Waste Burial in Arid Environments—Application of Information From a Field Laboratory in the Mojave Desert, Southern Nevada

U.S. Department of the Interior—U.S. Geological Survey

Accumulation and management of waste is a pressing problem facing the United States today. Improper disposal of hazardous wastes poses a threat to public health and environmental quality. As arid sites increasingly are being sought for disposal of the Nation's radioactive and other hazardous wastes, concern about the potential effect of contaminants on water resources in the arid western United States is being raised. In addition, volumes of locally generated municipal and industrial wastes are increasing because of rapid population growth and industrialization of the region.

The suitability of a waste-burial site or landfill is a function of the hydrologic processes that control the near-surface water balance. Precipitation that infiltrates into the surface of a burial trench and does not return to the atmosphere by evapotranspiration from the soil and plants can percolate downward and come in contact with buried waste. Water that contacts the waste can enhance the release of contaminants for subsequent transport by liquid water, water vapor, or other gases.

A prevalent assumption is that little or no precipitation will percolate to buried wastes at an arid site. Thick unsaturated zones, which are common to arid regions, also are thought to slow water movement and minimize the risk of waste migration to the underlying water table. On the basis of these assumptions, reliance is commonly placed on the natural system to isolate contaminants at waste-burial sites in the arid West.

Few data have been available to test the validity of assumptions about the natural soil-water flow systems at arid sites, and even less is known about how the construction of a waste-burial facility alters the natural environment of the site. The lack of data is the result of (1) technical complexity of hydraulic characterization of the dry, stony soils and (2) insufficient field

Figure 1. Location of waste-burial site, Death Valley, and Mojave Desert of southwestern United States.

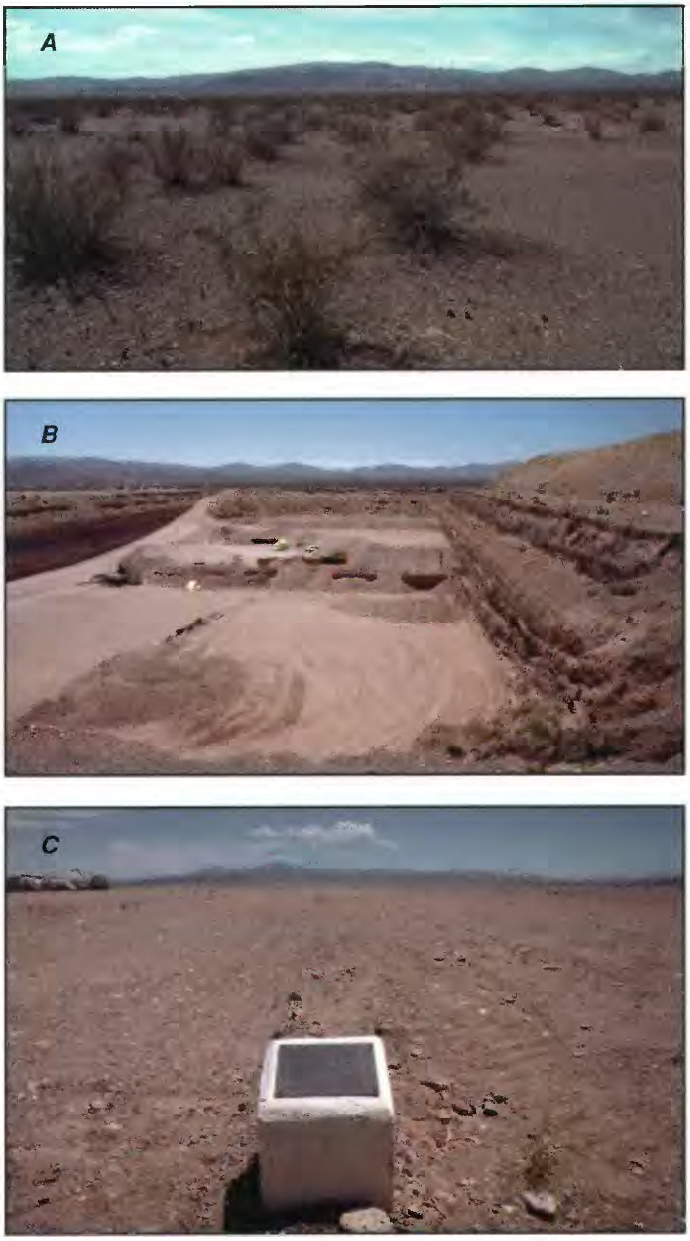

Figure 2. Undisturbed, vegetated area near waste-burial site, October 1991 (*A*); low-level radioactive waste burial trench (*B*); and nonvegetated surface of backfilled waste-burial trench with identifying monument, June 1988 (*C*).

studies that account for the extreme temporal and spatial variations in precipitation, vegetation, and soils in arid regions. In 1976, the U.S. Geological Survey (USGS) began a long-term study at a waste-burial site in the Mojave Desert near Beatty, Nev., to collect the necessary data and evaluate untested assumptions. This fact sheet summarizes the findings of investigations at the site and discusses how this information is important to issues of waste burial in an arid environment.

Mojave Desert Waste-Burial Site

The waste-burial site, 30 miles east of Death Valley National Park, is in one of the most arid parts of the United States (fig. 1). Precipitation in the area averages about 4 inches per year. The water table is about 360 feet below land surface. Vegetation in the area is sparse (fig. 2*A*). Burial trenches at the site have been used for disposal of low-level radioactive waste (1962-92) and hazardous-chemical waste (1970-present). Burial-trench construction includes excavation of native soil, emplacement of waste, and backfilling with previously stock-piled soil (fig. 2*B*). The surfaces of completed burial trenches and perimeter areas are kept free of vegetation (fig. 2*C*). Regulations governing burial of low-level radioactive waste do not require that trenches be lined with impervious materials. Prior to 1988, linings were not required for chemical-waste trenches. As a result, only the most recent chemical-waste trench at the site is lined.

Field Laboratory Established

Recognizing the need for long-term data collection, the USGS established a study area adjacent to the waste-burial site through agreements with the Bureau of Land Management and the State of Nevada. This 40-acre area serves as a field laboratory for long-term data collection and the study of hydrologic processes under natural-site and waste-burial conditions.

Lessons Learned to Date

Early (1962) evaluation of the general hydrologic conditions at and near the waste-burial site suggested that low average annual precipitation and high average annual evapotranspiration would prevent water from percolating downward more than 1 or 2 feet below land surface. This assumption, however, did not consider the extreme annual and seasonal variations in a desert climate. During 1985-92, annual precipitation measured at the USGS study site ranged from 0.55 to 6.51 inches and monthly precipitation ranged from 0 to 2.34 inches. Monthly average temperature ranged from 38 to 92 degrees Fahrenheit. Most of the precipitation falls during the cool winter months when evaporative demands are low (fig. 3). Initial water-balance modeling by the USGS demonstrated that, under particular climate and soil-moisture conditions, the potential for deep percolation does exist, in spite of high annual evaporative demands (Nichols, 1987).

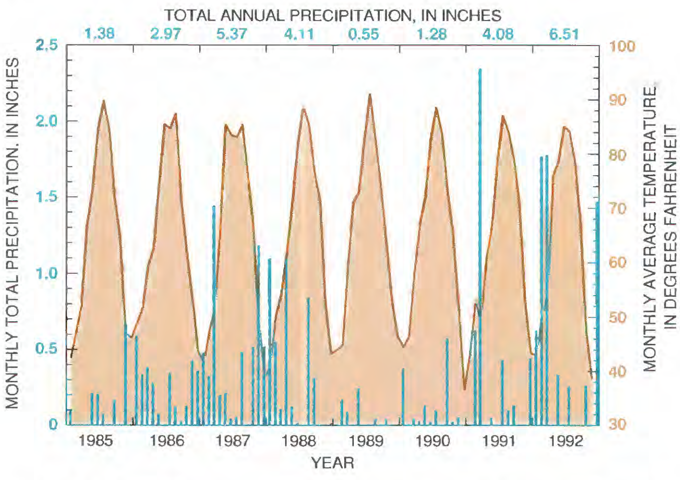

Figure 3. Annual and monthly total precipitation and monthly average temperature measured at U.S. Geological Survey field laboratory during 1985-92.

Field investigations to define the rates and directions of water movement through the deep unsaturated zone beneath an undisturbed, vegetated area began in the early 1980's and continue today. A study of chloride concentrations in the unsaturated zone indicates that deep percolation of water was limited to the upper 30 feet during the past 16,000 to 33,000 years (Prudic, 1994a). To monitor present-day flow processes, an instrument shaft was installed that allows access for operation of electronic devices to a depth of 45 feet (fig. 4; Fischer, 1992). Additional instrumentation has been installed to study flow processes throughout the unsaturated zone (Prudic, in press). Meteorological data are collected by an automated weather station (Wood and Andraski, 1995).

Water movement in the unsaturated zone is complex. Several variables—water content, water potential, humidity, and temperature—must be monitored to define rates and

Figure 4. Installation of vertical shaft used for soil-moisture monitoring in upper 45 feet of unsaturated zone beneath undisturbed, vegetated area. Photograph by David S. Morgan, U.S. Geological Survey, August 1983.

directions of water movement. Water content indicates how much water is held in the soil. Water potential indicates how tightly the water is held by the soil matrix. Water moves through soil in liquid and vapor form, and the two forms can move simultaneously as a consequence of water-potential, humidity, and temperature gradients in the soil.

Ongoing investigations at the undisturbed, vegetated site indicate that the natural soil-plant-water system effectively limits the potential for deep percolation. During more than 5 years of monitoring, downward percolation was limited to the upper 3 feet of soil (Fischer, 1992; Andraski, 1994). Between the depths of 40 and 160 feet, water movement, as liquid and as vapor, is consistently upward. Preliminary evidence indicates that upward flow of water vapor through the thick unsaturated zone may potentially serve as a contaminant-release pathway (Prudic, 1994b; Prudic and Striegl, 1994).

Little is known about how, or to what degree, features of the natural system may be altered by installation of a disposal facility. Investigations to determine the effects of disturbance on soil properties and the long-term soil-water balance began in 1987. Two nonvegetated test trenches and an area of bare soil are monitored (fig. 5; Andraski, 1990). The effects of disturbance are evaluated in terms of observed differences between data collected at the undisturbed, vegetated site and data collected at the disturbed sites.

Accurate characterization of hydraulic properties is critical to calculations of water movement through soil. Characterization data normally are measured to a minimum water-potential value referred to as the permanent wilting point for crops. Below this value, water is held so tightly by the soil matrix that a crop plant cannot extract the water and will wilt and die. Data collected by the USGS at the Mojave Desert site, however, show that this lower limit is not adequate for nonirrigated, desert soils and plants, nor is it appropriate for the extremely dry backfill material produced by trench construction. Thus, characterization of hydraulic properties at the site has been extended to include data measured over a soil-moisture range that is representative of seldom-studied arid conditions (Andraski, in press).

Backfilling with very dry material will, at least initially, increase the importance of vapor flow as a potential transport mechanism in the trench fill (Andraski, in press). These initial dry conditions can change substantially, however, in response to subsequent precipitation and a lack of vegetation. On an annual basis, no water accumulates in the vegetated soil because water is removed by the plants (fig. 6). In contrast, even under conditions of extreme aridity, water accumulates in the nonvegetated soil and test trenches. Water that has accumulated at the three disturbed sites is continuing to percolate downward (Andraski, 1994). Thus, the construction of waste-burial trenches and removal of native vegetation markedly alters the natural site environment and may increase the potential for release of contaminants (Gee and others, 1994). Surprisingly, such changes typically are not considered in the evaluation of a proposed waste site and may not be considered in management of existing sites.

Well-Informed Decisions Needed

Regulations governing the licensing of solid-waste landfills and hazardous-waste sites require an assessment of the potential for deep percolation of water through buried waste before disposal operations can begin. Numerical models commonly are relied on for this assessment. For a proposed low-level radioactive waste site, 1 year of preoperational monitoring of site conditions also is required. Thus, data used in numerical

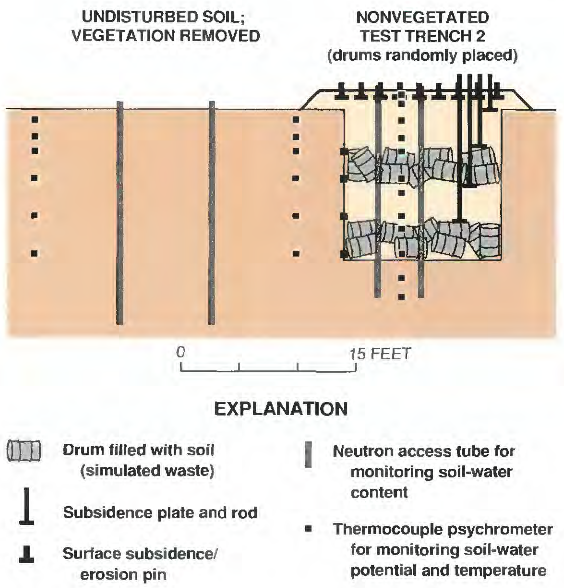

Figure 5. Schematic diagram of instrumentation used to determine effects of vegetation removal and trench construction on water movement through unsaturated zone. Subsidence and erosion are monitored to determine changes in structural integrity of test trenches. In second test trench (not shown), soil-filled drums are stacked in orderly fashion.

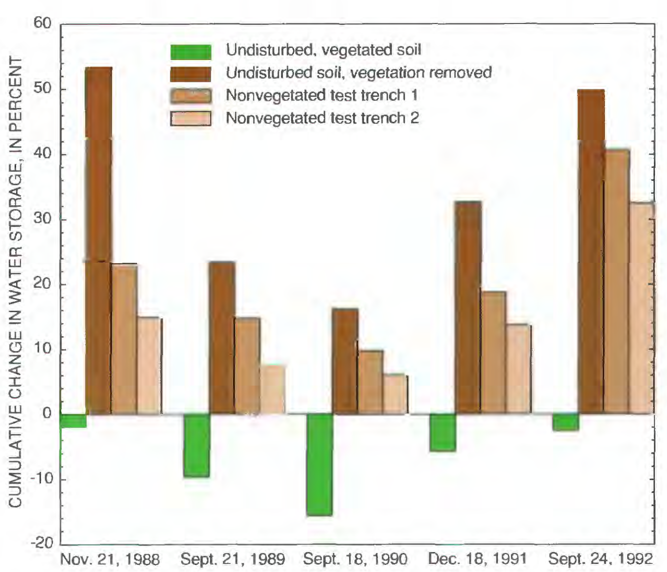

Figure 6. Cumulative changes in quantity of water being held in uppermost 4 feet at four monitoring sites: undisturbed, vegetated soil; undisturbed soil where native vegetation was removed; and two nonvegetated test trenches. Values are based on measurements during first 5 years following vegetation removal and trench construction at disturbed study site in October 1987.

analysis of a proposed waste-burial site may be based solely on hydraulic information available in the literature, or the data may include some site-specific information, which typically is limited to natural conditions and a short period of time. This approach is of particular concern for waste sites in arid regions because, compared with the amount of information available for more humid sites, the amount of hydraulic-property data and long-term field data for arid sites is negligible. In addition, although significant advances have been made in the development of soil-water flow models, the lack of long-term field data has resulted in these models remaining largely untested as to how well they represent flow systems at arid sites.

Long-Term Benchmark Information

Ongoing work by the USGS at the Mojave Desert field laboratory continues to provide long-term, quantitative "benchmark" information about the hydraulic characteristics, water movement, and the potential for release of contaminants through the unsaturated zone in an arid environment. Monitoring methods developed and tested at the Mojave Desert site have helped others in their study and evaluation of waste-isolation processes at the Nevada Test Site, and at proposed waste sites in Texas and California. The U.S. Nuclear Regulatory Commission and Pacific Northwest Laboratory have chosen the Mojave Desert waste site for use in numerical modeling of infiltration because it is representative of burial operations in an arid environment. Data collected at the USGS field laboratory are being provided for this effort. The National Academy of Sciences also has used information from the site in the evaluation of issues related to waste disposal in an arid environment.

Because of the potentially harmful effect of improper waste disposal on water resources in the arid West, comprehensive laboratory and field studies are critical to identifying likely contaminant-release pathways and the potential for waste migration at arid sites. However, the quandary for those charged with assessment of the suitability of potential disposal sites is that site characterization and evaluation must be accomplished in a relatively short period of time—only 1 to 2 years.

Data collection at the Mojave Desert field laboratory provides the needed long-term benchmark against which short-term data from proposed arid sites can be compared. The data base and monitoring facilities developed at the field laboratory also provide an excellent foundation upon which to build collaborative efforts with universities and local, State, and other Federal agencies to further the study and understanding of hydrologic processes in an arid environment.

—B.J. Andraski, David E. Prudic, and William D. Nichols

References Cited

Andraski, B.J., 1990, Water movement and trench stability at a simulated arid burial site for low-level radioactive waste near Beatty, Nevada: LaGrange Park, Ill., American Nuclear Society, Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, Nev., September 1989, Proceedings, p. 166-173.

——1994, Disturbance effects on soil properties and water balance at a low-level radioactive waste site, Amargosa Desert, Nevada [abs.]: American Society of Agronomy, Agronomy Abstracts, v. 86, p. 227.

——in press, Properties and variability of soil and trench fill at an arid waste-burial site: Soil Science Society of America Journal.

Fischer, J.M., 1992, Sediment properties and water movement through shallow unsaturated alluvium at an arid site for disposal of low-level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 92-4032, 48 p.

Gee, G.W., Wierenga, P.J., Andraski., B.J., Young, M.H., Fayer, M.J., and Rockhold, M.L., 1994, Variations in water balance and recharge potential at three western desert sites: Soil Science Society of America Journal, v. 58, no. 1, p. 63-72.

Nichols, W.D., 1987, Geohydrology of the unsaturated zone at the burial site for low-level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Water-Supply Paper 2312, 57 p.

Prudic, D.E., 1994a, Estimates of percolation rates and ages of water in unsaturated sediments at two Mojave Desert sites, California-Nevada: U.S. Geological Survey Water-Resources Investigations Report 94-4160, 19 p.

——1994b, Effects of temperature on water movement at the arid disposal site for low-level radioactive wastes near Beatty, Nevada [abs.]: Geological Society of America, Abstracts with Programs, v. 26, no. 7, p. 391.

—— in press, Water-vapor movement through unsaturated alluvium in Amargosa Desert near Beatty, Nevada—Current understanding and continuing studies, *in* Stevens, P.R., and Nicholson, T., eds., Conference on Disposal of Low-Level Radioactive Waste, Reston, Va., May 1993: U.S. Geological Survey Water-Resources Investigations Report 95-4015.

Prudic, D.E., and Striegl, R.G., 1994, Water and carbon dioxide movement through unsaturated alluvium near an arid disposal site for low-level radioactive waste, Beatty, Nevada [abs.]: Eos, American Geophysical Union Transactions, v. 75, no. 16, p. 161.

Wood, J.L., and Andraski, B.J., 1995, Selected meteorological data for an arid site near Beatty, Nye County, Nevada, calendar years 1990 and 1991: U.S. Geological Survey Open-File Report 94-489, 49 p.

For more information about the Mojave Desert studies, contact:

Brian J. Andraski
U.S. Geological Survey
333 W. Nye Lane
Carson City, NV 89706
(702) 887-7600, ext. 7636
andraski@usgs.gov