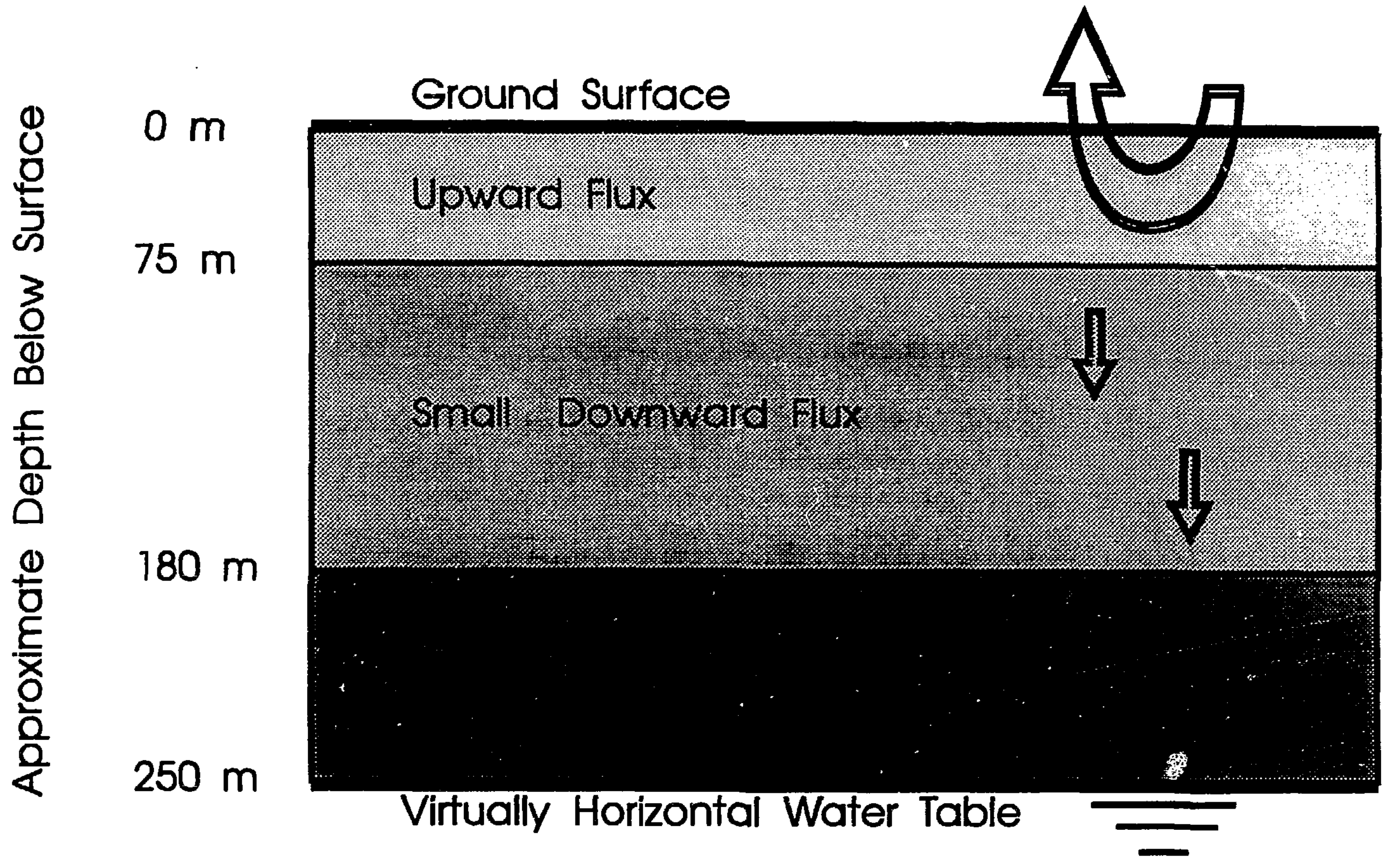

Fig. 6. Hydrologic zones beneath the Area 5 RWMS.

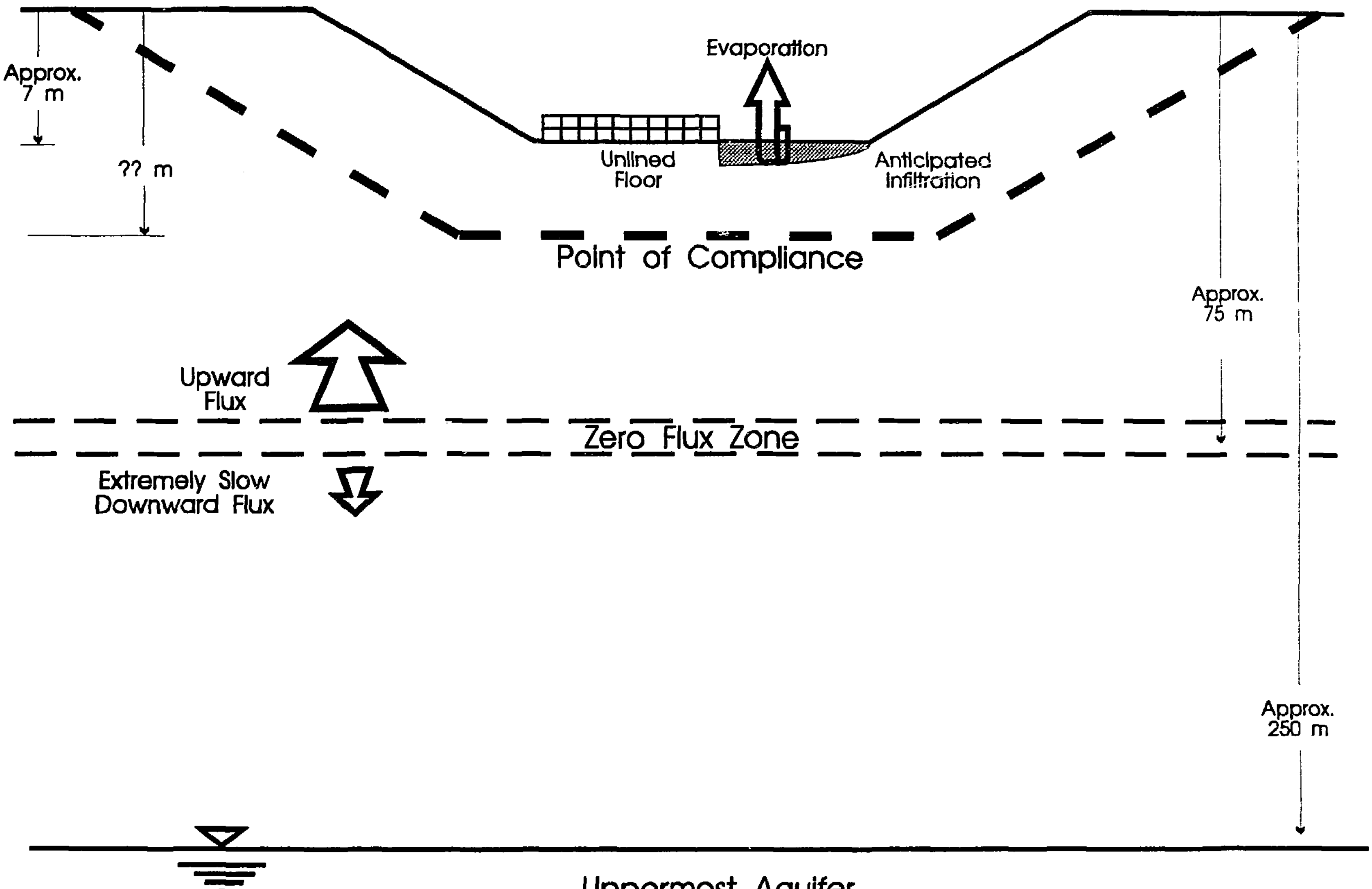

Fig. 7. Proposed point of compliance.

TABLE I. RCRA Regulatory Requirements	
Groundwater Monitoring Waiver	**Liner Exemption**
264.90(b)(2) The owner or operator demonstrates that the unit: **(i)** is an engineered structure **(ii)** contains no free liquids **(iii)** excludes precipitation, run-on, run-off **(iv)** has double liner system **(v)** has leak detection in each liner **(vi)** provides leak detection during active life, closure, and post-closure **(vii)** to a reasonable degree of certainty, does not allow migration outside the liner	**264.301(b)** the owner or operator demonstrates that alternative design and operating practices, together with location characteristics, will prevent migration to ground or surface water considering: **(1)** nature and quantity of wastes **(2)** alternative design and operation **(3)** hydrogeologic setting **(4)** all other factors that affect the quality and mobility of leachate and the potential for migration
264.90(b)(4) no migration of liquid to uppermost aquifer	